GESTÃO & PRODUÇÃO

ISSN 0104-530X (Print)
ISSN 1806-9649 (Online)

ORIGINAL ARTICLE

Product development in technology based firms in innovation environments

Desenvolvimento de produtos em empresas de base tecnológica instaladas em ambientes de inovação

Carlos Augusto França Vargas[1], Silvio Aparecido dos Santos[1], Guilherme Ary Plonski[1], Márcio Shoiti Kuniyoshi [2]

[1]Universidade de São Paulo – USP, Faculdade de Economia, Administração e Contabilidade – FEA, Programa de Pós-graduação em Administração – PPGA, São Paulo, SP, Brasil. E-mail: carlosaugusto.vargas@usp.br
[2]Pontifícia Universidade de São Paulo – PUC-SP, Faculdade de Economia, Administração e Contabilidade, São Paulo, SP, Brasil. E-mail: m_kuniyoshi@pucsp.br

How to cite: Vargas, C. A. F., Santos, S. A., Plonski, G. A., & Kuniyoshi, M. S. (2020). Product development in technology based firms in innovation environments. *Gestão & Produção*, 27(2), e4551. https://doi.org/10.1590/0104-530X4551-20

Abstract: Technology based firms (TBFs) require innovative products to survive and compete in the market. The creation of products that sustain the competitiveness of companies depends directly on their product development process (PDP). The objective of this research was to investigate how PDP is carried out in TBFs in innovation environments. The research is qualitative, based on multiple case studies. Three companies in technology parks in the South and Southeast of Brazil were studied. The companies produced the following products: multiparametric monitor, an *ondaleta* and a microfiltration system. The key findings of the research were a lack of formal PDP planning and unstructured development processes. As a contribution, the study proposes that TBFs use a milestone strategy in the PDP microphases, guaranteeing greater efficiency in product development without the need to create rigid processes in project development. The study also highlights the importance of cooperation with clients and suppliers during the revision phases of PDP. The products resulting from PDP of the companies studied were identified as incremental innovation, novel for the national market, but with established technology on the international market. Future studies should assess the evolution and learning curve in the product development phase of TBFs.

Keywords: Product development process; Technology based firms and technology parks.

Resumo: Empresas de base tecnológica (EBTs) necessitam criar produtos inovadores para sobreviver e competir no mercado. A criação de produtos que sustentem a competitividade das empresas depende diretamente do seu processo de desenvolvimento de produtos (PDP). O objetivo desta pesquisa foi investigar como foi realizado o PDP em EBTs instaladas em ambientes de inovação. A natureza da pesquisa é de cunho qualitativo, baseada no estudo de múltiplos casos, foram investigadas três empresas instaladas em parques tecnológicos das regiões Sul e Sudeste do Brasil. Nestas empresas foram estudados três PDPs, que resultaram nos seguintes produtos: monitor multiparamétrico, ondaleta e sistema de microfiltração. Dentre os achados desta pesquisa, destaca-se que os PDPs não são formalmente planejados e os processos de desenvolvimento não são estruturados. Como contribuição, o estudo propõe que as EBTs utilizem a estratégia de *milestones* nas macrofases do PDP, garantindo maior eficiência ao desenvolvimento do produto e sem a criação

Received Dec 28, 2017 - Accepted Aug 7, 2018
Financial support: CAPES.

de processos rígidos no desenvolvimento dos projetos. O estudo ainda destaca a importância da cooperação com clientes e fornecedores durante as etapas de revisão do PDP. Os produtos resultantes do PDPs das empresas estudadas foram identificados como inovações incrementais, inéditos para o mercado nacional, mas com tecnologias já conhecidas no mercado internacional. Para pesquisas futuras, sugere-se estudar mais de um desenvolvimento de produto em EBTs, para verificar a evolução do PDP e a curva de aprendizagem.

Palavras-chave: Processo de desenvolvimento de produtos; Empresas de base tecnológica e parques tecnológicos

1 Introduction

Firms that operate in high technology sectors need to develop new products and/or services to compete in the market. The outcomes from a product or service on the market depend on the management of the firm and on the Product Development Process (PDP). This process has been a challenging task, and it is surprising that the vast majority of organizations consider product development the main tool for overcoming the competition (Tyagi et al., 2015). Efficient PDPs are necessary to reduce the development time, managerial risks and to create better products (Unger & Eppinger, 2011).

The ability to consistently generate new products is dependent on the scientific and technological capacity of a firm (Deeds et al., 2000). Competition, technological advances, market changes and product life cycles are all factors that force firms to develop new products regularly (Unger & Eppinger, 2011). In that sense, the internal activities of the project and development provide and attractive option for small business to improve their competitiveness and increase profits, compared to the traditional low aggregated value product fabrication route (Millward & Lewis, 2005).

In Technology Based Firms (TBFs) this situation is particularly relevant, given that companies need to invest in product development, which require great effort in R&D, and not all companies have the resources to do this. Small and medium enterprises, especially in high technology, tend to have disadvantages such as limited financial resources, scarce human resources, reduced time for project development and the need for high levels of investment in the product (Laurell et al., 2017; Laforet & Tann, 2006; Millward & Lewis, 2005; Tolstoy & Agndal, 2010).

Technology parks are a distinct environment for product development in TBFs because of the close proximity of different stakeholders, such as the university, research institutes, R&D centers in large companies, among others, which give an environment favorable to technological development. The park also provides specialized services, shared resources and businesses, financial support and greater reputation and legitimacy (Ferguson & Olofsson, 2004; Siegel et al., 2003b), which could contribute positively to PDP in firms.

2 Product development process in technology based firms

Research in the last twenty years have advanced significantly in the comprehension of various aspects of the use of tools in the attempt to help firms to improve their PDP efforts (De Waal & Knott, 2016). However, despite their potential benefits, firms tend to adopt PDP tools slowly and, often in an inadequate way. Furthermore, firms have difficulties in the design and selection of the process that best serves them, in part

because of the history of ideological decisions and the difficulty of distinguishing between different PDPs based only on forms or diagrams (Unger & Eppinger, 2011).

