Open innovation in the semiconductor industry: analysis of Brazilian design houses

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Abstract

Purpose – This study aims to understand how Brazilian design houses (DHs) use open innovation in joint development projects for integrated circuits.

Design/methodology/approach – As a research strategy, qualitative research using multiple case studies was made. As sources of evidence, semi-structured interviews were conducted with three DHs of Programa integrated circuit [circuito integrado(CI)]-Brasil and with four specialists in the field, as well as analysis of documents. The data were analyzed through content analysis.

Findings – The results showed the DHs use sources of external knowledge in their innovation process, to assist the development of new products, to access new knowledge and skills, to attract financial resources and to be competitive in the market of high technology.

Originality/value – The study has important implications on the semiconductor industry in Brazil, as the industry is considered strategic for the competitiveness of final goods sector. The importance of encouraging the development of partnerships in the sector, the possibility of using informal agreements to mediate the collaboration between DHs and external agents, and the improvement and long-term continuity of public policies to support the industry are among the implications. In addition to suggestions for new business approaches to assist the strengthening of this segment.

Keywords Innovation, Open innovation, Microelectronics, Semiconductor industry, Programa CI-Brasil

Paper type Case study

1. Introduction

The semiconductor industry determines the rate of growth of the global economy and is closely linked to the financial system. Its performance requires attention and it is an

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important indicator of industrial and financial stability worldwide (Chow & Choy, 2006; Wu, Ding, Jane, Lin & Wu, 2015).

Also known as microelectronics, the semiconductor industry, has several applications, ranging from the automotive industry and cell phones to medical diagnostic equipment [Agência Brasileira de Desenvolvimento Industrial (ABDI), 2011]. In Brazil, according to information provided by the Brazilian Association of Electrical and Electronics Industry [Associação Brasileira da Indústria Elétrica e Eletrônica (ABINEE)], in 2018, among the main electronic products imported into the country, the semiconductors totalized approximately US$5bn in imports, a result 7.3 per cent above the figure registered in 2017 [Associação Brasileira da Indústria Elétrica e Eletrônica (ABINEE), 2019].

According to the US Semiconductor Industry Association – SIA, the industry is crucial for innovation and productivity growth of the country. Its technology allowed virtually all sectors of the US economy, from agriculture to manufacturing, to become more effective and efficient, boosting their economic growth. In addition, it is one of the industries with more investments in research and development. In 2018, the industry was the second in R&D investments, only behind the pharmaceutical and biotechnology industry (SIA, 2019). In addition to the USA, countries such as China, India, South Korea and Taiwan also invest in this sector (Gutierrez & Leal, 2004; Ibrahim, 2015; Wu *et al.*, 2015; Wu, Chen, Chen & Chien, 2019).

In addition to the impacts on the balance of trade of the countries, the production and the technological field in the semiconductor industry covers strategic factors. Among them, opportunity for generation of skilled jobs; increase of devices connected to internet, which will boost the consumption of components; and the added value of these components, which corresponds to an ever greater portion of the costs of goods and equipment in sectors such as telecommunications and automotive. In addition, the industry can be considered an innovation engine, as the electronic has become increasingly present in society (Lima, Teixeira, Azen, Miguel & Sales, 2015).

In Brazil, according to ABDI (Agência Brasileira de Desenvolvimento Industrial – Brazilian Agency for Industrial Development), the strategic content of the semiconductor industry makes its consolidation in the country crucial for the competitiveness of the industry of final goods, as it provides the domain of technologies used in these products (ABDI, 2011). Furthermore, according to the Brazilian Association of the Semiconductor Industry [Associação Brasileira da Indústria de Semicondutores (ABISEMI)], Brazil represents a relevant market for the electronic complex and is a business opportunity. In addition to the possibility of supplying the domestic market, it can export final goods because Latin America countries do not have local production (ABISEMI, 2019a).

Despite its importance, the scenario of semiconductors Brazilian industry indicates a country dependent on import of components and modules [Associação Brasileira da Indústria Elétrica e Eletrônica (ABINEE), 2019; Bortolaso *et al.*, 2013]. The implementation of new business approaches can help the strengthening of this sector, as indicated by Lima *et al.* (2015), innovation is essential for the success of the industry.

The open innovation model has proved to be a determinant factor for the increase of innovation and economic performance of companies (Cruz-Cázares *et al.*, 2018), in addition to give opportunities in high-technology and knowledge-intensive industries, such as semiconductors (Chesbrough, 2012; Sydow & Müller-Seitz, 2019). To Dahlander & Gann (2010), the opening of the innovation process is based on the idea that a single organization cannot innovate alone. With open innovation, research and development start to be seen as an open system, where the paths for the market and the internal and external resources to the organization are equally important (Chesbrough, 2011; Tucci *et al.*, 2016).

According to Chesbrough (2012), this approach allows organizations to continue making profits, even not being owners of the different technologies of the process of innovation. The model of open innovation comprises the organizational changes in the innovation process, to better distribute the activity among different actors (Dodgson *et al.*, 2006). They can be suppliers, consumers, research institutions, competitors or organizations in different industries with solutions to enhance the innovations of or explore technologies developed by the company (Greco *et al.*, 2017; Huizingh, 2011; Un *et al.*, 2010).

Because of its characteristics, the open innovation can help companies to reduce the costs of product development and process improvement, improve the quality and put products faster in the market (Wallin & Von Krogh, 2010). These are important advantages to the current competitive environment, especially for the technology and semiconductors industries, characterized by high uncertainty and constant need for the development of new technologies (Sydow & Müller-Seitz, 2019).

In the productive chain of semiconductors, the focus of analysis of this study will be the design houses (DHs), companies responsible for the definition of the functions of semiconductors incorporated into final products. These companies are considered agents drivers of innovation in industry and play an important role in the productive chain of semiconductors (Aita, 2013; Faccin & Balestrin, 2015).

This study presents important implications about the semiconductor industry in Brazil because of the need of more studies and debates on the theme (Faccin & Balestrin, 2015; Faccin *et al.*, 2016a), and the amplitude of new possibilities for the development of new products and services of semiconductors because of the growth of mobility, intense use of social networks and cloud computing (ABDI, 2014). It is also strategic for the competitiveness of the industry of final goods, in addition to present suggestions for new business approaches to assist the strengthening of this segment, by the vision of companies and specialists working in the industry.

The objective of this study is to understand how Brazilian DHs use open innovation in joint development of projects for integrated circuits.

2. Theoretical framework

2.1 The model of open innovation

The model of open innovation consists in the use of external sources of knowledge in the innovation process. In the open innovation model, internal and external resources can be integrated throughout the innovation process. Then, the external contributions should be significant, i.e. more than just a partnership, companies need to work together on solving problems and needs (Chesbrough, 2012; Lindegaard, 2010).

