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The joint R&D project: The case of the first Brazilian microcontroller chip

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RESUMO

P&D colaborativo: o caso do primeiro *chip* microcontrolador brasileiro

A cooperação interorganizacional, por meio da atuação conjunta com diversos atores, permite que empresas de setores de alta tecnologia possam complementar recursos, especialmente em projetos de P&D. Os projetos colaborativos têm sido apontados em diversos estudos como uma importante estratégia para produzir produtos e serviços complexos em ambientes de incerteza e competitividade. Nesse sentido, pretende-se com a presente pesquisa aprofundar o entendimento de como ocorre a dinâmica de desenvolvimento de um projeto colaborativo de P&D em uma indústria de alta tecnologia. Para alcançar o objetivo proposto, definiu-se como objeto de análise o projeto de P&D do primeiro microcontrolador da indústria brasileira de semicondutores. A escolha empírica justifica-se pela singularidade do caso e por trazer uma diversidade de atores e um nível de complementaridade de recursos que foram significativos para o êxito do projeto. Dada a motivação para conhecer quem foram os atores e quais as principais formas de coordenação utilizadas neste projeto interorganizacional, realizaram-se entrevistas bem como se utilizou um questionário e demais documentos relativos ao projeto. Os resultados apresentados evidenciam uma rede de nove atores e suas funções no processo de colaboração interorganizacional, bem como as formas de imbricamento social e temporal utilizados na coordenação dos esforços coletivos. Focalizando nos mecanismos de inserção temporal e de inserção social destacados ao longo do estudo, propõe-se a inclusão dos projetos de P&D na tipologia para projetos interorganizacionais proposta por Jones e Lichtenstein (2008).

Palavras-chave: P&D, projeto colaborativo, imbricamento, tipologia de projetos, semicondutores.

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1. INTRODUCTION

Inter-organizational cooperation – work performed jointly by different organizations – enables companies in the high-tech sector to access new features and complement existing resources, especially in research and development (R&D) projects. Inter-organizational cooperation is also referred to as collaborative projects and has been identified in numerous studies such as those of Jones et al. (1997), Berggren et al. (2001), Jones and Lichtenstein (2008), Saenz Perez-Bouvier (2014) and Conell, Kriz and Thorphe (2014) as an important strategic alternative to develop products and services in environments surrounded by uncertainty, complexity and competitiveness. The academic work of Dittrich and Duysters (2007) on Nokia, Dyer and Nabeoka (2000) on Toyota, Dodgson and Gann (2006) on P&G, highlight the importance of collaborative relationships in innovation processes. Additionally in this context, we highlight the work of Jones and Lichtenstein (2008), who detail the ways that various companies participating in a collaborative project coordinate the implementation of joint activities.

This literature may suggest that, in the environment of high-tech industries, innovation is often the result of the collaborative exchange of information and resources with actors that are external to the company, which requires joint action between various agents. Contributing to this problem, we intend to deepen the understanding of how the dynamic of the development of a collaborative R&D project in a high-tech industry occurs. To achieve this proposed objective, we define the joint R&D project of the first microcontroller in the Brazilian semiconductor industry as our object of analysis. This empirical choice is justified by the uniqueness of the event and the diversity of actors and the resource complementarity level, which were significant for the success of the project, which were involved.

To facilitate the presentation of the theoretical reflections and empirical evidence, this paper is organized as follows: in addition to this introduction, we present the theoretical framework that will be the basis for the description of the experience of the study project. Then, we describe in detail the methodological strategy employed. In the third part of the article, we present the main results of the study and, finally, the concluding remarks.

2. THEORETICAL FRAMEWORK

2.1. Collaborative R&D projects

Since the 1990s, the innovation model has been highlighted as corresponding to an open and networking model, especially by scholars such as Rothwell (1995). The trend is that R&D teams work collaboratively with various internal and external actors. Thus, the result of innovation becomes a joint and cooperative action between different stakeholders of the company. In general, innovations in technology require the simultaneous use of different skill sets and knowledge bases in a process of innovation that is difficult for an individual company to solve (Powell et al., 1996). Hage and Hollingsworth (2000) point to the lack of research in the area of innovation that analyzes the influence of external actors, and they indicate that most published articles have considered only the internal organizational characteristics that affect innovation, bypassing external aspects.

Authors such as Del Giudice and Maggioni (2014), Huizingh (2011) and Huston and Sakkab (2006) claim that inter-organizational collaborative relationships can enable access to a wealth of knowledge for innovation processes, allowing the company to open up to new ideas from the outside environment and move towards the development of combined R&D models and new value co-creation practices (Huston & Sakkab, 2006). Some knowledge-intensive industries in areas such as semiconductor, telecommunications, biotechnology and communications systems, for example, have already adopted collaborative processes in R&D projects (Dittrich & Duysters, 2007; Dodgson & Gann, 2006; Saenz & Perez-Bouvier, 2014). This strategy has been adopted with the aim of expanding the possibilities for knowledge creation, process synergy and the reduction of risks and costs.

In addition, Aronson (2001) complements the concept, considering that cooperation in R&D projects is defined as the merger of two or more parties, institutions or individuals who have a different assignment but work together to achieve better results. According to Jones and Lichtenstein (2008), collaborative projects involve working together to create a product or service for a limited period of time, represented by a set of activities that enables multiple organizations to achieve individual and collective goals.

The initiation of the R&D process in cooperation with external actors is an attempt by companies to access additional resources to innovation beyond their borders. Thus, companies engage in the acquisition of specific forms of knowledge and technology through a wide range of collaborative arrangements: licensing, joint ventures, alliances and joint projects with universities and other public and private institutions (Roijakkers & Hagedoorn, 2006). Typically, among the main actors intertwined in innovation processes, we highlight the following: suppliers (Un et al., 2010; Pittaway et al., 2004.), science and technology institutions (Cohen & Levinthal, 1990), consumers (Gassmann et al., 2010; Bueno & Balestrin, 2012), competitors (Bengtsson & Kock, 1999) and intermediaries (Howells, 2006).

2.2. Collaborative R&D project management

Managing collaborative projects with different actors is a task of significant complexity (Coussi et al., 2015). The complex nature of R&D in industry is associated with very different activities, including: innovation in concepts

and ideas, the joint creation of knowledge (Connel, Kriz & Thorpe, 2014), the complementarity of knowledge between specialized fields (Lopez & Esteves, 2013) the definition of new scientific questions and hypotheses (Todeva, 2006). Jones and Lichtenstein (2008), in addition to Saenz and Perez-Bouvier (2014), note that studies in the organizational literature have very rarely considered how multiple actors coordinate their collaborative efforts and that they have also seldom considered how the expectation of limited duration modifies their interactions. The shapes of both social and temporal Embeddedness can end up affecting the complex activities related to the management of inter-organizational projects (Jones & Lichtenstein, 2008). Thus, for a better understanding of the effect of collaboration on innovation, not only the scale and density of the cooperation agreement but also the depth of such networks (in terms of the types of employed agreements: short-term versus long-term or a combination of both) and their operational performance (i.e., the proper functioning of the network in terms of planning, working methods, commitment, monitoring and evaluation) must be analyzed (Saenz & Perez-Bouvier, 2014).