This study aims to contribute to increasing knowledge of PDP in TBFs. Despite these businesses being well studied, because of their importance in job, income and technology creation, they are not the type of firm which is usually studied in terms of PDP. The development of products in TBFs remains an important issue, especially given the importance frequently attributed to startups for their economic growth and through the maintenance of innovative dynamism in business clusters. (De Waal & Knott, 2016).

Another important gap that this research explores is the relationship between TBFs with different partners during PDP in firms installed in technology parks. This study contributes to filling this knowledge gap with an original perspective in the literature. The majority of studies on PDP tend to focus on interorganizational relations through a specific partner, for example, the supplier-client relationship (Knudsen, 2007). In this research, the environment of technology parks provides a new context for the study of PDP in the firms installed there, in contrast with the majority of studies in which the firms are not installed in innovation ecosystems and, especially, in technology parks.

With this context in mind, in which the TBFs need to conduct PDP in order to compete and survive in the market, together with the limitations of human and financial resources of these companies and the environment provided by technology parks, the problem consists in verifying how technology based firms installed in technology parks develop PDP in innovation environments. The research question can be summarized thus: *how is PDP carried out in TBFs installed in technology parks?*

3 Theoretical foundation

3.1 Product development process

To develop a product means materializing an idea in the form of a product or service. The process of development is composed of planned, coordinated and controlled activities that aim to make the objective of creating a new product reachable (Machado & Toledo, 2008). In the attempt to understand PDP, various conceptual models have been proposed, each with its own individual characteristics. All models seek to offer a sequence of steps that basically originate from an idea and arrive at a model ready for launch (Machado & Toledo, 2008). According to Browning et al. (2006), a model is the abstract representation of the reality that is constructed, verified, analyzed and manipulated to increase the understanding of this reality.

The use of a reference model for PDP seems to be important, because it allows the vision of the process and calls important aspects that can go unnoticed by the project team to attention. The model also can serve as a tool of evaluation and script to conduct the project, as well as serving as a guide of recommendation for the management of PDP (Alliprandini & Toledo, 2003). An efficient PDP is simply a facilitator of better products of higher quality and lower costs (Tyagi et al., 2015).

As well as being organized by key activities, the individual phases of PDP can be separated by points of verification (gates) or process markers. When the phases are separated in this manner, the stages of the PDP are referred to as stage-gates (Leithold et al., 2016). According to the authors, research in small and medium sized firms showed that those with better innovation performance are those who follow PDPs,

corresponding to the system of stage-gates. Some consequences of an efficient PDP are diminishing the waiting time of the process and integration with the clients (Leithold et al., 2016).

Toledo et al. (2008a) present the stages of PDP based on a model of project integration and key activities. The stages of product development are separated into the activities of viability analysis; technical development (projection of the product); construction of prototypes; product and market testing; lastly, commercial launch. In another article, Toledo et al. (2008b) define the phases of PDP in conception, projection of the product, project process, pilot production and launch. Some authors, such as Clark & Wheelwright (1992) and Rozenfeld et al. (2006) have proposed the study of PDP in three large macrophases: pre-development, development and post-development.

The theoretical models for PDP can have different stages and activities, but also reunite many common characteristics. Taking these similarities and differences in consideration, PDP is defined in three broad phases (pre-development, development and post-development), conforming to the model proposed by Rozenfeld et al. (2006). This definition corroborates other studies of PDPs in TBFs (Fass et al., 2009; Jugend & Silva, 2010). From this classification and according to the theoretical foundation, the main activities in each of these macro-phases, as shown in Table 1.

Table 1. Phases of Product Development Process.

Phases of PDP	Main activities	Publications
Pre-development	- Strategy formulation; - Generation of ideas; - Identification of opportunity - Portfolio management; - Product concept; - Evaluation and definition of market potential;	Cooper (1983), Clark & Wheelwright (1992), McGrath (1996), Ulrich & Eppinger (2000), Rozenfeld et al. (2006), Toledo et al. (2008a),Toledo et al. (2008b), (Mendes & Toledo, 2012)
Product development	- Product projection; - Technical development; - Prototype construction (or pilot production); - Product test and homologation;	Cooper (1983), Clark & Wheelwright (1992), McGrath (1996), Ulrich & Eppinger (2000), Toledo et al. (2008a), Toledo et al. (2008b)
Post-development	- Product market launch; - Product accompaniment; - Discontinuation of product on the market; - Management of product portfolio;	Cooper (1983), Clark & Wheelwright (1992), McGrath (1996), Ulrich & Eppinger (2000), Rozenfeld et al. (2006), Toledo et al. (2008a), (Mendes & Toledo, 2012)

Source: Adapted by the authors (2018).

3.2 Product innovation in technology based firms

TBFs have fundamental importance in the development of new technology, by launching innovative products and services with high growth potential. There is no single definition in the literature for TBFs, which can turn the comprehension of these firms ambiguous. In that sense, Toledo et al. (2008a) claim that the lack of a standard and a precise meaning of the content of these terms has led to cognitive and operational difficulties in the differentiation of these companies from others.

Such high technology companies are important in the growth of new industries and in the renovation of existing ones, because they introduce new technological innovation (Bjørgum & Sørheim, 2015). Among the characteristics of this type of firm, the most

significant are high levels of technological knowledge in their human resources, investment in research and development and products and processes with a relatively reduced life cycle (Andrade Junior, 2014). In this way, TBFs are small and medium sized firms, that use knowledge intensively for the production of goods and/or services, employing a highly qualified workforce and developing radical and/or incremental innovation in products and processes (Vargas et al., 2016).

Because TBFs by their nature develop new products and processes, principally through R&D and engineering, it was opted for metrics of technological innovation that investigate the type of product and/or service that was developed. According to Toledo et al. (2008a), TBFs are associated with technological innovation, fundamentally of products, which makes the development of products a critical process for these firms. In this study, the results of innovation were identified by indicators that evaluate the innovation of production in companies, as shown in table 2. Such indicators observe the result or the outcome of PDP. In this study, to evaluate the results of innovation in products a period of at least one year and at most three, as proposed by the Oslo Manual (OECD, 2005).

Table 2. Innovation and range of product.