Figure 1 shows the model of open innovation. The boundaries of organizations, represented by the dashed lines, are permeable and reflect the interaction between the sources of internal and external resources of the company. In this scenario, the ideas are abundant, not only in the companies' internal environment but also in its surroundings (Chesbrough, 2012).

As observed in Figure 1, the ideas can arise internally through company research processes (Chesbrough, 2012). However, companies can develop them adding external knowledge and skills, for example, through the acquisition of technologies (Pénin *et al.*, 2011).

The projects can be brought to market through internal and external paths, and new technologies can be integrated into the innovation process at any step of the process, both in the research process and in the development step. The creation of new business (spin-offs) and the licensing of technology are just a few examples of how the projects of the

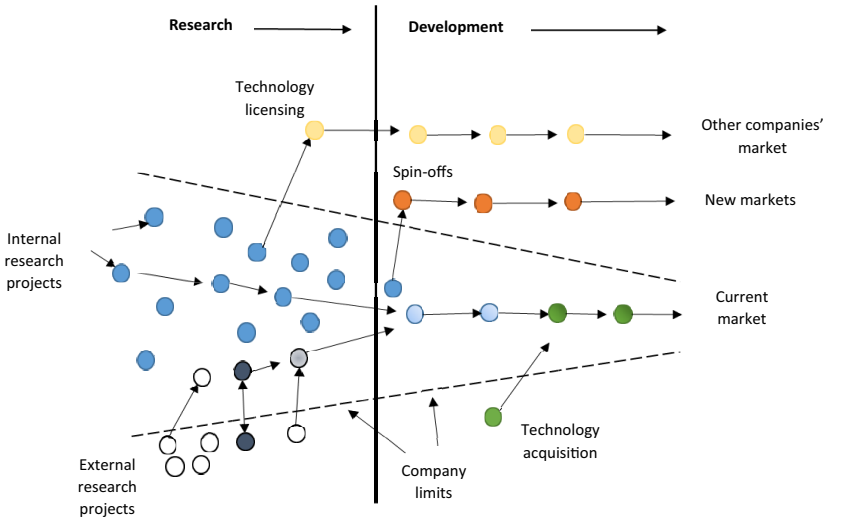

Figure 1.
The model of open innovation

Source: Adapted from Chesbrough (2012)

organization can be put on the market, in addition to the channels of sales of the company (Chesbrough, 2011).

2.2 Internal sources of knowledge for innovation

To launch new products, improve processes or increase competitiveness, organizations use different sources of learning and technology, internal or external (Tigre, 2006). Activities of research and development (R&D); ideas from marketing and strategic planning of the company; market information and human resources of the organization are among the main internal sources of knowledge for innovation (Docherty, 2006; Tigre, 2006).

Internal R&D activities acquire a new role in the paradigm of open innovation. The internal researchers, in addition to being responsible for the generation of new knowledge, are intermediaries responsible for identifying and accessing external expertise. They also mobilize the knowledge between the internal and external limits of the organization (Chesbrough, 2012).

According to Chesbrough (2012), companies do not need to rely exclusively on internal technologies but can and should access knowledge created by the laboratories from third parties. With the new justification of internal R&D, companies must be able to: identify, select and connect with the knowledge available externally; integrate the internal and external knowledge, create more complex combinations of knowledge; and generate additional profits from the sale of technologies to other organizations.

2.3 External sources of knowledge for innovation and mechanisms for collaboration with external agents

The increasing technological complexity and changes in the needs of the market transformed the cooperation in a fundamental resource to organizations obtain additional competencies (Yoon & Song, 2014), increase their capacity for innovation and reduce the time to launch an innovation in the market (Enkel *et al.*, 2009).

The concept of cooperation or co-development in R&D, adopted by Chesbrough & Schwartz (2007), refers to two or more agents working together, with the purpose to create and distribute new products, services or technologies. Depending on the goals of innovation, external sources of knowledge accessed may be different. For example, companies can develop partnerships with universities and research institutes to explore the potential of a new technology, create networks of collaboration with customers and suppliers to launch new products and services based on a new business model or purchase/create alliances with technology-based startups (Eslami & Lakemond, 2016; Janeiro *et al.*, 2013; Vanhaverbeke, 2011).

For Un *et al.* (2010), each kind of partnership in R&D results in a different impact on innovation. They are different in amplitude and easiness of access to new knowledge. The sources of external knowledge that can benefit the process of open innovation of enterprises, are consumers, competitors, universities and research institutes, government and development agencies, intermediaries, etc.

Intellectual property is seen as a facilitating mechanism and a means to promote an exchange of important inputs to the process of innovation (Chesbrough & Ghafele, 2014), guaranteeing and structuring the collaboration between businesses (Pénin *et al.*, 2011).

The process of open innovation covers several forms of collaboration, some of them more open and interactive, others more closed (Pénin *et al.*, 2011). These mechanisms of collaboration can be established through formal agreements, when the exchanges of knowledge between organizations are established by contracts and formal documents (Cruz-Cázares *et al.*, 2018; Simard & West, 2011); and informal agreements. The last one may result from informal communication between employees or organizations research teams without direct formal ties or formal collaboration (Bönte & Keilbach, 2005; Han *et al.*, 2018; Hannigan *et al.*, 2018). Different forms of collaboration are provided in Table I.

With several possibilities of collaboration, companies can adopt the ones best meets their needs for innovation, considering the benefits and requirements of each of them.

3. The semiconductor industry in Brazil

Defined as a link to generate innovation and technological progress in different branches of the electronic complexes, the semiconductor industry is seen as a sector with potential to the creation of competitive advantages, impacting gross domestic product – GDP of the country, in addition to other sectors of the economy, as automotive and aerospace industry (ABDI, 2011).

The semiconductor industry, also known as microelectronics, has several applications. The automotive industry, mobile phones, smartphones, tablets, laptops, equipment, medical diagnosis, the telecommunications and entertainment industries, among other applications, strongly depend on semiconductors (ABDI, 2011).

In Brazil, the data about the semiconductor industry are presented by ABINEE and are classified as a theme of a sectoral field of electrical and electronic components. According to information of the balance of trade presented by Associação Brasileira da Indústria Elétrica e Eletrônica (ABINEE) (2019), in 2018, imports of electrical and electronic components were approximately US$18.5bn, representing 58 per cent of total imports in the sector of electrical and electronic products.