Different structures and patterns of relationships may facilitate or impede the flow of communication and knowledge between organizations. These structures and patterns of relationships define different forms of social Embeddedness between different actors in a collaborative project. The social Embeddedness can be divided into relational Embeddedness and structural Embeddedness (Jones & Lichtenstein, 2008)

Relational Embeddedness is related to the quality of exchanges or the recognition of mutual needs and goals. It also encompasses the conduct of the parties during the exchange, assessing patterns linked to trust, confidence and the sharing of information (Uzzi, 1996). One of the main characteristics linked to social-relational Embeddedness is the development of trust-based relationships. The need for innovation increases the uncertainty of contingencies, making it difficult to specify the mechanisms of formal governance, especially through contracts, a fact that increases the need for collaboration based on trust (Noteboom, 2008).

Structural Embeddedness, by contrast, relates to the network of relations as a whole. Such properties are associated with flexibility and the easy exchange of information through the degree of contact promoted among network members (Nahapiet & Ghoshal, 1998). Structural Embeddedness facilitates the sharing of understandings and rules for collaboration when different organizations work collaboratively. In this sense, it is emphasized that there are some aspects with which the partners must agree and some perspectives, often tacit, related to norms, values, standards, results, skills and ways of doing things that they need to share.

As discussed by Nooteboom (2008), there must be a balance between cognitive distance (necessary for the variety and novelty of cognition) and cognitive proximity (necessary for mutual understanding and agreement). Structural Embeddedness should facilitate coordination through the existence of rules and shared understandings. These rules and understandings provide a shared macroculture, which is a set of tools that actors use when they coordinate collaborative activities (Jones et al., 1997).

Furthermore, the management of inter-organizational projects also depends on temporal Embeddedness. For Jones and Lichtenstein (2008), temporal Embeddedness relates to the coordination techniques used to maintain the pace of collaborative work. The literature on the forms of demarcation and organization of activities, mainly the studies by Clark (1985) and Gersick (1994), has three main types of stimuli: a) *chronological* stimuli, based on events and synchronization, are those guided by the passage of time and by the schedule; b) stimuli based on *events*, which are based on reaching major goals towards the objectives; and c) stimuli based on *synchronization*, which are those in which activities are synchronized by environmental influences. It can be said that the time insertion is set by the expected duration of a project, i.e., temporal integration provides numerous mechanisms to coordinate activities under tight deadlines (Jones & Lichtenstein, 2008).

Temporal Embeddedness is essential because inter-organizational projects exist for a limited period of time, with pre-specified objectives that, when reached, cause the organization of the project to literally dissolve. The existence of temporal Embeddedness and social Embeddedness contributes to the contingency management revealed in the development of the project.

2.3. Typology of collaborative projects based on the embeddedness form

This type of temporal Embeddedness and social Embeddedness provides mechanisms for managing the uncertainty associated with projects and facilitates collaboration among the actors involved. Thus, focusing on the temporal and relational insertion mechanisms, (Jones & Lichtenstein, 2008) have offered a proposal of a typology for inter-organizational projects through empirical examples. The authors offer four different types of projects, two that are relatively short, such as film production and architectural design and construction, and two of longer duration, such as emergency projects or responses to crises and infrastructure projects (table 1). According to empirical evidence, these are the various forms of social and temporal Embeddedness in each type.

2.4. Theoretical-conceptual framework of research and methodology

Seeking empirical evidence to meet the objective of deepening the understanding of how the dynamics of a collaborative R&D project occurring in a high-tech and

Table 1

Typology of Collaborative Projects Based on the Embeddedness Form

Project Name	Single Project	Network Alliance	Multiple Parts	Constellations
Duration	Relatively short	Relatively short	Highest duration	Highest duration
Relationship	Have rarely interacted before and have no probability of new interaction	Organizations that interact in a repeated manner	Involves organizations and representatives that rarely work together	Involves a single client, generally a public agency, responsible for a social challenge
Example	Film projects	Architecture and construction	Emergency and crisis responses	Large-scale infrastructure projects such as energy, aerospace and telecommunications Ex.: Apollo/NASA
Who coordinates it?	Specifically hired actor – director	Leader company – product/ service supplier	Various organizations Ex.: Red Cross	Leader company or government entity
How is the coordination done? **Temporal Embeddedness**	Deadlines determined in the contract Based on sequential events (pre-production, production and post-production)	Deadlines and activities determined in contracts contain penalties Based on pace events	Not based on pre-established deadlines but in emerging and spontaneous situations Incentives based on sync, emergency coordination sense	Based on events or project phases Time stimulus: goals
How is the coordination done? **Social Embeddedness**	Relational Embeddedness: low Structural Embeddedness: dense relations order - everyone has a shared and clear understanding of their specific tasks accumulated by their socialization in industry and film school	Relational Embeddedness: Recurring relations among some project partners – institutionalized practices - Structural Embeddedness: intermediate density due to repeated relationships among stakeholder groups	Relational Embeddedness: low Structural Embeddedness: can share understandings arising from technical standards	Relational Embeddedness: tends to be high between the customer and the company Structural Embeddedness: the use of hierarchy can facilitate coordination

Source: Jones and Lichtenstein (2008)

knowledge-intensive industry develop, the empirical object is analyzed from three different dimensions: a) *types of relationships*: these are the types of relationships surveyed in a collaborative R&D project and the contributions of each actor involved in the process to develop the project at each stage of the production phase; b) *social Embeddedness*: we seek empirical evidence on knowledge sharing, common goals, shared norms, cognitive distances and governance; this dimension was divided into relational Embeddedness and structural Embeddedness; and c) *temporal Embeddedness*: temporal Embeddedness constitutes the main forms of the temporal coordination of activities between the actors involved in the collaborative project. These three dimensions of analysis allow a definition of how multiple organizational actors coordinate their activities together and how these actors are involved in relationships and shared understandings. Figure 1 illustrates the theoretical model that guides this research.

This study aims to present the experiences of the project that gave rise to the first microcontroller chip of the Brazilian semiconductor industry, the ZR16. To achieve the proposed objective, the field survey has been conducted in three stages.

The first step consisted in developing the data collection instrument. The questions were organized into two groups. One group allowed the analysis of the entire network of inter-

organizational relationships that participated in the ZR16 project and the role and contribution of each of the respective process phases. The second information group was related to the coordination mechanisms used in the collaborative project.