Product innovation (good or service)	Range of innovation	Type of innovation	Publications
New products	For the firm	Radical or incremental	Oslo Manual (OECD, 2005), IBGE (2008), Germain (1996), Song & Thieme (2009), Woschke et al. (2017)
	For the national market		
	For the global market		
Significantly improved products	For the company	Radical or incremental	Oslo Manual (OECD, 2005), IBGE (2008), Germain (1996), Song & Thieme (2009), Woschke et al. (2017)
	For the national market		
	For the global market		

Source: Adapted by the authors (2018).

3.3 Technology parks

The concept of parks is very diverse, owing to the countless experiences of technology parks spread across the world, making a definition that encompasses all of the models observed almost impossible. For Siegel et al. (2003a), technology parks have particular objectives in terms of the relationship and impact on companies and the region, and do not necessarily produce similar results and as a result, definitions vary.

Technology parks can provide various benefits for the actors with which they relate. They are notable for being an environment that favors the creation of TBFs, allowing research projects developed in universities to find a support structure to turn them into real companies.

According to Vedovello et al. (2006), technology parks have been recognized as instruments of integration of multiple actors, institutions and activities related to processes of technological innovation.

In the environment of a technology park there are various types of actors present, such as research institutions, universities, laboratories, resident firms, investors, governmental funding agencies, incubators, among others. These actors can vary significantly due to the diverse experiences in the establishment of technology parks.

However, the majority of studies have pointed out the contribution of parks to innovation in TBFs installed in innovation environments (Colombo & Delmastro, 2002; Lindelöf & Löfsten, 2004). On the other hand, it is important to state that some studies have indicated that the contribution of technology parks for innovation in TBFs is not significant (Siegel et al., 2003b; Vedovello, 1997; Westhead, 1997). This study aims to explore this knowledge gap, to deepen knowledge of TBFs in technology parks by studying the PDPs of these firms.

3.4 Conceptual model of research

Interviews with specialists in product development management and technology parks were conducted based on the theoretical foundation in order to increase the credibility for the construction of the research. According to Yin (2005), the validation of the construction is to establish correct operational measures for the concepts under study. Two professors who are experts in the area of product development management were consulted. And three specialists in technology parks were consulted to validate the agents present in this type of enterprise.

A conceptual model for the research was produced based on the theoretical foundation and the interviews conducted with specialists, as shown in Figure 1. Three phases of PDP in TBFs are described, and their relation to the actors linked to the technology park environment. The actors can be divided into those who are installed in the technology park (laboratories, management teams, incubators and resident firms) and those that are not installed there. Among those who are not installed, it is important to distinguish between those with links to the parks and those without a direct link, but which can be present in the park ecosystems.

The actors linked to the park, the Centers of Research, University and Research Institutes and Foundations, have a much closer relational proximity to the parks, often being located geographically next to them. The actors' contributions to PDP are shown by dotted arrows, that indicate the possibility of contribution. In counterpart, the arrows under the products resulting from PDP indicate an obligatory output of the development process.

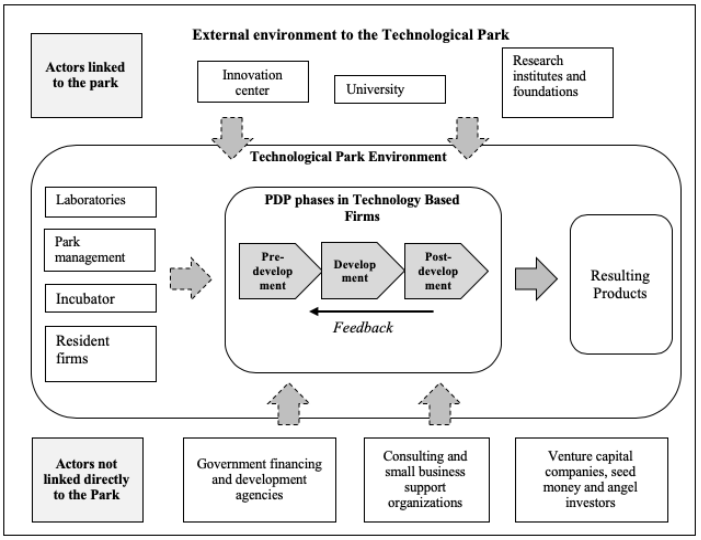

Figure 1. Conceptual Model of Research. Source: the authors (2018).

4 Research methods

PDP is a complex process whose investigation requires a deep analysis of activities, and that requires special attention of the details of this process. Because of the nature of the study and the research problem, the qualitative approach is more appropriate for the research objectives than a quantitative approach. The qualitative focus uses data collection without measurement to discover or improve the research question, the emphasis is not on measuring variables involved in the phenomenon, but in understanding them (Sampieri et al., 2006). According to Herriot and Firestone (1983) *apud* Yin (2005), the evidence resulting from multiple cases is considered more convincing and the overall study is seen as more robust as a consequence.

The inclusion criteria for companies were the following: 1) development of technology intensive products, 2) to have carried out PDP inside their installations in the park; 3) being a small company – those with fewer than 99 employees and service companies with fewer than 49 employees (SEBRAE, 2017). Table 3, panorama of TBFs studies, presents some relevant information about the companies, such as area of activity, product developed in the study and the technology park in which it is installed. It is important to state that the companies preferred not to be identified in the research and also asked for confidentiality in their financial information.

Table 3. Panorama of TBFs studied.

	Firm A	**Firm B**	**Firm C**
Year of foundation	2008	2006	2005
Year of entry into the park	2011	2010	2009
Area of activity	Medical and hospital equipment	Analysis of oceanographic data	Treatment of water and sewage
Number of posts of employment	15 people	31 people	33 people
Product developed	Multiparametric monitor	*Ondaleta*	Membrane microfiltration system
Federation State	RS	RJ	RJ
Technology park	Tecnopuc	UFRJ Park	UFRJ Park
Origin of capital	National	National	National
Main market of operation (national or international)	National	National	National
Business focus (B2B or B2C)	B2B	B2B	B2B
Patents on the product studied	No	Yes	No
University spinoff	No	Yes	Yes
Incubated	No	Yes	Yes
Interview time	1h30min	2h30min	1h20min

Source: the authors (2018).