Semiconductors are one of the most imported products for the electronics industry in Brazil (US$5bn), with the components for telecommunications (US$4.7bn), shipped electronics (US$1.6bn) and components for computing (US$1.6bn). The semiconductors are also included in products of telecommunications, informatics, industrial equipment, etc. This information increases the value of imports of this component, confirming the

Collaboration	Description
Strategic alliances and joint ventures	Strategic technological agreements between organizations, to obtain, integrate or generate knowledge. This kind of agreement usually involves development projects in nearby markets and for a certain time. The alliances cover the joint ventures and a variety of technological collaboration agreements between companies and universities, suppliers, customers, and competitors (Grant & Baden-Fuller, 2004; Hagedoorn & Duysters, 2002; Tidd et al., 2008)
Licensing of IP	The most direct way for a company to buy or sell technology, it is essential to open innovation. The company may sell their technology, and explore the intellectual property from other organizations, in exchange of fee payment or royalties. In relation to internal development, the low cost of development, less technological and market risks, and agility in the development and launching products on the market are among the advantages of licensing (Pénin *et al.*, 2011; Sikimic *et al.*, 2016; Tidd *et al.*, 2008)
Acquisition or creation of enterprises	Direct applications of the processes of exit and ingress of open innovation. The company may acquire a technology acquiring the company that developed it (ingress process) or it can create a new enterprise to exploit a technology created by it (exit process) (Pénin *et al.*, 2011)
Research consortium	Companies work together on a specific project, which can be the creation of a new enterprise in common or a new research facility. The sharing of costs and risks of the research, the establishment of standards, and the combination of different skills and knowledge of the companies are among the advantages of joining a research consortium. SRC and SEMATECH are examples of research consortia in the semiconductor industry (Logar *et al.*, 2014; Tidd *et al.*, 2008)
Innovation networks	Intermediary networks from which companies are associated to generate new products and technologies. To facilitate access to new markets and technologies, integrate complementary competences and guarantee the rights of ownership are among the benefits to join a network. In addition, participation in a network of innovation can be crucial to the company to reach a greater degree of novelty in product innovation (Chesbrough & Prencipe, 2008; Dittrich & Duysters, 2007; Lyu *et al.*, 2019; Nieto & Santamaría, 2007)

Table I.
Forms of collaboration

Notes: SCR = semiconductor research corporation; SEMATECH = semiconductor manufacturing technology
Source: Prepared by the authors based on the literature (2019)

dependence of productive components for the development of electro and electronics activities in the country [Associação Brasileira da Indústria Elétrica e Eletrônica (ABINEE), 2019].

To give Brazilian DHs the opportunity to have global operations, and to encourage the consolidation of the semiconductor industry in the country, the Brazilian Government has instituted laws and programs. Some of them are presented in Table II.

4. Methodology

This study may be classified as exploratory (Neuman, 1997) and descriptive (Saunders *et al.*, 2009). Exploratory, as the subject is underexplored in the Brazilian industry of semiconductors. It is an attempt to bring theoretical contributions to the field. Descriptive because it is grounded in a theoretical framework known, open innovation, to study the semiconductor industry in Brazil and to describe it in a new perspective.

In addition, the study adopted a qualitative approach, as it emphasizes the use of words and analyzes the data from how individuals interpret the social world in which they are

Law/program	Description
PNM	Created by the Ministério da Ciência e Tecnologia (Ministry of Science and Technology) in 2002, to promote the development of the microelectronics industry in Brazil. PNM was divided into three subprograms: project of integrated circuits (DHs); fabrication of integrated circuits (foundries); and encapsulation and tests (back-end). Each one had specific strategic objectives [Ministério da Ciência e Tecnologia (MCT), 2002]
PITCE	Launched by the federal government in 2004, the objectives were to increase the efficiency of the productive structure, increase the innovation capacity of Brazilian companies, and expand exports. The industries of semiconductors, software, drugs and capital goods were strategic (Salerno & Daher, 2006)
Programa CI-Brasil	Established by CATI, from MCTI, on June 15, 2005. It integrates the PNM design, and its objective is to develop an ecosystem in microelectronics to put Brazil on the international scene of semiconductors (CI-BRASIL, 2019).
PADIS	Instituted by Law no. 11, 484, created by Decree no. 6, 233, both in the year 2007. The purpose was to encourage R&D, and the production of semiconductor electronic devices, reducing to zero the aliquots of the contribution for Brazilian taxes PIS/Pasep, COFINS and IPI, in addition to income tax rate (Law no. 11, 484/2007)
Training Program of the Brazilian DHs	Created in 2011 by the working group of semiconductors, a partnership of MCTI, MDIC, BNDES, FINEP, APEX, and ABDI. ABDI was the coordinator and responsible for the steps of the program. Based on the actions of the Programa CI-Brasil, the aim of the program was empowering the DHs in business management, providing their sustainable development, through some specific goals, among them the dissemination and training of companies to use incentive mechanisms, such as PADIS and the Law of Informatics (ABDI, 2011)

Notes: PIS = social integration program [programa de integração social]; COFINS = contribution to social security financing [contribuição para o financiamento da seguridade social]; IPI = taxes over industrialized products [imposto sobre produtos Industrializados]; MDIC = Ministry of Industry, Foreign Trade and Services [Ministério da Indústria, Comércio Exterior e Eerviços]; APEX = Brazilian Export and Investment Promotion Agency [Agência Brasileira de Promoção de Exportações e Investimentos]
Source: Prepared by the authors based on the literature (2019)

Table II.
Public policies to support the semiconductor industry

(Saunders *et al.*, 2009; Bryman & Bell, 2011). As a research strategy, the choice was the multiple case study (Eisenhardt, 1989; Yin, 2015). As a criterion for the selection of companies to compose the study, they should be DHs Programa integrated circuit [circuito integrado(CI)]-Brasil participants operating normally at the time of the survey. The Programa CI-Brasil was established by the Comitê da Área de Tecnologia da Informação (Committee in the Area of Information Technology – CATI), Ministério da Ciência, Tecnologia e Inovação (Ministry of Science, Technology and Innovation – MCTI), on June 15, 2005 and integrates the National Program of Microelectronics (Programa Nacional de Microeletrônica) – PNM design. The objective is to develop an ecosystem in microelectronics able to insert Brazil in the international scenario of semiconductors (CI-Brasil, 2019).

In addition to the DHs, specialists of microelectronics were also interviewed. Professors and engineers were selected according to accessibility and availability criteria.

As sources of evidence, three managers of DHs and four specialists were interviewed. The DHs were contacted by e-mail and by a message on the field "Fale conosco" (contact us) available on the company website. The interviews occurred in online mode, with a structured script sent by e-mail. The interviewees received an access link to the online platform "Forms" of Google®, in which they could answer the questions proposed.

To clarify doubts and complement the information sent, the respondents were contacted more than one time with new pending questions. Table III presents information about the legal nature and the number of DHs employees participating in the survey. The names of the companies were omitted to ensure their anonymity.