The second stage consisted of selecting the necessary respondents to make the description of the experiences of the case of the ZR16 chip and the definition of the data collection techniques that would be used. We chose to focus on the collection of data in three DHs (Design Houses): SMDH, CHIPUS and C&P. This selection was made because the project had been designed for them. It should be noted that they are also the holders of the patent that led to the microcontroller. Thus, we conducted an in-person interview with the CTO of the Santa Maria Design House (SMDH). This interview occurred December 7, 2012; it lasted 1 hour and 35 minutes, and its transcript was 17 pages. This respondent also replied to a questionnaire on the general characteristics of the company, the number of employees, designs, patents, investments, partners and the benefits from collaborative partnerships.

The owner-director of CHIPUS provided some important data by email concerning the process and also answered the same questionnaire. In April 2014, a new interview was conducted with the current director of SMDH technology and the co-owner of C&P, from whom part of the project idealization was originated. This interview lasted 50 minutes, and its transcript was 24 pages.

The third stage consisted of the collection of the secondary data needed to contextualize the empirical object. This step is important for validating the information collected in the interviews.

Table 2 lists the conceptual elements and dimensions of analysis used to conduct the case study.

To perform the description of the case, we used other sources of secondary data to show who the main actors of the project were, the form of collaboration and the coordination mechanisms used in the management of the collaborative project. For the presentation of data, we used a visual map. Regarding visual maps, they are attractive representations of the mapping process. Temporal strategies decay strategies or processes at various stages (Langley, 1999). Furthermore, we present the analysis of the data according to the proposed variables. For reasons of confidentiality, the companies and respondents are not identified.

3. RESULT ANALYSIS

The analysis of the results section presents a retrospective on the semiconductor industry. Then, we present in detail the major players and their contributions in the collaborative project of the ZR16, the first microcontroller. Finally, the section ends with an analysis of the social and temporal mechanisms used in the coordination of the first microcontroller project.

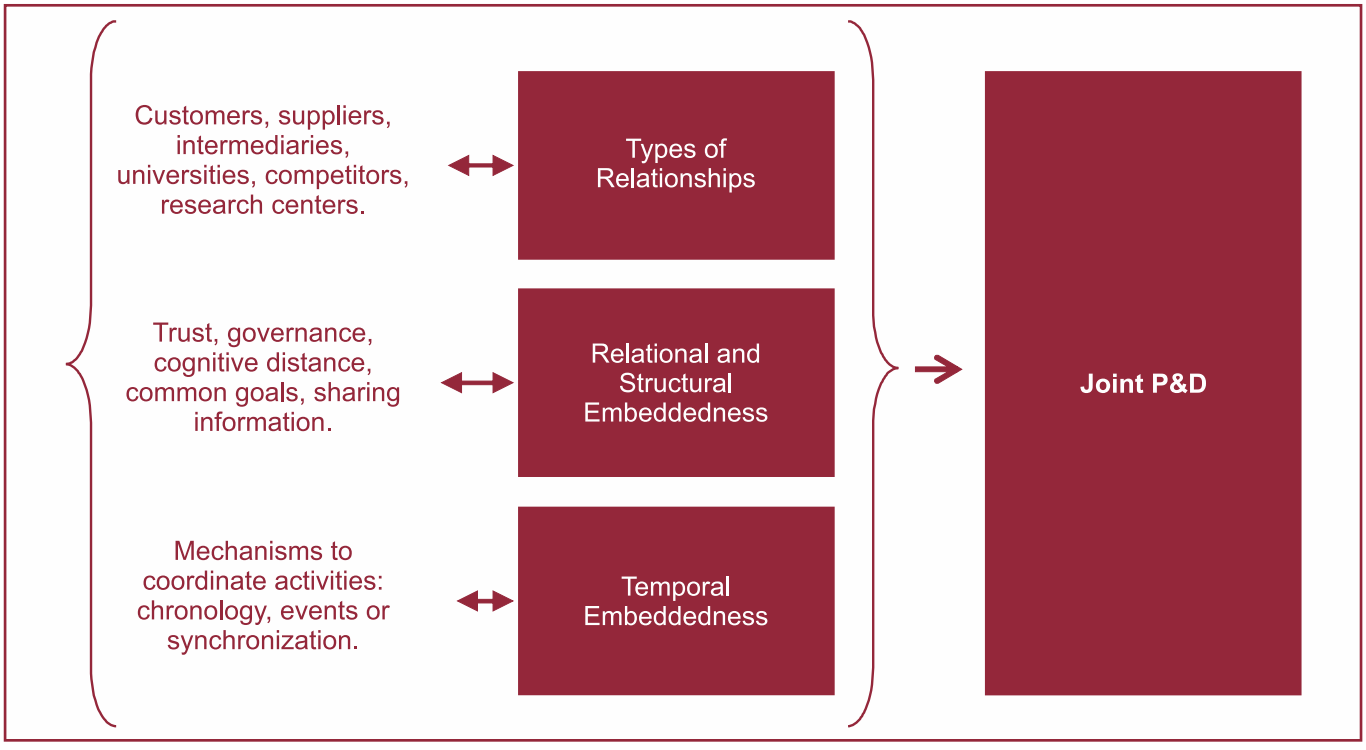

Figure 1: Research Theoretical-Conceptual Framework

Table 2

Definitions of Conceptual Elements and Analytical Dimensions

Conceptual Elements	Analytical Dimensions
Types of Relationships	- Origin of the ZR16 - Actors participating in the project - Activities performed by each of the actors - Value chain activities of product development - Types of relationships - Contributions of collaborative relationships for the outcome of the project
Relational Embeddedness	- Confidentiality and information sharing - Complementarity of resources and expertise - Common objectives existence - Repeated interactions - Forms of governance
Structural Embeddedness	- Project management - Distribution of activities - Technical cognitive distance between the partners - Existence of shared rules or institutionalized understandings
Temporal Embeddedness	- Project duration - Tools for the coordination of activities at a distance - Form of coordination of activities over time

3.1. The semiconductor industry

The semiconductor industry excels on the international stage as one of the most dynamic segments of the technology industry. Since 1950, the semiconductor industry has shown an impressive growth rate. The semiconductor industry stands out on the international stage as one of the most dynamic segments of the information technology industry, with multiple applications in entertainment, education and industrial safety, generating impacts that are cultural and economic in nature. Annual sales in 2014 reached US$ 335 billion annually, and this industry has achieved record sales for two consecutive years and is well positioned for continued growth in 2015 (Semiconductor Industry Association, 2015). Brazil is one of the few countries among the world's major economies that do not have an electronics complex that contemplates the manufacture of integrated circuits (Gutierrez & Leal, 2004). Furthermore, despite being among the top five global markets for personal computers, producing over 70% of what it consumes, Brazil still depends on imports of semiconductors and displays to supply its production lines. Note that semiconductors represent a growing portion of the cost of many products. The non-participation in the production of intellectual property or production parts of these microelectronic components will have a very negative effect on the Brazilian industry and the country's trade balance in future decades. Thus, there is no doubt about the importance for Brazil to have training in integrated circuit design and to participate in part of the microelectronics ecosystem (Ministério da Ciência, tecnologia e Inovação [MCTI], 2011).