4.1 Process of collection and processing

Data collection was done via deep interviews with entrepreneurs and managers, documentation and direct observation of the researcher. The interviews were the principal collection technique. In the case of documentary evidence collection, the main

information was gathered through information available on the sites of the companies and in documents such as reports and folders supplied by the interviewees.

The interviews were done using a semi-structured questionnaire. The analysis strategy between the companies was done through a synthesis of crossed cases. This technique consists in comparison between individual cases, according to the same structure (Oliveira et al., 2009). According to Eisenhardt (1989), the general idea behind the crossed cases technique is to force the investigation to go beyond initial impressions, especially through the use of a structured and diverse lens over the research data.

5 Presentation and case analysis

5.1 Firm A

Business A is installed in a technology park located inside a private university in the south of Brazil. The person interviewed in the company was the administrative manager. He is not a partner in the company, but has broad knowledge of the engineering activities and of the relationships with the actors in the technology park. Firm A is active in R&D of medical and hospital equipment, developing products for use in hospitals. It licenses products developed to manufacturers of health equipment.

5.1.1 Product development process of Firm A

The first product developed by the company was the multiparametric monitor and the second, and most recent, was a defibrillator. According to the administrative manager, the monitor was the most innovative and most relevant product developed by the company, and for this reason was chosen as the PDP to study. At the time of its development, in 2008, there were no similar products on the national market.

Firm A was founded when three engineers left their jobs in a company that produced medical and hospital equipment and together with a medic and an administrator decided to bet on the development of a multiparametric monitor, which they judged to have a market for its commercialization. Concomitant to the development of the project, the partners sought a partnership to invest in the development of the product and had contact with the owners of a national manufacturer of medical equipment, firm X. The entrepreneurs presented the project of the multiparametric monitor to firm X, which at the time was interested in manufacturing equipment like the monitor, proposed by firm A. The businesses then signed a contract, in which firm X invested in the capitalization of firm A.

The development of the product was done over the course of a year. The resources to invest in the development of the monitor was obtained through capital from the founders and of the partner investors in firm X. These financial resources were used to hire a workforce, mainly engineers, equipment, materials, and some mechanical projects, which according to the manager interviewed were important for the product development. The development of the project of the monitor was done entirely by the firm's team of engineers composed of twelve collaborators, during all phases, including in the manufacturing phase by client firm X.

When commenting on the procedures used in the post-development phase, specifically those related to accompanying the product installed in the clients of firm X, the interviewee highlighted that it is up to his company to continue the technological

development of the product. In this extract, the manager comments on the principal alterations made to the multiparametric monitor:

> *Recently, at clients' suggestion, we switched the display for a more advanced technology, because what was in the original version of the monitor acquired by the client had problems and the supplier of the component had ceased to produce it. Even today we improve the monitor, because the components become obsolete quickly*.

The firm is responsible for the updating of the software of the equipment and alteration of its components and parts. Firm A is responsible for the development strategy and changes to the monitor, while firm X is responsible for the maintenance and technical assistance of the sold units. This maintenance includes installation and accompaniment of the product, technical problems appearing in the units and their calibrations and tests.

5.2 Firm B

Firm B is installed in a technology park in the southeast of Brazil belonging to a well-recognized Brazilian public university. Three people were interviewed in the firm; the entrepreneur, the financial manager and a project engineer. Firm B works in the offshore market, with products and services for processing and analysis of oceanographic data, including bathymetric collection. The firm acts in the area of oceanographic instrumentation, analysis of oceanic data and survey of submarine relief and bathymetry.

5.2.1 Product development process of Firm B

The opportunity for PDP of the *ondaleta* arose from the services that the firm delivered for the research center of firm Y, which is installed on the university campus. At that time, the firm was incubated and the development of products was not among their objectives. With the deepening of the relations and services with the research center of firm Y, the opportunity for the firm to contribute to the development of equipment to measure the waves and tides with the research center of firm Y arose. The product was in prototype phase.

Following this, with the advance of the project of the monitor of maritime currents and waves, the directors of firm Y invited firm B to participate in a bidding process, to compete for the patent of the equipment. Firm B participated in the bidding and made an offer that was chosen as the best proposal, to complement the development of the product and produce it commercially. From this moment, the firm began to work on the improvement and development of the product, which took two years to launch on the market. In the words of the entrepreneur interviewed, the fact that the business was located in a technology park and had interactions with the university and the research center contributed to the company winning the bidding process:

> *At the time our company had an oceanographer, a manager, which was me and a systems analyst. Then, we didn't have the team to develop this product on our own. Then, we joined with the center to finish developing the product. And the fact that we were installed in the park was a factor that helped us to compete in the bidding process*.

The first stage of development was to understand the code that the firm received when it acquired the product patent. Despite the firm having contributed to part of this development, there was technology in the equipment that the firm had not participated in. The patent acquired also did not include the software of the *ondaleta* solution and this type of programming to capture and analyze the data would be made by the firm's team. According to the entrepreneur, one of the main jobs of the team in the product development was to conceive of the satellite and radio transmission.

The first tests of the prototype of the *ondaleta* were made in the oceanic tank in the oceanic technology laboratory of the university, which reproduces the main characteristics of the marine environment and simulates phenomena such as tides and waves. Later, when the prototype was already more advanced, the firm made a second set of tests on the quays of the technology park. The *ondaleta* was commercialized for an oceanographic institute of a university in São Paulo, for the university of the park and for a mining company, which uses the *ondaletas* in the port of Vitória in Espírito Santo.

5.3 Firm C

Firm C is located in a technology park attached to a well-regarded university situated in the southeast of Brazil. The business operates in manufacturing of systems of filtering through selective membranes for the process of treatment of water and sewage, and is one of the pioneering businesses for this type of activity in Latin America. One of the entrepreneurs of the firm, who today is the director, and one of the key figures in the administration of the business was interviewed.

5.3.1 Product development process of Firm C

The pre-development began with the idea of developing and manufacturing membranes of filtration whose technology had been developed by other researchers 18 years previously in the Membrane Separation Research Laboratory at the university. On that occasion, the entrepreneur stated that he became aware of this technology and its market potential for filtering water and industrial sewage for commercialization for residences and business while studying for a doctorate with the researchers in the same laboratory.