The interview script was prepared in two versions on the online platform "Forms" of Google®, the version for companies and the version for specialists. Both versions contain open questions to explore the opinions of the interviewees about the current scenario of microelectronics in Brazil. The interview script was delivered between December 27, 2016 and January 10, 2017.

In addition to the interviews, a documentary analysis was performed about the information on the DHs sites, such as contacts, main customers, successful cases, services and products offered. Also, the information contained on the websites of ABISEMI, ABDI, ABINEE and MCTI, as well as reports, economic landscape and news about the sector.

The collected data were analyzed according to Table IV categories and elements of analysis. They were pre-defined based on the literature studied, as according to Eisenhardt (1989), the definition of priori elements provides a more consistent analysis of the phenomenon studied.

To analyze the data, the content analysis technique was used. According to Laville & Dionne (1999), the content analysis aims to dismember the components of the content analyzed to find characteristics and meanings to allow the researcher to analyze the material collected through data collection. The responses were downloaded using the tool "Forms" of Google®, which allow the exam of the transcriptions of interviews. As suggested by Laville and Dionne (1999), the raw material was evaluated and compared to interpret the data by the categories and elements of analysis adopted in the study.

The data obtained through interviews with managers of DHs, specialists in the field, and the documental analysis were compared to generate theoretical dimensions consistent with the study.

5. Presentation and discussion of results

5.1 Collaboration with external agents

Regarding the implementation of partnerships with other companies, there was a consensus between the managers of DHs interviewed about the implementation of partnerships with different external agents, such as suppliers, intermediaries, universities, development agencies and other DHs. The partnerships occur for several reasons, among them the development of new products, access to financial resources and qualified labor.

Interviewees	Legal nature	No. of employees of the company	Targeted business
DH-1	For-profit	Between 21 and 50	RFID solutions, signal processing, development of digital and analog Ips
DH-2	Nonprofit	Between 11 and 20	Telecommunications, digital-TV
DH-3	Nonprofit	Between 11 and 20	Energy, electrical and electronic equipment, electronic business, and supplies business to portable devices and telecommunications

Table III.
Institutional profile of design houses

Note: RFID = radio-frequency identification
Source: Field study

Categories	Elements of analysis	References
Collaboration between Brazilian DHs and its partners	Objective of the partnership: develop new products, obtain financial resources, qualified labor, etc Kinds of partnership agreement and reasons that led the company to use them	Biazzi, 2012, Bönte & Keilbach (2005), Camboim (2015), Chesbrough (2011, 2012), Faccin & Balestrin (2015), Faccin *et al.* (2016a), Han *et al.* (2018), Janeiro *et al.* (2013), Kapoor & Mcgrath (2014), Oliveira & Balestrin (2015), Pénin *et al.* (2011), Rasiah *et al.* (2016), Simard & West (2011), Striukova & Rayna (2015), Sydow & Müller-Seitz, 2019), Tidd *et al.* (2008) and Vanhaverbeke (2011)
Protection of IP	Patents registry by companies for IP protection Process of registering patents in Brazil	Campanario *et al.* (2009), Chesbrough (2011), Holgersson & Granstrand, (2017), INPI (2017), Jungmann & Bonetti (2010), Law no. 11,484 (Law no. 11,484/2007), Pénin *et al.* (2011) and Sikimic *et al.* (2016)
Government policies to support the industry	Availability of public resources by development agencies policies developed by the Brazilian Government to promote the industry of microelectronics: PNM and PADIS Evaluation of the Programa CI-Brasil	ABDI (2011, 2014), ABISEMI (2018), Breier *et al.* (2013), Campanario *et al.* (2009), Faccin *et al.* (2016a, 2016b), Law no. 11,484 (Law no. 11,484/2007), Motta & Maia (2015); PNM (MCT, 2002), Salerno & Daher, (2006), Programa CI-Brasil (2019), Rasiah *et al.* (2016), Wu et al. (2019)
Future of microelectronics in Brazil	The future of microelectronics in Brazil Recommendations for the improvement of the industry and for Brazilian DHs	ABDI (2011, 2014), ABISEMI (2018, 2019a)

Source: Prepared by the authors based on the literature (2019)

Table IV. Categories and elements of analysis

When asked about the development of innovations in partnership with other institutions, the manager of DH-2 mentioned the joint development of a new integrated circuit. The first batch of parts of it was sold in the year 2016, and it was in process of development in volume of scale. The project had the participation of different companies, among them one other DH, proving the studies by Faccin and Balestrin (2015) and Faccin *et al.* (2016a). The authors say companies usually seek access to complementary capabilities with partnerships. The collaboration between manufacturers of semiconductors can be motivated by a desire to acquire new knowledge and learning, as well as generate economic efficiencies in R&D connecting resources of enterprises (Kapoor & Mcgrath, 2014).

DH-3 quoted projects with universities and research centers to develop innovations. DH-1 said to maintain strong ties with Federal University laboratory and research group, its point of origin, by scientific-technological cooperation and training of human resources. In addition, the company maintains strong interaction with electronic engineering university course, as most of the company employees studied at the university.

This kind of partnership has also been observed in studies of Camboim (2015), Faccin & Balestrin (2015), Oliveira and Balestrin (2015). They showed the existence of collaboration between the DHs, Brazilian universities and research institutes. Universities and research institutes can act as intermediaries for knowledge, bringing together different organizations to an environment-friendly to collaboration. The existence of universities and research groups active in software development and in microelectronics can be explored by Brazilian DHs to advance the implementation of its activities (Biazzi, 2012; Striukova & Rayna, 2015).

As an example, to be implemented in the Brazilian industry, Rasiah *et al.* (2016) observed semiconductor companies in Taiwan and indicated the support of engineers and scientists, as well as universities and laboratories, as important elements in supporting the technological modernization of industry in the country.

About the type of partnership, formal or informal, formal agreements prevail as a means for collaboration, given the contractual guarantees and legal security. As observed by Faccin and Balestrin (2015), who said the Brazilian DHs attribute the success of a collaborative project to formalized agreements with its partners, the manager of DH-2 says the agreements are formal to guarantee by contract the division of the royalties originated from the exploitation of new products.

Although the predominance of formal agreements to mediate the collaboration with partners, the informal agreements can also bring significant contributions to the process of innovation of DHs, as they are more dynamic and do not need contracts. Especially in high-tech industries, such as the semiconductor industry, requiring the creation of innovations continuously (Bönte & Keilbach, 2005; Han *et al.*, 2018; Hannigan *et al.*, 2018).

About the possibility of establishing more partnerships between Brazilian DHs and other companies to develop innovations, the managers of the DHs have expressed different opinions. The managers of DH-1 and DH-3 claim partnerships could strengthen the ecosystem of microelectronics in Brazil, and to be strategically desirable, as it could provide economies of scale, in addition to enabling the sharing of costs and responsibilities between the companies. On the contrary, the manager of DH-2 believes the existing partnerships are already significant, as the focus of the DHs is distinct, it is not necessary a greater number of partnerships.