Taking this context into consideration, the sector finds support when it extends the country's ability to compete in the knowledge economy (Agencia Brasileira de Desenvolvimento Industrial [ABDI], 2011). According to ABDI (2011), the consolidation of a semiconductor component industry in the country is crucial for competitiveness because it generates the conditions for the field of technology, the expansion of innovation and the generation of wealth. Therefore, the national government has established the CI-Brazil program, giving life to a development strategy and the re-creation of the domestic semiconductor industry, focusing on the design stage and operationalized by companies called *Design Houses* (DHs).

3.2. The case of the ZR16: the main actors and their main contributions

The ZR16 is a microcontroller chip used in security equipment such as motion sensors, alarm triggers and automatic ignition lights. A microcontroller is placed inside some other device (often a consumer product) so that its functions or actions can be controlled. As noted by the director of the

company, "*The ZR16 is the first microcontroller with a 100% collaborative project [design stage of the chip] developed in the country*". However, another interviewee notes that "*the ZR is an innovation in its context. It is not a single thing, a global innovation, but it is not a copy, and it is not like the others. We had to create things, it has very particular characteristics*".

In a collaborative R&D project, the role of inter-organizational relationships as a diffuser mechanism of information and as a facilitator of the socialization of knowledge is significant and complex. Interactions in collaborative projects have the advantage of allowing rapid access to new technologies through their channels of information. Under this approach, the study by Shan et al. (1994) suggests that the number of collaborative relationships in which a company is involved is positively related to the promotion of innovation. With regard to the inter-organizational relations for the ZR16 project, one of the interviewees notes that the company "*has no way to make a chip design and not have collaboration [...] it has collaboration with the company that does the test, it has collaboration with the customer in the specification. Collaboration may be small, at different stages, but it exists! If the DH is small and has to make a chip and is unable to carry out all the processes, the company has to cooperate*". Another director complements this observation, saying, "*There's many interaction. The other has to understand what we did, we have to understand what they do [...] It is not a single thing, none of the steps is 'go on and do it, bring it to me when it's ready', it is not like that*".

It is possible to say that this situation is mainly due to the intensity of knowledge, the required investments and the value added to the product. One respondent stated, "*We joined knowledge, we always seek a partner who knows, we need someone to give agility to the process because a single company does not know everything*". The various semiconductor chain phases can be developed by several companies located in different regions, thus allowing the unbundling of the segment. During the process of development for the ZR16, nine actors were directly involved collaboratively in the different stages of the manufacturing process. Among them, there were customers, suppliers, competitors and government agencies.

The conception stemmed from a relationship among three individuals working together. They recognized a market opportunity and already glimpsed a potential customer: EXATRON. Imagining the potential of the development of this innovation, one of these individuals, the owner of C&P, started working on the development of the processor alone.

Between 2009 and 2010, the directors of C&P and CHIPUS (which was one of the individuals who initially envisioned the idea) undertook a postgraduate course in project management. During this course, they decided to base the case study in the development of his idea, which would give rise to the ZR16 chip. When they finalized this stage of formation, and with very precise planning on the project development steps, they decided to visit the EXATRON client, given that they had already recognized its need. EXATRON agreed to participate in the project, helping in the definition of some peripheral blocks.

During this period, the partners determined that CHIPUS would develop the analog part and C&P would define and codify the microprocessor, the bus and some peripheral blocks. Subsequently, after the collaborative work had begun, the director of C&P joined the CHIPUS workforce.

The ZR16 was primarily designed to meet a specific demand for a client, EXATRON, which specializes in security and energy control systems and is headquartered in Porto Alegre, RS. One of the directors noted that "*EXATRON helped a lot in the process, in a way that made it more than a client: it was a great partner.*" The microcontroller embedded in the customer's product, which performs the function of the ZR16, is imported. Accordingly, the ZR16 is presented as a "*cheaper alternative that competes with the imported ones*", said one respondent. The ZR16 is a customized solution for the client. It will subsequently be extended to others clients. Until then, EXATRON uses a board with several chips, each with different functionalities.

The director of company B notes that "*the project team worked in close cooperation with the customer's development team*". Thus, the entire product specification was made in a co-creative way with the client. This fact shows that the client had an active role in the innovation process. In addition, EXATRON played an important role in product testing. The client also performs the task of "tester". This practice has been recognized as the value co-creation of goods and services, as highlighted by Biemans (1991), who explored a case in which Microsoft released copies of Windows for users to test. According to the director of the enterprise, "*One thousand chips from the pilot batch are for EXATRON, they put them in their products and did chip quality control. So, after this client assessment, the microcontroller goes to the production scale*".

At this point, there were still some activities related to the development of peripheral blocks and the verification and synthesis of both the logical and physical digital parts of the project. The verification and the logical and physical synthesis could not be performed in C&P, which was not part of the CI Brazil and had no contract with CADENCE (a company that provides software licenses). Thus, to finish the formal specification of the ZR16, C&P and CHIPUS agreed to include SMDH in the development of the digital part. Thus, during this phase of the project, the director of C&P started working for SMDH, a DH that had the structure to complete the digital part of the chip. It was agreed that C&P would hold part of the patent and royalties on production. At this stage, CHIPUS, SMDH and EXATRON worked together.

When designing the chip architecture, they realized that there was the need for analog blocks and digital blocks, which were the core competence of SMDH. Meanwhile, realizing the need for complementary skills and knowledge, the partnership was undertaken with the Santa Catarina-based CHIPUS, a

company that had core competence in analog blocks. The development of a collaborative project, according to the director of the enterprise, "*helped each company to gain momentum and complementarity as both were small and new*". Both CHIPUS and SMDH were two DHs. They were founded in 2008 with the encouragement of the CI-Brazil program and received funds from the CNPq notice 59/2008. CHIPUS is a privately held, for-profit company. SMDH, by contrast, is a public, non-profit company. CHIPUS is located in Florianópolis, SC, and SMDH is in the city of Santa Maria, RS, based at the Federal University of Santa Maria (UFSM). The two companies have a similar structure, employing between 10 and 20 employees.

For the partners, the collaborative work provided innovation because "*there were different skills*". In this sense, it is possible to demonstrate the technological cognitive distance. In other words, there was a difference between the cognitive focus of the main partners of the project. This difference played a major role in driving the companies to collaborate. Nooteboom (2008) proposes an interaction between the advantages and disadvantages of the distance between partners. In this study, Nooteboom (2008) finds that the potential for generating innovation increases with cognitive distance whereas the ability to collaborate declines with this distance. Therefore, the author emphasizes that there must be an optimal cognitive distance between the partners to achieve significant breakthrough results.