In relation to the development of the technology necessary for manufacturing the microfiltration membranes, the entrepreneur stated that he did not require processes of R&D, because they had already been carried out 18 years before. Despite this, the entrepreneur stated that the firm needed to complement the technological solution, of filtering, developing some additional modules to facilitate the manufacturing of the filtering equipment. In this extract, the entrepreneur comments on the process of development of this equipment and complementary modules:

> *We manufactured the membrane, and from them we make filtering element, and from the filtering element the firm mounts the equipment. The equipment is fully automatic, you turn on the computer and it has six or seven filtering devices installed at the client's that are operated remotely from here at our company*.

The scope of the activity of the firm includes not only the development of the system and of the aggregated filtering equipment for water and industrial waste, but also in the installation, accompaniment and monitoring of operation of equipment in the productive conditions of the client business. The entrepreneur also stated that the first filtering systems that were sold were

more manually operated. The control and accompaniment of the system were made by the client, and the team needed to visit the installed location.

6 Discussion

In this section the crossed analysis matrix is presented on how PDP was developed and about the contribution of the actors linked to the technology park for PDP of the firms studied. Following Yin (2005), the exposition of the extracted information of the case studies facilitates the crossed analysis. Table 4 was constructed based on the information collected together with the interviews, which describes how the development of products was carried out in the three phases analyzed; the pre-development, development and post-development.

Table 4. Synthesis of PDP in firms studied.

Phases of PDP	Firm A	Firm B	Firm C	Similarities	Singularities
Pre-development	Identification of the opportunity occurred when engineers perceived the opportunity to develop a multiparametric monitor with national technology.	The opportunity to develop the *ondaleta* occurred when the firm learned of the bidding process of a project in prototype phase.	Identification of the opportunity occurred when the entrepreneur worked in a membrane separation laboratory of the university and recognized the commercial potential of the process of fabricating microfiltration membranes.	The companies did not use ideation and project selection techniques in opportunity identification. The businesses did not undertake formal planning for the product development.	Firm A was the only that was not incubated in which the market opportunity was not related with any of the actors in the technology park.
Development	Project development of the monitor was made entirely by the team of engineers at the company. In terms of resources, the firm used its own resources and those of firm X.	The company carried out the development internally, but counted on the strong support of researchers from the course of oceanography of the university and of the research center of firm Y.	Development was done by the team of the company and counted on the participation of the researchers from the membrane laboratory.	The majority of development was done by the teams of the companies, but all had the contribution of at least one actor of the park.	Only the monitor of firm A needed certification to be commercialized. In the case of the other firms there was no certifying body for the products.
Post-development	The maintenance and technical advice of the sold units falls to firm X, while firm A is responsible for the continuity of technological development of the product.	The firm is responsible for the maintenance of the equipment, and transmission and management of information for the client. The firm has also made changes to the equipment in terms of sensors and data transmission.	The firm provides advisory and equipment maintenance services. It also has already made changes to the microfiltration system over time, such as automatization of equipment and modifications of the modules.	All firms made modifications of their products after launch, these updates require information suggested by clients and partners.	

Source: the authors (2018).

The firms did not make formal plans in the pre-development phase. Firm B, for example, when it received the patent of the equipment had many difficulties in understanding the documents they received, despite having participated in a part of the project. Firm C also did not undertake formal planning for the filtration system and made a range of adaptations and alterations during the development. Firm A had a more detailed planning compared to the others, but even so did not elaborate product or project planning.

The lack of planning can also have certain benefits for TBFs, such as greater flexibility in product planning and interaction with potential clients. Cosh et al. (2012), in a study of new high technology businesses, stated that the creativity of these companies is in part supported by informal structure, and decentralized decision making processes are less important. On the other hand, the lack of formality of processes can increase the inefficiency of PDP.

This lack of formal planning seems to be related to the youth of the companies and the little experience of teams in product development, because engineers and managers of these firms did not have much experience in product development. PDP tends to happen according to the resources available and the perspectives of the market, without a contingency plan for possible problems that can occur during this process. These findings corroborate the hypothesis of Barbalho & Rozenfeld (2004) about the lack of project management practices in TBFs.

In terms of financial resources applied to PDP, all firms required resources from third parties for the development of R&D activities. The innovation funding agencies were the most important actors in this sense, with a decisive contribution for the firms being able to hire a qualified workforce for investment in research and engineering. Because of the small size of the companies and their limited human and financial resources, the financial grants were a primordial factor for the firms being able to invest in product development.

The majority of product development made by the firm's team, with their own technological infrastructure, but all firms had a contribution of at least one actor connected to the technology park. The TBFs tended to initially use their own laboratory structure, and in the testing and validation stage sought greater support from university laboratories, research centers and even future clients, who will be responsible for the manufacturing of the developed products. These findings are in line with the observations of Jugend & Silva (2010), who studied management practices that influence the success of new products in technology based firms. According to the authors, the internal development of technology constituted the main mechanism for the development of technologies that are transferred to products.

In the post-development of PDP, the firms developed and launched the products and gradually improved them, in some cases developing complementary products. In firms B and C, the products are offered with an additional service of technical support and, for this reason, post-sale is a crucial phase to secure client loyalty and obtain feedback. The firms use this feedback to make changes and updates in order to develop a more advanced version of the product. The offering of technical assistance services and maintenance is one of the most important steps for the continuous development of the product.

Table 5. Main activities of PDP.

	PDP Activities	Firm A	Firm B	Firm C
Pre-development	*Opportunity identification*	*X*		*X*
	Minimum viable product	*X*		*X*
	Evaluation of market potential	*X*	*X*	*X*
	Planning of the product project	*X*		
Development	*Prototype construction*	*X*	*X*	*X*
	Testing in specialized laboratories	*X*	*X*	
	Partnership with suppliers			
	Partnership with clients			
	Partnership with research institutes		*X*	
	Partnerships with universities		*X*	*X*
	Certification	*X*		
	Launch	*X*	*X*	*X*
Post-development	*Maintenance and support of the product*		*X*	*X*
	Changes and improvements of the product	*X*	*X*	*X*
	Derivation of new products	*X*		*X*
	Discontinuity planning			

Source: the authors (2018).