Regarding the specialists interviewed, all of them agree the DHs could develop more innovations using partnerships. According to the respondents, although there are already this kind of partnerships in the industry, they are isolated, and more incentives are needed to make it reality. The Specialist-2 believes these partnerships could complement the companies' know-how, enabling the DHs to meet various demands simultaneously.

Specialist-1 agrees "there is no reason to not make partnerships." According to him, the microelectronic industry focus in Brazil should be the establishment of know-how, due to the high complexity of the market and the immaturity of the DHs to deal alone with the high technology the industry requires. For Specialist-3, it is necessary to think in projects in common, with projection of sales in scale, projects able to justify the elaboration of a chip. According to him, in the current model, the DHs compete for small and specific projects to meet the needs of a company, with sales projection of a thousand to ten thousand chips, which does not justify the development of a chip project.

The increasing technological complexity and changes in the market need to be transformed the cooperation in a fundamental resource for organizations obtain additional skills, increase their capacity for innovation and reduce the time to launch innovation to the market (Enkel *et al.*, 2009; Yoon & Song, 2014). In the case of the semiconductor industry, defined by fast technological changes and requiring high levels of investment in R&D to develop new products, technological progress can be activated by a collaborative network including suppliers, users, and research organizations, cooperating to develop innovations (Kapoor & Mcgrath, 2014; IC Insights, 2019; Sydow & Müller-Seitz, 2019).

The study prepared by Faccin *et al.* (2016a) can be mentioned as a practical example of how the design of a chip can be time consuming and expensive. According to the authors, to develop the first Brazilian microcontroller chip, at least 3.5 years of work were needed, in addition to a series of investments of the government and the companies involved. However, among the main benefits of the collaboration, the reduction of risks and costs, agility to the delivery of the product, and the maturation of the teams can be highlighted.

As a result, the DHs may adopt different forms of partnerships to develop new projects and enjoy the benefits of collaboration. For example, they can develop partnerships with universities and research institutes to explore the potential of a new technology, create networks of collaboration with customers and suppliers to launch new products and services based on a new business model or even purchase or create alliances with technology-based startups (Pénin *et al.*, 2011; Vanhaverbeke, 2011).

5.2 Protection of intellectual property

About the process of registering patents in Brazil, and if this record should happen only when innovation has commercial viability, one of the managers of the DHs recognized do not have an opinion on the matter, while the other two agreed the process is time-consuming and costly.

For the manager of DH-1, the process of registering patents in Brazil is still very slow. Although investments improve the process, it is pointed out as "discouraging" for investors who have few resources to protect their creations, especially in cases of patents for international repercussions. The investment for protecting them is outside the capacity of DHs, usually small businesses. For these reasons, the industrial secret is the most used resource for the protection of innovation. The manager of DH-3 also considers the process of registering patents slow and expensive. According to him, the patents shall be deposited as soon as the commercial viability of innovation is proven.

The rights on intellectual property and patents are key mechanisms to ensure small businesses can buy or sell technology. They are essential to open innovation (Pénin *et al.*, 2011; Sikimic *et al.*, 2016). In the case of integrated circuits, in Brazil, the protection is the registration of topography (INPI, 2017). According to Instituto Nacional da Propriedade Industrial (Industrial Property National Institute - INPI, 2019) data, between 2009 and 2019, 26 records of integrated circuit topography were granted in the country. However, for the Brazilian Association of the Semiconductor Industry [Associação Brasileira da Indústria de Semicondutores (ABISEMI), 2019b], among the associated companies, 42 patents have been issued or are in the process of analysis by INPI.

Internationally, according to information from World Intellectual Property Organization, in 2017, Brazil recorded 312 patent applications for semiconductors, while countries as China and USA registered, respectively, 20, 314 and 21, 290 requests [World Intellectual Property Organization (WIPO), 2019]. The data show differences in investment between the countries in the semiconductor industry.

Regarding specialists, three interviewees confessed do not know the process or have no opinion on the matter. For Specialist-3, the lack of knowledge about the process is not a consequence of the lack of interest in the subject. According to him, few people know the steps to register a patent, and for this reason, patents are deified at universities.

Specialist-2 also believes the process is very time consuming but it is important to serve as a warranty in the search for business opportunities. Similarly, Specialist-1 defined the process as expensive and time-consuming. However, he suggested the creation of an analysis committee to make the process faster: "It could be a commission for analysis of patents, subsidizing only those products with high scientific or commercial potential or at least the best products patentable".

By the interviews, it is possible to realize, although companies and specialists try to control and protect the intellectual property (IP) through the registration of patents, the knowledge about this protection mechanism is still deficient. Jungmann & Bonetti (2010) explains that due to the complexity and technological intensity demanded by the design and manufacturing of integrated circuits, the knowledge about the system of intellectual

property protection helps to ensure the rights of the company in their business transactions, and consequently, the continuity of its competitiveness on the market.

About companies providing services in knowledge, the management of intellectual property rights, marketing strategies and pricing are essential elements for achieving success. These strategies allow businesses to develop a package of IPs to license, use it in the creation of new products or even be a basis for a new company (ABDI, 2014). In addition, companies believe to be more important to patent their innovations when they make use of open innovation than when they adopt the internal development of ideas (Holgersson & Granstrand, 2017).

Campanario *et al.* (2009) showed the Brazilian Government understands the importance of intellectual property protection in the semiconductor industry, the creation of a law project for topography of integrated circuits is among the measures of PITCE (Política Industrial, Tecnológica e de Comércio Exterior – Industrial, Technological and Foreign Trade). The goal was to encourage the process of innovation in industry and ensure the rights on IP, an extremely important factor in high technology industries. Law no. 11,484/2007 instituted the Program of Support for the Technological Development of the Semiconductor Industry and Displays (Programa de Apoio ao Desenvolvimento Tecnológico da Indústria de Semicondutores e Displays – PADIS) also provides, among other items, the process of intellectual property protection of topographies of integrated circuits (Law no. 11,484/2007).

5.3 Public policies to support the semiconductor industry

About the public policies to support the semiconductor industry in Brazil, the managers of DHs were concerned about their continuity. The manager of the DH-1 says, despite having well-defined objectives, the interruptions of these policies, which may have been motivated by a lack of resources or even by the perception of the government regarding their priority and performance over time, can impair their efficiency. For the manager of the DH-2, the difficulty in developing R&D in microelectronics in Brazil, without programs such as PADIS, would be greater.