The development of the ZR16 featured a number of other inter-organizational actors. That is, the ZR16 was designed in an open and collaborative manner. From the collection of survey data, it was possible to specify the network of inter-organizationally overlapped relationships in product development. For the director of Company A, "*it is possible to design individually in the semiconductor area only when the project is small or of low complexity; otherwise, there must be collaboration*". This collaboration led to patent 10070907.

The value chain of an integrated circuit can be divided into five macro phases: conception, design, front-end, back-end and customer service. Conception is the stage where the idea is born. Typically, a chip is designed to meet a market need, and conception can be performed, or not, in conjunction with the client or manufacturer of the final product. The second stage, design, is the step in which integrated circuits are designed. Manufacturing is the phase in which silicon effectively turns into a chip. The assembly, encapsulation and the integrated circuit test (CI) phase, called back-end, is one of the final stages of the chain and consists of chip insertion into a housing equipped with wires, pins and other microconnectors with specific functions, allowing the chip to communicate with other circuits (Gutierrez & Leal, 2012; Banco Nacional Desenvolvimento Econômico e Social [BNDES], 2004). Finally, the service is presented to the client.

In the conception phase, an important project partner warrants attention: the federal government, which transferred funds through bodies such as the Financier of Studies and Projects (FINEP) and CNPq. The government acted as a funding partner. The innovation strategy adopted by a company is influenced by the institutions that provide incentives or constraints to innovation. In this sense, Arranz and Arroyabe (2008) highlight that public institutions promote the development of R&D networks as part of their technology policies to increase competitiveness and the technological field of the country. In the case of the ZR16, it was the industry's development policy (BNDES SETORIAL, 2004, CI BraSil, 2012) that influenced innovation. The CNPq provided scholarships for the payment of adequate wages to qualified professionals for product development. The two DHs involved in the project received scholarships for their designers of values between R$ 4,000.00 and R$ 8,000.00 monthly. In addition, the government funded the necessary software to develop the project, whose annual license can cost US$ 500,000.

Faced with this scenario and respecting the value chain phases, competitors, customers and financing partners, in constant interaction, started giving life to the ZR16. They counted on the participation of important suppliers, who helped identify necessary improvements in the product.

In the semiconductor industry, this collaborative model with the supplier is called consulting. It occurs "*when the contractor provides the necessary know-how to perform the phases that the contractor is unable to undertake alone*", according to the company representative D. This consulting model was used in choosing the *wafer* (silicon wafer) and compatible technologies, in addition to the IPs more suitable to the product memories. Consulting also occurs in the test phase. According to the director of the enterprise, companies must inform the supplier what should be tested because "*the company that performs the test will need to develop software and hardware to develop the tests and test that particular chip*". That is, the test phase undergoes a co-creation process. It is important to note that suppliers were essential for the acquisition and licensing of technology. For Grassman et al. (2010), technology hiring and licensing are configured in the first stage of the open innovation process.

After registering the patent for the ZR16, CHIPUS and SMDH worked together and cooperated in parallel with QC computing and X-FAB. This collaboration gave rise to the prototype that began to be displayed at trade shows. With the prototype in hand, CHIPUS and SMDH sought APTASIC to conduct pilot tests. Almost simultaneously, they co-created the development kit with Chip Inside.

It should be noted that the project had national and international partners, especially for the steps in which the domestic industry still did not have the know-how. According to Arranz and Arroyabe (2008), companies join other institutions for networking, not only at the local level but also nationally and internationally, to develop a technological project that positively influences competitiveness. In early 2014, the arrival of the first pilot batches and microcontroller sales were predicted.

Starting from the survey of all the actors involved in the ZR16 collaborative project, we can observe that the project had the involvement of actors participating in all stages of the industry chain, in addition to the heterogeneity also implied by direct interface partners in the value chain and institutional interface. For Fayard (2010), an operating mode such as that in this case, which brings together a different set of objects and beings around a common purpose, tends to dissolve the physical boundaries of the organization, towards which other actors, skills and information sources with a view to the creation of operational knowledge converge. For an organization, this dynamic porosity is a strategic agility condition in an unpredictable and highly competitive world. According to respondent reports and notes made in the questionnaire, collaboration with the competitor DH promoted economies of scale, a reduction in R&D costs, the combining of the unique skills of each company and the maturation of work teams.

Thus, we elaborate Table 3, which contains not only the major inter-organizational practices of the nine actors who participated in the microcontroller chip development but also their contributions to the product and the name of the phase of the development process in which each contributed.

After examining the agents involved and their importance in the collaborative process, we employed two analytical dimensions to evaluate the forms of coordination used in the development of the project: social Embeddedness and temporal Embeddedness.

Image 2 highlights the evolving relationship throughout the process of creating the ZR16 chip from 2009 to 2014. This figure is the representation of the network of inter-organizational relations that allowed the dissemination of information and

Table 3

Involved Agents and their Importance in the Collaborative Project

Actor name	Actor category in the value chain	Phase of the chip's value chain	Form of collaboration	Contributions to the product
CHIPUS Brazil	*Design House* for profit - competitor	*Design*	R&D collaboration	Responsible for the digital part of the chip, complementary capacities
SMDH Brazil	*Design House* non-profit - competitor	*Design*	R&D collaboration	Responsible for the analogue part of the chip, complementary capacities
EXATRON Brazil	Client	Idea and conception specification	R&D collaboration, quality testing	Created a competitive product
C&P	*Design House*	Idea and *design*	R&D collaboration	Created the ZR16 processor
Federal Government of Brazil	Government funding partner	Funding of idea conception and *design*	R&D funding	Provided scholarships for the payment of qualified professionals for the development of the product and the technology needed to build the project
XFab Germany	Supplier	Manufacture *(front-end)*	Technology acquisition and licensing of IP of memory / manufacturing	*Wafer* acquisition (silicon wafer) for the 350 nanometer technology and compatible memories
APTASIC USA	Supplier	Encapsulation and testing *(back-end)*	Test co-creation / suggestion of necessary improvements	Chip test, the testing process is in the form of a joint creation, with a considerable exchange of information on possible improvements in chip design and suggestions to facilitate large-scale testing
QC Informatics Brazil	Supplier	Client service	Co-creation – software acquisition, software project	Created the simulator and the compiler to program the chip
Chip INSIDE Brazil	Supplier	Client service	Co-creation – hardware project to computer connection	Development kit (Board and connector to develop the application)

facilitated the socialization of knowledge for driving the project. In the illustration, we can see the heterogeneity of the actors involved and the constant modification of dyads and triads. Image 2 appears to be in line with the results of both Stuart and Podolny (1996) and Romijn and Albu (2002). These authors note that the variety of actors is a crucial source of innovation.

In view of this illustration, it is possible to understand that the metaphor of the innovation funnel and the macro phases of the open innovation process were used, as proposed by Cropper (2008), for the development of the product. Internally, we highlight the micro processes of the first two phases of the innovation process: conception and development (which encompasses all stages of research and development). The micro processes were defined from the change in the network of relationships.