Table 5, main activities of PDP, details which tasks were executed by TBFs studied. Only firm A carried out project planning of the product, the other firms did not have this preparation. The director of firm B explained that they did not carry out formal product planning, and added that about the phases of development “the team had in mind which functions and objectives the equipment should have”. These testimonies show that it is difficult to find PDPs structured in small technology based companies, because of the lack of structuring of processes of these companies. De Waal & Knott (2016) have also verified that the majority of TBFs do not formalize their PDP, and that the low formalization of PDP leads the companies to adopt a lower number of tools for product development.

The companies also showed low cooperation with clients in product development. Despite that in this case the lack of cooperation was related to the lack of certainty in relation to the future clients, it is important that the businesses seek closer approximation with potential clients during PDP, to validate the product in development and receive suggestions for tools and configurations. Greater distancing from clients in

product development can lead to firms having to do more work in development and post-development.

The products resulting from PDP were the multiparametric monitor (firm A), the *ondaleta* (firm B) and the microfiltration system (firm C). An important indicator to evaluate the innovation of a product is to see whether the invention generated a patent, or, whether the firm made a deposit request of the patent of invention of the new product or of correlated technologies. In a general analysis, the products developed by firms were unseen on the national market, with a few innovations in functionality and design. However, they are not significant innovations for the international market, not being pioneers in their areas, but also not being mere copies of competing products. The development of these products in Brazil allows the substitution of products imported and reduced costs of manufacturing and maintenance.

From the analyses in Figure 2, a conceptual summary of the main points of analysis of the research on PDP in companies. The PDP's main characteristic was the development of the product carried out mainly by firm's own team, relying on partnerships with laboratories, research institutes and other professionals and researchers, but without product development in conjunction with businesses, research institutes or research centers.

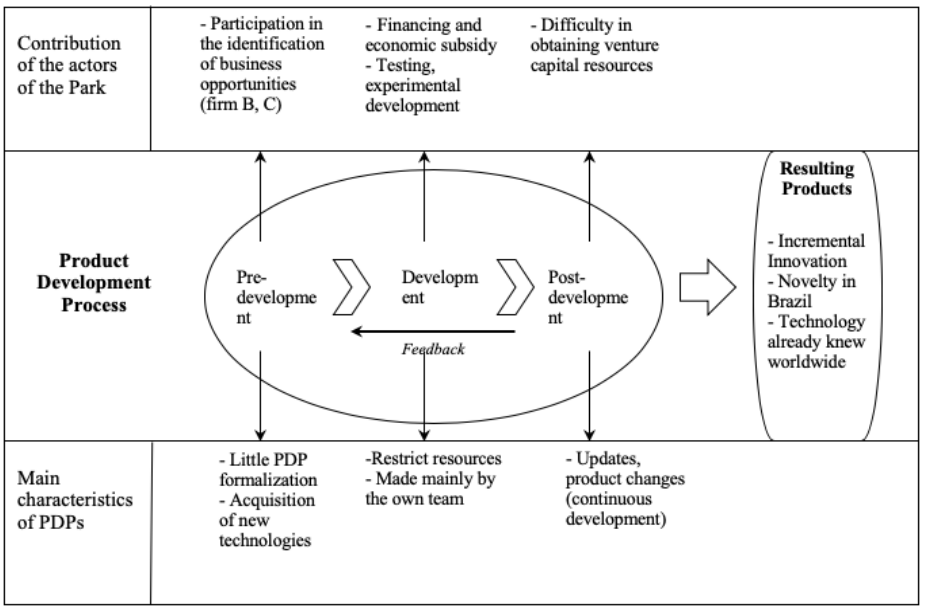

Figure 2. Conceptual Analysis of the Product Development Process. Source: the authors (2018).

The contribution of the university was important for PDP, helping firms in their relationships with professors and researchers, as well as the use of laboratories for experimental development and prototype testing. The firms also benefitted from the proximity with the university for contracting a qualified workforce, such as Master's and PhDs. The relationship with the actors could have been more explored by the firms, such as joint development of part of the product technology. Kamuriwo et al. (2017) recommend that managers of TBFs should seriously consider cooperation with external partners if they value rapid development of products that make use of disruptive innovation.

In terms of resources, the firms had heavy restrictions on human and financial resources for product development. The governmental funding agencies have a key role in financing R&D activities and in hiring qualified labor. The firms did not rely on support from venture capital, even though they had spoken to some investors.

PDP is a dynamic process, that occurs in two senses, allowing the products to continue to be development after commercialization. This confirmation was observed in the three firms, in which after launch the companies continue working on more advanced versions of the product. Leithold et al. (2016) observed that TBFs that performed better had more flexible PDPs, which allowed a process of accelerated innovation. This could be an indication that small businesses should seek to formalize their PDP activities, without creating rigid processes that cause them to lose their flexibility.

The formalization of product development activities and adoption of tools for the organization and efficiency of PDP can generate efficiency gains for TBFs. Despite this, given that the firms have little internal and organizational structure, the proposition of formal PDP in TBFs as in large companies does not seem viable. However, according to the cases described in this research it is possible to propose greater formalization of PDP in these firms, which have a high level of informality and little planning.

The use of milestones in PDP can be a viable option of TBFs with low levels of formalization in product development. Milestones are verification points, or stage-gates, which divide the phases of PDP and organize macrophases for main key activities. TBFs should at least carry out two important milestones, according to the three broad phases of PDP proposed in this article. The first is at the end of pre-development, and the second at the final phase of development. In each milestone the firm should reunite a team of technicians, clients, engineers and managers to decide whether the development should continue, be suspended or abandoned. According to Cooper (2014), the most modern understanding of PDP the innovations of the project do not move any more from gate to gate but from milestone to milestone. In TBFs, this understanding could be even more useful, because it allows the possibility of greater formalization of PDP and at the same time ensures that the firm does not end up with ingrained processes and excessive controls.