For this reason, the Associação Brasileira da Indústria de Semicondutores (ABISEMI) (2018) endorses the continuity of these policies, showing the Law of Informatics (Law no. 8,248/1991) and PADIS has contributed as a legal framework for the competitiveness of the industry of information and communication technology. They allow the Brazilian companies fight for their space in the international market on equal terms with imported products. Without the policies, the companies will not be able to join global projects. In addition, the association clarifies that incentives for the development of the semiconductor industry should benefit the national production, encourage innovation and development, ensuring the competitiveness and the continuity of companies and jobs.

Breier *et al.* (2014) also pointed out some difficulties if PADIS is not renewed. According to the authors, a dramatic reduction of the potential profits of companies benefited by it may occur. In the semiconductor industry, investments in R&D should be continuous to companies remain competitive in the market. The non-renew of the program may represent a risk, as the company will need structure during the first ten years to arrive at the eleventh with a consolidated financial basis.

About the Programa CI-Brasil, most of DHs managers and specialists believe it brings several benefits for the microelectronics industry. However, there is also a concern regarding the continuity of the program in the long term. The manager of DH-2 believes the program is doing its job regarding the generation of human resources for the industry. The Specialist-1 also mentioned the stimuli provided by Programa CI-Brasil are effective. However, as

observed by the manager of DH-1, they need to be thought of in the long term, not finished early.

For Specialist-2, resources should be extended beyond a single government term, as the policies are essential and assist the industry development. He also emphasizes the procedures must be rethought to make the process faster and less bureaucratic. Stating the opinion of respondents, authors such as Breier *et al.* (2014) and Motta & Maia (2015), also says the investments in R&D in the semiconductor industry should be continuous to ensure the success of these actions.

Although the government's efforts to create an environment favorable to the development of the semiconductor industry, the Specialist-3 recognizes the industry is very dependent on government investment. He imputes the end of the activities of some DHs to the absence of a more active role of entrepreneurs in the industry. He also ensures it will be impossible to progress if companies do not take an active role in the development of microelectronics in Brazil. The expert also says the current model of Programa CI-Brasil is not suitable. Despite creating qualified professionals, they do not meet the demand of the market, as the content of the training course is very specific.

In contrast, the Specialist-4 mentioned the training program of human resources supported by the government has shown great results. Despite considering the market demands, the incentive to the creation of DHs by these professionals was a strategy not explored appropriately. Authors such as Faccin *et al.* (2016b) and Motta & Maia (2015) also highlights the positive results of the program CI-Brazil regarding the training of qualified labor. They show the professionals trained or qualified by the program had good acceptance in the market.

Regarding the provision of financial resources to the industry by development agencies, such as CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico – National Council for Scientific and Technological Development) and FINEP (Financiadora de Estudos e Projetos – Financier of Studies and Projects), if these public resources are adequate to finance the development of innovations in the semiconductor industry, both managers of DHs and specialists have different opinions on the subject.

The manager of DH-1 admitted the adequacy of resources made available by development agencies should be related to governmental projects with clear goals and objectives. They must be established by industrial policy, especially for long term. For him, the innovation in industry must be firmly connected to economic goals and quality.

For the interviewee of DH-3, investments are not enough, they should be significantly higher to compensate for the development of the entire chain of semiconductors. The manager of DH-2 reinforced the scholarships provided by CNPq are outdated and has not been readjusted, as its implementation, and it is not attractive to professionals of the industry. In addition, the resources needed to develop projects in semiconductors can be a challenge to FINEP, as the volume needed for microelectronics projects is higher than for other projects of innovation in information technology.

For Specialist-1, the combination of the resources of these development agencies with those from BNDES (Banco Nacional de Desenvolvimento Econômico e Social – National Bank for Economic and Social Development) is satisfactory. However, the money received by the fellows and the bureaucracy to release the resource are problems for this kind of financing. In contrast, the Specialist-2 disagrees. According to him, it is far from the ones from countries with a solid tradition in the semiconductor industry.

Specialist-3 believes these resources are appropriate to finance the development of innovation in industry but warns for the diversion of funds and the overpricing in projects. Specialist-4 believes the resources have been adequate to create human resources in the field,

however, they are insufficient to encourage the development and competitiveness of the industry.

As observed in other countries (Wu *et al.*, 2015), the performance of the Brazilian Government plays a central role in the semiconductor industry, as it is dependent of incentives and requires support policies designed in the long term [Associação Brasileira da Indústria de Semicondutores (ABISEMI), 2018; Lima *et al.*, 2015]. This emphasizes the importance of the continuity and improvement of these policies for the development of the industry in the country.

Internationally, the Brazilian industry will be able to follow the example of the support of Taiwan Government to the semiconductor companies. The companies stated, as well as the support of universities and laboratories, the scholarships of R&D represented important support for technological modernization in the semiconductor industry in the country (Rasiah *et al.*, 2016).

5.4 The future of microelectronics in Brazil

About the future of microelectronics in Brazil and the path of the country to a technologically independent industry, the interviewees expressed different points of view on the subject.

For the manager of DH-2, Brazil is beginning to become technologically independent. It will require cultural changes and macroeconomic policies, as well as changes on how to look for the role of innovation in the economy of the country, becoming economically viable. The manager of DH-1 warns the strategy to be adopted by the industry should be directed to the external market, and from this, new aspects of the market can be exploited. The interviewee of DH-3 did not opine on the subject.

The report of ABDI (2014) pointed out the national semiconductor industry still has a low demand for the services of integrated circuits design, and multinational companies have no interest in hiring the local DHs to develop projects. Moreover, the DHs do not have the resources needed for investment and their projects do not accept an increase in scale. Despite the problems, Associação Brasileira da Indústria de Semicondutores (ABISEMI) (2019a) believes Brazil represents a relevant market for the electronic complex and presents business opportunities. In addition to the possibility of supplying the domestic market, it is possible to export final goods, as Latin America does not have local production.

As well as the managers of the DHs, specialists showed distinct views on the matter. For Specialist-1 the industry's future will always be uncertain because it strongly depends on the government and the government does not consider microelectronics a priority. Furthermore, it considers the investment in industry not enough for their growth. Specialist-4 agrees the independence of the industry is far and due to the economic and political crisis, it is difficult to think on the matter. For him, there is a lack of connection between the needs of the market and what DHs develop, and this impairs the development of industry.

For Specialist-2, the future seems promising, and there is a demand for solutions to regional problems. However, the actors of the sector must be more coordinated. Despite that according to him, the industry presents some opportunities in the development of microelectronic solutions and related fields, such as light-emitting diodes, sensors, actuators and cameras, and they can be exploited for local consumption and exports.

Specialist-3 recognizes wages are not appropriate to the knowledge required by industry. Therefore, engineers are not motivated to specialize in the field. This factor is a problem for industry development.