3.3. Social and temporal mechanisms used in project coordination

Unlike other projects in which there is a single leader or a group of organizations (Jones & Lichtenstein, 2008), here, the coordination of the project was overseen by the product patent holders. Regarding the idea of the design phase, the Embeddedness with the client was fundamental; that is, with these three actors, relational Embeddedness tended to be very strong due to the frequent repetition of the interactions during the project duration. Differently, with the other actors, this interaction was not as frequent and was restricted to the stage in which only the collaboration was necessary, with a tendency not to be as recurrent in the development of the ZR16 chip.

The collaborative R&D project, which led to the ZR16, had an average duration of 3.5 years of work, involving a complex range of actors and, throughout this period, highly complex tasks that required the interaction of multiple partners. It should be noted that this type of interaction requires broad structural interaction. The main rules shared, or shared understandings that ensured structural Embeddedness, are primarily due to received training in training centers, given that over 50% of the teams of the two DHs that coordinated the project studied at one of two centers in Brazil, which would have guaranteed a clear understanding of the specific tasks to all the designers of the two DHs.

According to the director of the company, "*this particular course of the training centers for graduates is for engineers to mature a little [...] there, they learn a single theory [...] in the course, they have a general notion of all the working tools that can be used*". This shared training is related to the

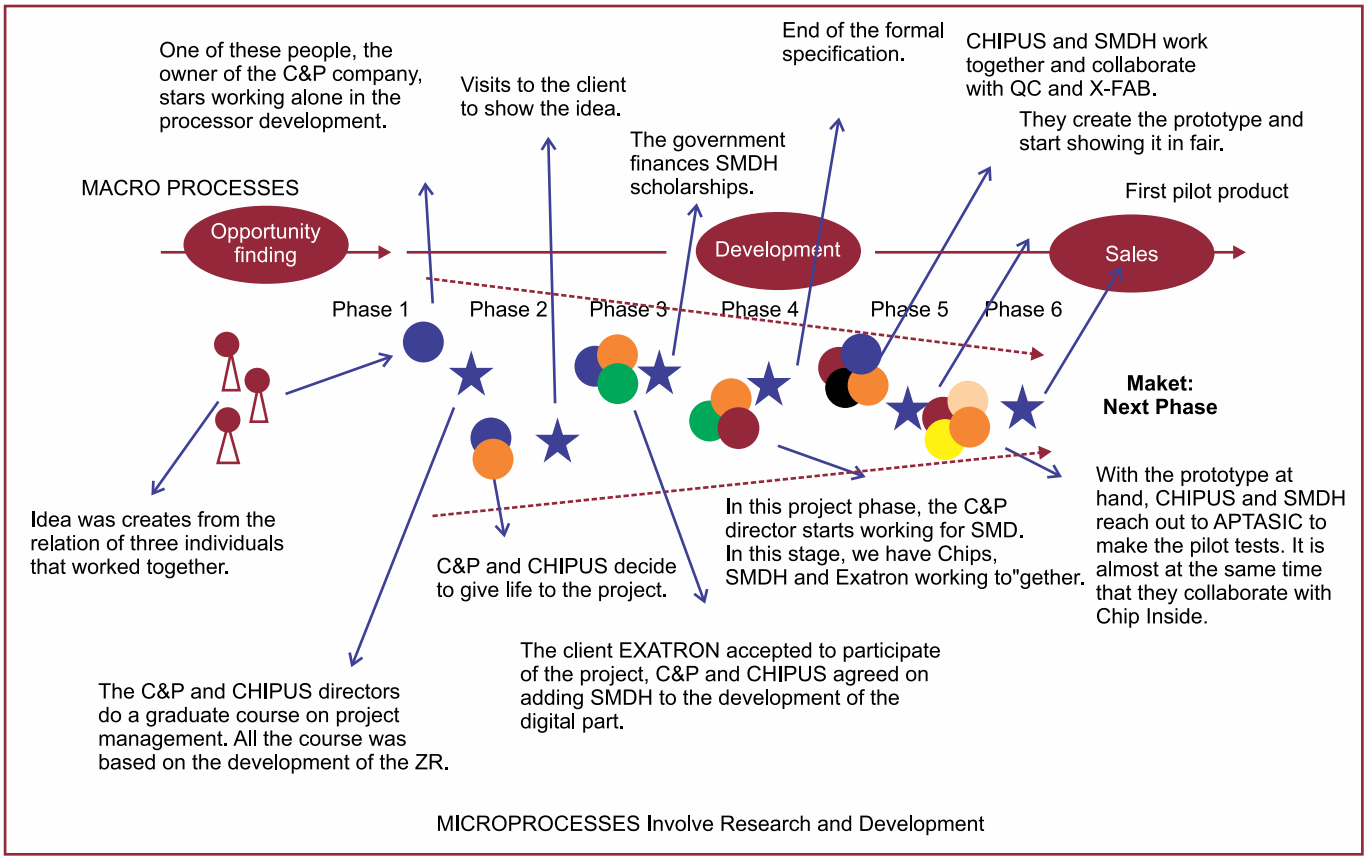

Figure 2: ***Relationship Evolution During the Creation Process of the ZR16 Chip***

macroculture of an industry and provides the basis of trust between all project stakeholders. For Jones and Lichtenstein (2008), this basis of common and institutionalized knowledge in an industry is important, especially when actors have never worked together before, as in the case of the ZR16.

Social Embeddedness, in the relational sense, as in the case of industrial projects with highly complex demands such as semiconductors, appears to require stimulation based on harmony. Harmony seems to be crucial for social Embeddedness in collaborative R&D projects. The notion of harmony is essential to understanding knowledge sharing. For Fayard (2010, p. 59), *"[...] it translates itself into a willingness to share without prejudice, in a presence and a receptivity to everything that is happening in an environment at any given time*". When asked about the existing guarantee that companies would provide the best engineers to work on the ZR16 project, in addition to the best designers and all the existing knowledge, respondent A reported, "*there is no guarantee [...] but the gain is collective; if someone does not give his best, everyone loses*". The report seems to indicate a predisposition to share without borders. The report also highlights the need for incentives based on the existence of harmony so that exchanges of knowledge occur and then establish social Embeddedness.

According to Jones and Lichtenstein (2008), to create shared relational understandings, organizational actors need to have clarity with regard to their roles and repeated collaborations. It seems that the development of collaborative projects included the assumption of repeated interactions among the companies' engineers. One of the main designers at SMDH worked with the director of CHIPUS in the past, in a large national company in the semiconductor area and as the director of C&P. Both worked together in this company for approximately 3 or 4 years or had collaborated before. This fact contributed to reducing transactional uncertainty while driving the project. One of the directors interviewed stressed that "*the relationship between people in this type of project tends to be always very good and great* [in the sense of the existence of friendship]".