7 Conclusion

In all of the cases studied there was no formal planning of PDP activities and their respective projects. In fact, the entrepreneurs and other interviewees had a variety of attributes and functions that the products should offer to attract the interest of potential clients. This finding corroborates Barbalho & Rozenfeld's (2004) hypothesis about PDP in small and medium firms, which identifies a lack of project management practices, such as activities related to documentation of project status. Millward & Lewis (2005) also found that small businesses tend to focus their efforts more on time and cost than other key factors and fail to understand the importance of the product project.

In terms of practices, managers of small and medium sized firms should seek to formalize the development process, using milestones as stage markers for product development. The use of these markers especially in the phases from pre-development to development, and from development to post-development can guarantee greater efficiency of PDP, without the firm losing their creativity and flexibility to carry out activities sequentially or simultaneously. The informality can be an advantage for TBFs, because they guarantee greater agility in the execution of activities. However, when there is no control over the principal activities and stages of PDP the firms can lose

time and efforts to optimize an inefficient PDP. Cooperation with clients and suppliers should take place to optimize PDP and avoid duplication of efforts. Cooperation of clients and key suppliers to discuss project progress.

The majority of product development is made by the internal team and laboratory infrastructure of the firm. Studies such as Toledo et al. (2008a), Jugend & Silva (2010) also indicated that the core product development is made by the firm itself. Despite there being cooperation of companies and other actors for product development, no development took place in conjunction with firms and research institutes, in all cases the core of the engineering of the product was developed by the firm itself, and when necessary the firms sought partnerships or services for the development of the product.

The innovation of products resulting from PDP were incremental, because the products and services added new formats, materials and functionalities, but did not present disruptive concepts in problem solving. The products of the firms replaced imported products, based on the technological competence and knowledge of Brazilian researchers and entrepreneurs. Among the advantages arising from this nationalization of technology from PDPs of the companies studied, is the reduction of manufacturing costs and technical assistance services to clients during the post-sale period.

There were a few limiting factors in this research, beyond the restriction on generalizations for traditional or large firms, there are also limitations on transversal studies, which are done at only one moment in time, restricting the temporal understanding of decisions and activities that are being developed in the company. Based on the case studies in this research and in the literature on this theme it is clear that there some theoretical gaps. Generally, the first PDP of these companies is less structured than the second, possibly because of the gains in experience of the managers and employees. Therefore, it would be interesting to study the sequence of product development in new firms in high technological sectors. Future studies should seek to understand the difficulties of TBFs in developing countries, and especially in Brazil, in attracting venture capital.

References

Alliprandini, D. H., & Toledo, J. C. (2003). Modelo para gestão do processo de desenvolvimento de produtos: uma proposta baseada em dimensões críticas. In *Anais do Congresso Brasileiro de Gestão e Desenvolvimento de Produtos.* Gramado: CBGDP.

Andrade Junior, P. P. (2014). Modelo de avaliação e superação das dificuldades de empresas de base tecnológica em incubadoras. *Gestão & Produção*, 24(4), 809-819. http://dx.doi.org/10.1590/S0103-65132013005000085.

Barbalho, C. S. M., & Rozenfeld, H. (2004). Análise do Processo de Desenvolvimento de Produtos de uma Pequena Empresa de Alta Tecnologia. In *Anais do Encontro Nacional de Engenharia de Produção* (Vol. 24, pp. 2839-2846). Florianópolis: ABEPRO.

Bjørgum, Ø., & Sørheim, R. (2015). The funding of new technology firms in a pre-commercial industry – the role of smart capital. *Technology Analysis and Strategic Management*, 27(3), 249-266. http://dx.doi.org/10.1080/09537325.2014.971002.

Browning, T. R., Fricke, E., & Negele, H. (2006). Key concepts in modeling product development processes. *Systems Engineering*, 9(2), 104-128. http://dx.doi.org/10.1002/sys.20047.

Clark, K. B., & Wheelwright, S. C. (1992). *Creating project plans to focus product development.* Cambridge: Harvard Business School Pub.

Colombo, M. G., & Delmastro, M. (2002). How effective are technology incubators?: evidence from Italy. *Research Policy*, 31(7), 1103-1122. http://dx.doi.org/10.1016/S0048-7333(01)00178-0.

Cooper, R. G. (1983). A process model for industrial new product development. *IEEE Transactions on Engineering Management*, *1*, 2-11. http://dx.doi.org/10.1109/TEM.1983.6448637.

Cooper, R. G. (2014). What's next? After state-gate. *Research-Technology Management*, *57*(1), 20-31.

Cosh, A., Fu, X., & Hughes, A. (2012). Organisation structure and innovation performance in different environments. *Small Business Economics*, 39(2), 301-317. http://dx.doi.org/10.1007/s11187-010-9304-5.

De Waal, G. A., & Knott, P. (2016). Patterns and Drivers of NPD Tool Adoption in Small High-Technology Firms. *IEEE Transactions on Engineering Management*, 63(4), 350-361. http://dx.doi.org/10.1109/TEM.2016.2603160.

Deeds, D. L., Decarolis, D., & Coombs, J. (2000). Dynamic capabilities and new product development in high technology ventures: an empirical analysis of new biotechnology firms. *Journal of Business Venturing*, 15(3), 211-229. http://dx.doi.org/10.1016/S0883-9026(98)00013-5.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, 14(4), 532-550. http://dx.doi.org/10.5465/amr.1989.4308385.

Fass, F. D. M., Salgado, E. G., Salomon, V. A. P., Mello, C. H. P., & Silva, C. E. S. (2009). Seleção de um Modelo de processo de Desenvolvimento de Produto para Indústria de Base Tecnológica do Ramo Eletroeletrônico. In *Anais do XXIX Encontro Nacional de Engenharia de Produção*. Rio de Janeiro: ABEPRO.

Ferguson, R., & Olofsson, C. (2004). Science parks and the development of NTBFs: location, survival and growth. *The Journal of Technology Transfer*, 29(1), 5-17. http://dx.doi.org/10.1023/B:JOTT.0000011178.44095.cd.