Still examining the future of microelectronics in Brazil, the interviewees were invited to provide recommendations for the improvement of the microelectronics industry in Brazil, as

well as for the DHs. In general, both companies and specialists suggested improvements regarding the payment of professionals working in the industry, improvement of incentive policies and investments by the government, and exploitation of new market opportunities, both in the industry and DHs.

For the manager of the DH-1, an industrial and marketing policy directed to the care of emerging markets with high-quality products should be created, with the support of the government. For Brazilians DHs, the suggestion is to identify market niches, based on the needs of miniaturization of electronics complex in Brazil and worldwide. Specialist-2 also believes the government subsidy must ensure, as it happens in other countries, the establishment of a strategic and competitive field. Also, there must be investments in niche markets, in addition to greater interaction with local research groups.

The creation and continuity of the conditions to motivate people, as well as an appropriate payment to the people with the knowledge necessary to work in industry are identified by Specialists 1 and 3 as fundamental to the development of Brazilian microelectronics and DHs.

To synthesize the results found, Table V was made. From it, it is possible to make some considerations about the practices of open innovation adopted by Brazilian DHs in the DHs managers' perception. In addition to the discussion about public policies to support the industry and the future of microelectronics in Brazil.

To present the perception of specialists on the semiconductor industry and practices of open innovation in Brazilian DHs, Table VI was made.

Observing Tables V and VI, it is possible to deduce managers of DHs and specialists had different views on the semiconductor industry and the practices of open innovation implemented in Brazilian DHs. Many of them were corroborated by the studies found in the literature on the topic, enabling point out some important implications about the semiconductor industry in Brazil.

6. Final considerations

The objective of this study was to understand how Brazilian DHs use open innovation in joint development projects for integrated circuits. The results demonstrated DHs implement practices of open innovation in the development of projects for integrated circuits.

As a contribution, this article presents important implications about the semiconductor industry in Brazil, as it is considered strategic for the competitiveness of the industry of final goods. The study also presents suggestions for new business approaches to assist the strengthening of this segment, by the vision of companies and specialists working in the industry.

First, it should be emphasized the importance and necessity of DHs to establish more partnerships with different external agents, considering the requirements and benefits of the collaborations. The aim is to develop new technologies and exploit new market opportunities, while the sector preserves competitiveness (ABDI, 2014; Faccin *et al.*, 2016a; Kapoor & Mcgrath, 2014; Rasiah *et al.*, 2016; Sydow & Müller-Seitz, 2019).

Second, the DHs can consider the use of informal agreements to mediate the collaboration with its partners. They can also bring significant contributions to the process of innovation of DHs, as they are more dynamic and do not need contracts (Bönte & Keilbach, 2005; Han *et al.*, 2018; Hannigan *et al.*, 2018).

Third, the process of registering patents in Brazil, as well as the registry of the topography of integrated circuits, is still in deficit, is time-consuming, and considered expensive. Despite the attempts of the government to encourage companies to use this mechanism of protection of intellectual property (Campanario *et al.*, 2009; Law no. 11,484/

Categories of analysis	DHs managers' perception
Collaboration between Brazilian DHs and its partners	All DHs participating on the survey implement partnerships with various external agents, among them suppliers, intermediaries, universities, development agencies and other DHs There are several objectives for these partnerships, including the development of new products, access to financial resources and qualified labor These results corroborate the findings by the research of Biazzi, (2012), Camboim (2015), Faccin & Balestrin (2015), Faccin *et al.* (2016a), and Oliveira & Balestrin (2015) about the Brazilian industry of semiconductors; and by studies carried out in other countries, as Kapoor & Mcgrath (2014), Rasiah *et al.* (2016), and Striukova & Rayna (2015). There is a consensus among the authors about the importance and benefits to the semiconductor industry by the development of partnerships between companies and other external agents To intermediate the collaboration with partners, formal agreements for collaboration between the DHs and its partners prevails, as they certify the contractual guarantees and legal security, as well as observed by Faccin & Balestrin (2015) About the possibility of establishing more partnerships between DHs and other companies to develop innovations, there was no consensus among the managers of the DHs interviewed Managers of DH-1 and DH-3 claim partnerships could strengthen the ecosystem of microelectronics in Brazil, in addition to being strategically desirable. The manager of DH-2 believes the existing partnerships are already significant Proving the favorable opinions to the development of new partnerships in the semiconductor industry, Kapoor & Mcgrath (2014) argue technological progress in the industry can be activated by a collaborative network, where different partners cooperate to develop innovations in the industry
Protection of IP	Regarding the process of registering patents in Brazil, and if this should happen only when innovation have commercial viability, one of the managers of the DHs recognized he has no opinion on the matter, while the other two agreed the process is time consuming and costly Authors such as Pénin *et al.* (2011), Sikimic *et al.* (2016) and Tidd *et al.* (2008) declares the rights over intellectual property and patents are key mechanisms to ensure small businesses can buy or sell technology, regarding it essential to open innovation Despite the benefits of IP licensing, authors such as Campanario *et al.* (2009) showed the Brazilian Government understands the importance of intellectual property protection in the semiconductor industry. To Brazilian DHs exploit this mechanism, the suggestion is to study ways to make the process of registering patents in Brazil more transparent and accessible
Government policies to support the industry	The managers of the DHs were unanimous about the concern of public policies continuity to support the semiconductor industry in Brazil. They stat they are important for the continuity and competitiveness of industry and must be thought in the long term Authors such as Breier et al. (2013) and ABISEMI (2018) also endorse the continuity of policies to the companies of the sector remain competitive in the market. The domestic production would be

(*continued*)

Table V.
DHs Managers' perception about the practices of open innovation, public policies to encourage and enable future in microelectronics in Brazil

Categories of analysis	DHs managers' perception
	benefited, innovation and development would be promoted, and the generation of jobs would be ensured
	About the Programa CI-Brasil, the managers of DHs believe it brings several benefits for the microelectronics industry. However, there is also a concern regarding the continuity of the program in the long term
	As well as the managers of the DHs, Breier *et al.* (2013) and Motta & Maia (2015) affirm that in the semiconductor industry, investments in R&D should be continuous to ensure the success of these actions
	There is no consensus for managers of DHs on the availability and adequacy of financial resources for the industry by means of developing agencies
	Only the manager of DH-1 believes they are appropriate. For the managers of DHs 2 and 3, investments are not enough and need to be adjusted considering the resources needed to develop projects in microelectronics
	As observed in other countries (Wu et al., 2015, 2019), authors such as Faccin *et al.* (2016b), Lima *et al.* (2015) and the ABISEMI (2018) reaffirm the importance of Brazilian Government actions in the semiconductor industry, as the industry depends on incentives and requires support policies designed in the long term
Future of microelectronics in Brazil	On the future of microelectronics in Brazil, the interviewee of DH-3 did not opine on the subject. The managers of the DHs 1 and 2 consider the industry is still at the beginning of the walk to become technologically independent, and strategies focused on the foreign market and the exploitation of new aspects should be adopted, for the development of industry
	Managers suggest improvements on the payment of professionals of the industry, improvement of incentive policies, investments provided by the government, and exploitation of new market opportunities, both in the industry and in the DHs
	In accordance with the interviewees, ABDI (2014) and the ABISEMI (2019a) believe in the amplitude of new possibilities in the semiconductor sector in Brazil, as it represents a relevant market for the electronic complex and presents business opportunities, nationally and in Latin America

Source: Field study

Table V.