Nonetheless, in regard to social Embeddedness, we can observe trust and the sharing of information between the parties while driving the project. That is, knowledge sharing was undertaken based on trust, and contracts were drawn up only after the results of the parties' inter-organizational insertion appeared. The director of the enterprise stressed the current existence of a patent. However, this situation is not established from the beginning of the creation process. The director also highlights, "*there was an informal agreement on the management of the results of the project, but the contract took place only later than that [...] to create a partnership of that level there has to be trust between companies, to enter into a partnership without a contract where investment and exposure of the knowledge of professionals is great*".

In this sense, the results found in the study are in line with the analysis by Noteboom (2008) with regard to the need for autonomy for the implementation of professional work and the difficulty of monitoring and evaluating results when working with the value of the novelty. For Noteboom (2008), rapid innovation increases the uncertainty of contingencies, making it difficult to specify the mechanisms of formal governance, particularly through contracts. This characteristic increases the need for collaboration based on personal trust. If the specification of detailed contracts, however, is performed, it threatens to form a straitjacket that could restrict the possibilities of innovation.

For Jones and Lichtenstein (2008), shared understandings are also possible only if each actor knows exactly what its role is during the process. These insights can come from training. For example, as already noted in previous reports, all the designers involved knew the theory; however, in the specification stage, they set "who would do what" and who would check and so on.

Additionally, to face the uncertainties associated with the project, they used some time management techniques to coordinate the group's activities. In the case of the ZR16, event-based stimuli have been the most frequently employed (Gersick, 1994), with well-established milestones. During the preparation of the ZR16, the *MS-Project* was used. Thus, through each completed event, it could be observed that the project was on track and appropriate to its market context.

The *MS-Project* has many focuses: time (dates, the duration of the project, the work schedule), a probabilistic model (for calculations related to planning), costs (fixed, not fixed, others) and a range of reports. Event-based stimuli cause them to have a set of reciprocal stimuli tasks among participants (Thompson, 1967). Importantly, the technologies of interaction unite the service of this collaborative movement, with organizational boundaries becoming permeable (Fayard, 2010). Thus, it is understood that information technology was essential for ensuring temporal Embeddedness or the coordination of activities among the group, which had 20 people on staff working simultaneously. According to the reports of the director of the enterprise, "*one needs communication, the internet, mainly because the work is done at a distance [...] these are the basic needs of any complex project in the area of microelectronics*". The director of Company B corroborates this point, noting that meetings were often undertaken via Skype.

Such reports allow us to assert that the use of information technology made it easier for project members with various skills to work in parallel and make mutual adjustments. For Jones et al. (1997), activities performed under these conditions contribute to reducing time and to the completion of complex tasks. Therefore, we present Image 3, which aims to synthesize the empirical contribution of this study to the theory on collaborative R&D projects.

Based on our findings, it is possible to claim that the ZR16 was the result of intense collaboration with the external knowledge of various agents in a coordinated manner.

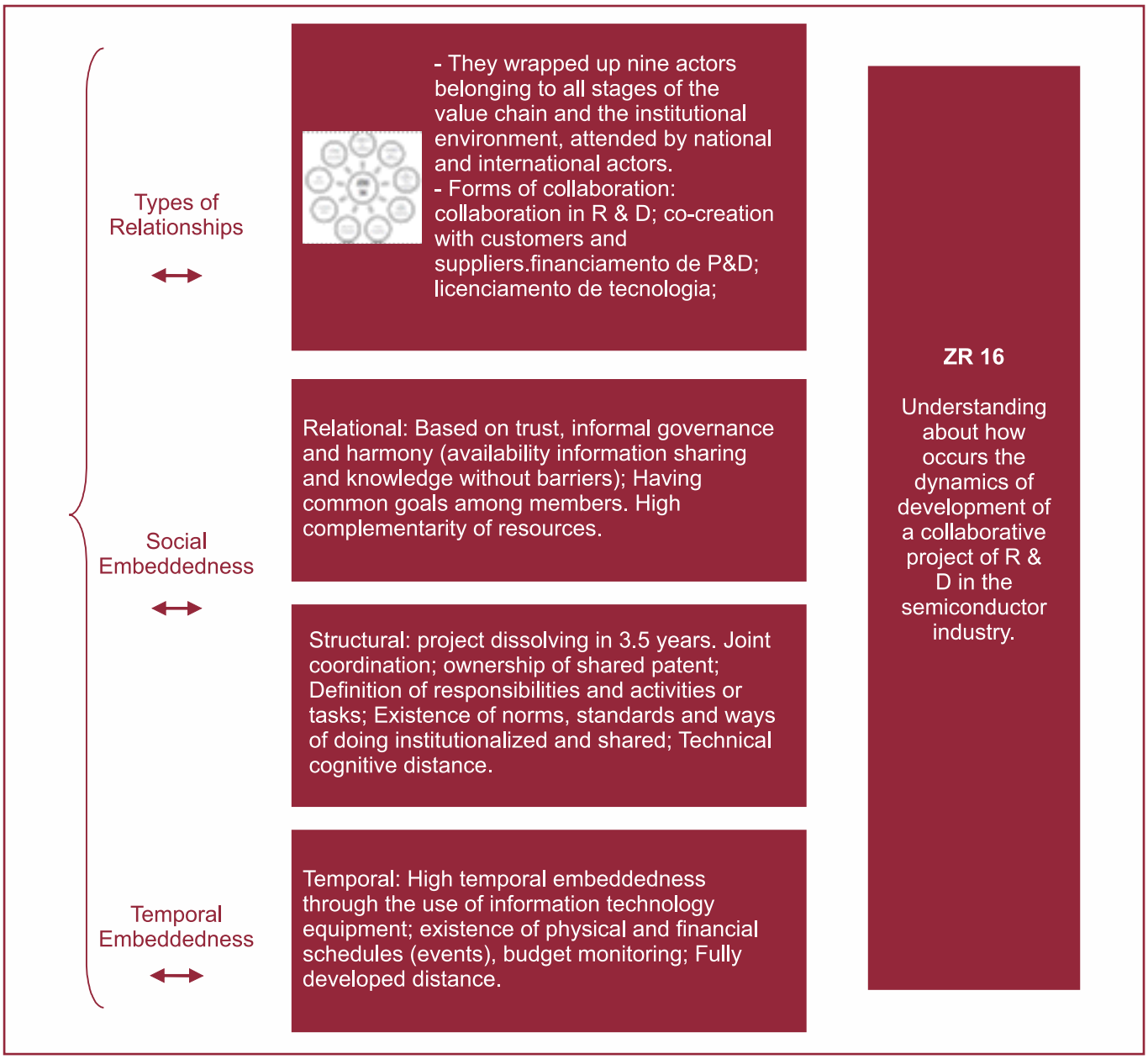

Figure 3: Main Empirical Contributions to the Theory of R&D Collaborative Projects

According to the survey of the actors, the types of interactions and Embeddedness in the ZR16 microcontroller design, we consider a possible inclusion in the typology proposed by Jones and Lichtenstein (2008).