2007), the data shows the number of records, both nationally and internationally, is still small in comparison to countries investing in this segment (INPI, 2019; WIPO, 2019). Among the collaboration ways with external agents in open innovation, the licensing of IP rights is considered essential, as it guarantees to companies the exploration of technologies developed by them or by other organizations (ABDI, 2014; Holgersson & Granstrand, 2017; Pénin *et al.*, 2011; Sikimic *et al.*, 2016). Therefore, it emphasizes the need to stimulate the DHs, as well as other companies and researchers who work in development of innovations in Brazil, to invest in the process of registration of patents, and it is a duty for the government to remodel and simplify this process.

Forth, due to the role of the government to be pointed out as crucial for the consolidation of national semiconductor industry, it is important to highlight it should invest in improving

Categories of analysis	Perception of specialists
Collaboration between Brazilian DHs and its partners	All the specialists interviewed agree DHs could develop more innovations using partnerships. The complement of the know-how of businesses and the development of projects with a projection of scale are among the benefits of the partnerships mentioned by them. However, there must be incentives for companies to collaborate with different partners The benefits of these partnerships for the semiconductor industry have already been presented by different authors, among them, Faccin & Balestrin (2015), Kapoor & Mcgrath (2014), and Sydow & Müller-Seitz (2019). According to them, the quick technological changes and the need for high investments in R&D to develop new products can be provisioned by the establishment of partnerships with different external agents
Protection of IP	The three specialists interviewed confessed to not having knowledge about the process of intellectual property protection or have no opinion on the matter However, the ignorance of the process is not a consequence of the lack of interest in the subject. According to them, the process of registering patents in Brazil is expensive and time consuming. Although it is important to be a guarantee as a business opportunity, the knowledge about this protection mechanism is still deficient Despite attempts by the Brazilian Government to promote the process of innovation in industry and ensure the rights on the IP by programs and public policies for the sector (for example, the Law no. 11,484/2007, establishing PADIS, and features on the protection of topographies of integrated circuits), the knowledge about this protection mechanism is still deficient. This highlights the need to simplify and make the registration process more accessible, for companies and for researchers, as it contributes to ensure the rights of exploitation of intellectual property (Jungmann & Bonetti, 2010; Pénin *et al.*, 2011)
Government policies to support the industry	About the Programa CI-Brasil, the three specialists interviewed recognize it brings benefits for the microelectronics industry. However, there is a concern regarding the continuity of the program in the long term, as pointed out by Breier *et al.*, (2013) and Motta & Maia (2015) Only one of the interviewees stated the current model of the Programa CI-Brasil is not suitable, despite training qualified professionals, they do not meet the demand of the market. The studies of Faccin *et al.* (2016b) and Motta & Maia (2015) diverge. According to the authors, the trained or created professionals by the program had good acceptance in the market The specialists also showed different points of view on the availability and adequacy of financial resources for the industry by developing agencies Two of the specialists interviewed believe the provision of these resources has been adequate and satisfactory for the development of innovation in the industry, despite pointing out problems in the payment received by the fellows and the bureaucracy for releasing the payment. In addition to the diversion of funds and the overpricing projects In contrast, other specialists do not agree the resources available are adequate to stimulate the development and competitiveness of the

(*continued*)

Table VI.
Perception of specialists on the semiconductor industry and the practices of open innovation in brazilian DHs

Categories of analysis	Perception of specialists
	industry. Although they are appropriate for training the human resources in the field
	On the dependence and the importance of the government for the semiconductor industry in Brazil, authors such as Lima *et al.* (2015), Faccin *et al.* (2016b), the ABDI (2014) and ABISEMI (2018) reaffirmed the importance of the continuity and improvement of these policies for the development of industry in the country
Future of microelectronics in Brazil	Only one of the specialists interviewed sees a promising future for the microelectronics in Brazil. He says there is demand for solutions to regional problems, and opportunities in the development of microelectronic solutions and related fields, in agreement with the ABDI (2014) and the ABISEMI (2019a)
	The other respondents believe the industry's future is uncertain. The strong dependence of the government, the lack of connection between the needs of the market and the products developed by DHs, and the low wages are among the reasons for this uncertainty. They jeopardize the development of the sector
	To improve the industry, better payment of professionals, improvement of incentive and investments policies provided by the government, and a greater interaction with the local research groups are among the suggestions made by the specialists

Source: Field study

Table VI.

and maintaining the long-term sustainability of public policies to support the industry, auditing the investments made and making the offer of financing alternatives more competitive (ABDI, 2014; ABISEMI, 2018; Breier *et al.*, 2014; Wu *et al.*, 2019). These actions can ensure the maturation of the industry, fostering innovation and development and generating jobs.

Fifth, due to the strategic content for the competitiveness of the industry of final goods, and for represent a relevant market for the electronic complex [ABDI, 2014; Associação Brasileira da Indústria de Semicondutores (ABISEMI), 2019a], it is advisable to continue investing in the segment of microelectronics in Brazil, through improvement of incentive policies and investments provided by the government, adequacy of payment of professionals working in the industry. It is a way to explore new possibilities and business opportunities, to make the industry technologically independent.

Finally, other forms of collaboration were not identified in the study. For example, the establishment of innovation networks, research consortia and strategic alliances (Chesbrough & Prencipe, 2008; Grant & Baden-Fuller, 2004; Logar *et al.*, 2014; Lyu *et al.*, 2019). The recommendation for DHs and for the industry is to explore new forms of collaboration, making the process of innovation more dynamic.

As study limitations, it is possible to mention the number of companies interviewed, as at the time of the survey 18 DHs linked to the Programa CI-Brazil were in normal operation (ABDI, 2014). The participation of these companies would allow a broader vision about the practices of open innovation implemented by DHs. In addition, interviewing other specialists, for example, students of training programs in the industry, to have a broader perspective on the development and the future of the semiconductor industry in Brazil.

For future research, it is suggested to compare the strategies adopted by DHs connected to Programa CI-Brazil with the ones adopted by DHs of the private sector; and to evaluate

the results of support public policies implemented by the government in the development of the semiconductor industry.

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