Table 4 shows the insight considering the description given in the ZR16 project. The first four types come from the insight of Jones and Lichtenstein (2008); the latter, R&D projects, lists the results of this research.

Although the ZR16 project had a duration that is similar to those indicated in other projects, used similar temporal coordination tools and, as in other projects, was guided by technical standards, it differs from those types listed due to the widespread need for the complementarity of expertise and the sharing of the same. This exchange is based on trust and harmony, indicating the importance of the relational Embeddedness of all stakeholders. In addition, the heterogeneity of the actors, both in the value chain and in the institutional national and international environments, and the form of coordination, in which the holders of the future patent and royalties coordinate the design and use of information technology tools to go beyond the boundaries of the firm, should be noted.

Table 4

Typologies of Inter-organizational Projects

Project Name	Single Project	Network Alliance	Multiple Parts	Constellations	R&D Projects
Duration	Relatively short	Relatively short	Highest duration	Highest duration	Highest duration
Relationship	Have rarely interacted before and have no probability of new interaction	Organizations that interact in a repeated manner	Involves organizations and representatives that rarely work together	Involves a single client, generally a public agency, responsible for a social challenge	Involves organizations that may or may not have worked together that have complementary knowledge and are embedded in the entire value chain of the industry
Example	Film Projects	Architecture and constructions	Emergency and Crisis Responses	Large-scale infrastructure projects such as energy, aerospace and telecommunications Ex.: NASA/Apollo.	Projects developed by the high-tech industry Ex.: ZR16
Who coordinates it?	Specifically hired actor – director	Leader company – product/service supplier	Various organizations Ex.: Red Cross	Leader company or government organism	Organizations that own patents, with chance of being competitors.
How is the coordination done? **Temporal Embeddedness**	Deadlines determined in the contract Based on sequential events (pre-production, production and post-production)	Deadlines and activities determined in contracts contain penalties Based on pace events	Not based on pre-established deadlines but in emerging and spontaneous situations Incentives based on sync, emergency coordination sense	Based on events or project phases. Time stimulus: goals	Event-based or project phases Use the PMBOK – MS Project Information technologies for mutual adjustment of complex tasks With / without contract schedule or defined events
How is the coordination done? **Social**	Relational	Relational Embeddedness: Recurring relations among some project partners – institutionalized practices Structural Embeddedness: intermediate density due to repeated relationships among stakeholder groups	Relational Embeddedness: low Structural Embeddedness: can share understandings arising from technical standards	Relational Embeddedness: tends to be high between the customer and the company Structural Embeddedness: the use of hierarchy can facilitate coordination	Relational Embeddedness: tends to be high among all actors and with high levels of trust and information sharing; the use of IT Structural Embeddedness: shared understandings: technical norms and formation

Source: Adapted by the authors from Jones and Lichtenstein (2008).

4. FINAL REMARKS

Indeed, in the case study of the ZR16 chip, we note that competitors and clients were the main actors of the collaborative project and, in turn, had a recurring and high relational and temporal Embeddedness. Nonetheless, among the different categories of agents in this inter-organizational project, they encountered various forms of collaboration with suppliers and the government. With regard to the forms of collaboration, we found evidence of co-creation with clients and suppliers and collaboration in R&D, R&D funding, procurement and technology licensing. Moreover, we perceived the expansion of the network to the outside and the participation of actors of both the value chain interfaces and the institutional environment. Among the main benefits of the collaborative work, we highlight the reduction of risks and costs, gains in agility in product delivery and the maturation of the teams.

Among the main forms of temporal Embeddedness, event-based schedules, containing deadlines and budgets to be met, were used. We highlight the importance of information technology for the boundaries of organizations to become permeable and for the collective work to be done in such a manner that distance does not represent an obstacle to collaboration and the meeting of deadlines. However, relational Embeddedness was highly based on trust, harmony and information sharing.

Therefore, the research agenda for projects in other industries remains, in addition to other projects in the same industry to check whether there is a pattern of social and temporal interactions. One must consider that the description was based on the project coordinators' reports and that other parties could be heard. In addition, comparisons with projects from other countries are also welcome and may enrich this line of study, making it possible to confirm the insights regarding the development dynamics of a collaborative R&D project in the semiconductor industry.◆

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ABSTRACT

The joint R&D project: The case of the first Brazilian microcontroller chip

The interorganizational cooperation, through joint efforts with various actors, allows the high-tech companies to complement resources, especially in R&D projects. Collaborative projects have been identified in many studies as an important strategy to produce complex products and services in uncertain and competitive environments. Thus, this research aims at deepening the understanding of how the development dynamics of a collaborative R&D project in an industry of high technology occur. In order to achieve the proposed objective, the R&D project of the first microcontroller in the Brazilian semiconductor industry was defined as the object of analysis. The empirical choice is justified by the uniqueness of the case, besides bringing a diversity of actors and a level of complementarity of resources that were significant to the success of the project. Given the motivation to know who the actors were and what the main forms of interorganizational coordination were used in this project, interviews were carried out and a questionnaire was also made, besides other documents related to the project. The results presented show a network of nine actors and their roles in the interorganizational collaboration process, as well as the forms of social and temporal overlapping, used in the coordination of collective efforts. Focusing on the mechanisms of temporal and social integration highlighted throughout the study, the inclusion of R&D projects in the typology for interorganizational projects is proposed in this paper, which was also proposed by Jones and Lichtenstein (2008).

Key words: R&D, collaborative project, overlapping, project typology, semiconductors.

RESUMEN

Proyecto conjunto de investigación y desarrollo: el caso del primer chip microcontrolador brasileño

La cooperación interorganizacional en I&D, permite que empresas de sectores de alta tecnología puedan complementar recurso. Los proyectos colaborativos han sido apuntados como una importante estrategia para producir productos y servicios complejos en ambientes de incertidumbre y competitividad. Se pretende, con la presente investigación, profundizar el entendimiento de cómo ocurre la dinámica de desarrollo de un proyecto colaborativo de I&D en una industria de alta tecnología. Se definió como objeto de análisis el proyecto de I&D del primer microcontrolador de la industria brasileña de semiconductores. Dada la motivación para conocer quién fueron los actores y cuáles las principales formas de coordinación utilizadas en este proyecto interorganizacional, se realizaron entrevistas, así como se utilizó un cuestionario y demás documentos relacionados al proyecto. Los resultados evidencian una red de nueve actores y sus funciones en el proceso de colaboración interorganizacional, además de las formas de imbricamiento social y temporal utilizados en la coordinación de los esfuerzos colectivos. Enfocando en los mecanismos de inserción temporal y social destacados a lo largo del estudio, se propone la inclusión de los proyectos de I&D, en la tipología para proyectos interorganizacionales propuesta por Jones y Lichtenstein (2008).

Palabras clave: P&D, proyecto de colaboración, entretejido, tipo de proyecto, los semiconductores.

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