Germain, R. (1996). The role of context and structure in radical and incremental logistics innovation adoption. *Journal of Business Research*, 35(2), 117-127. http://dx.doi.org/10.1016/0148-2963(95)00053-4.

Instituto Brasileiro de Geografia e Estatística – IBGE. (2008). *PINTEC Pesquisa de Inovação*. Brasília: IBGE. Retrieved in 2016, June 25, from http://www.pintec.ibge.gov.br/

Jugend, D., & Silva, S. L. (2010). Práticas de gestão que influenciam o sucesso de novos produtos em empresas de base tecnológica. *Gestão & Produção*, 20(3), 335-346. http://dx.doi.org/10.1590/S0103-65132010005000041.

Kamuriwo, D. S., Baden-Fuller, C., & Zhang, J. (2017). Knowledge development approaches and breakthrough innovations in technology-based new firms. *Journal of Product Innovation Management*, 34(4), 492-508. http://dx.doi.org/10.1111/jpim.12393.

Knudsen, M. P. (2007). The relative importance of interfirm relationships and knowledge transfer for new product development success. *Journal of Product Innovation Management*, 24(2), 117-138. http://dx.doi.org/10.1111/j.1540-5885.2007.00238.x.

Laforet, S., & Tann, J. (2006). Innovative characteristics of small manufacturing firms. *Journal of Small Business and Enterprise Development*, 13(3), 363-380. http://dx.doi.org/10.1108/14626000610680253.

Laurell, H., Achtenhagen, L., & Andersson, S. (2017). The changing role of network ties and critical capabilities in an international new venture's early development. *The International Entrepreneurship and Management Journal*, 13(1), 113-140. http://dx.doi.org/10.1007/s11365-016-0398-3.

Leithold, N., Woschke, T., Haase, H., & Kratzer, J. (2016). Optimising NPD in SMEs: a best practice approach. *Benchmarking*, 23(1), 262-284. http://dx.doi.org/10.1108/BIJ-05-2015-0054.

Lindelöf, P., & Löfsten, H. (2004). Proximity as a resource base for competitive advantage: university–industry links for technology transfer. *The Journal of Technology Transfer*, 29(3/4), 311-326. http://dx.doi.org/10.1023/B:JOTT.0000034125.29979.ae.

Machado, M. C., & Toledo, N. N. (2008). *Gestão do processo de desenvolvimento de produtos: uma abordagem baseada na criação de valor*. São Paulo: Atlas.

McGrath, M. E. (Ed.) (1996). *Setting the PACE in product development: a guide to product and cycle-time excellence.* Routledge.

Mendes, G. H. S., & Toledo, J. C. (2012). Explorando práticas do desenvolvimento de produtos em pequenas e médias empresas do setor de equipamentos médico-hospitalares. *Gestão & Produção*, 19(1), 103-117. http://dx.doi.org/10.1590/S0104-530X2012000100008.

Millward, H., & Lewis, A. (2005). Barriers to successful new product development within small manufacturing companies. *Journal of Small Business and Enterprise Development*, 12(3), 379-394. http://dx.doi.org/10.1108/14626000510612295.

Oliveira, M., Maçada, A. C. G., & Goldoni, V. (2009). Forças e fraquezas na aplicação do estudo de caso na área de sistemas de informação. *Revista de Gestão USP*, 16(1), 33-49. http://dx.doi.org/10.5700/rege357.

Organisation for Economic Co-operation and Development – OECD. (2005). *Manual de Oslo: diretrizes para coleta e interpretação de dados sobre inovação* (3. ed.). Paris: OECD.

Rozenfeld, H., Forcellini, F. A., Amaral, D. C., Toledo, J. C., Silva, S. L., Alliprandini, D. H., & Scalice, R. K. (2006). *Gestão de desenvolvimento de produto: uma referência para a melhoria do processo.* São Paulo: Saraiva.

Sampieri, R. H., Collado, C. H., & Lucio, P. B. (2006). *Metodologia de pesquisa* (3. ed.). São Paulo: MacGraw-Hill, 2006.

Serviço Brasileiro de Apoio às Micro e Pequenas Empresas – SEBRAE. (2017). Retrieved in 2017, July 25, from www.sebrae.com.br

Siegel, D. S., Westhead, P., & Wright, M. (2003a). Assessing the impact of university science parks on research productivity: exploratory firm-level evidence from the United Kingdom. *International Journal of Industrial Organization*, 21(9), 1357-1369. http://dx.doi.org/10.1016/S0167-7187(03)00086-9.

Siegel, D. S., Westhead, P., & Wright, M. (2003b). Science parks and the performance of new technology-based firms: a review of recent U.K. evidence and an agenda for future research. *Small Business Economics*, 20(2), 177-184. http://dx.doi.org/10.1023/A:1022268100133.

Song, M., & Thieme, J. (2009). The role of suppliers in market intelligence gathering for radical and incremental innovation. *Journal of Product Innovation Management*, 26(1), 43-57. http://dx.doi.org/10.1111/j.1540-5885.2009.00333.x.

Toledo, J. C., Silva, S. L., Alliprandini, H. D., Martins, F. M., & Ferrari, M. F. (2008a). Práticas de gestão no desenvolvimento de produtos em empresas de autopeças. *Production*, *18*(2), 405-422.

Toledo, J. C., Silva, S. L., Mendes, G. H. S., & Jugend, D. (2008b). Fatores críticos de sucesso no gerenciamento de projetos de desenvolvimento de produto em empresas de base tecnológica de pequeno e médio porte. *Gestão & Produção*, *15*(1), 117-134. http://dx.doi.org/10.1590/S0104-530X2008000100011.

Tolstoy, D., & Agndal, H. (2010). Network resource combinations in the international venturing of small biotech firms. *Technovation*, 30(1), 24-36. http://dx.doi.org/10.1016/j.technovation.2009.06.004.

Tyagi, S., Choudhary, A., Cai, X., & Yang, K. (2015). Value stream mapping to reduce the lead-time of a product development process. *International Journal of Production Economics*, 160, 202-212. http://dx.doi.org/10.1016/j.ijpe.2014.11.002.

Ulrich, K. T., & Eppinger, S. D. (2000). *Product design and development*. New York: MacGraw-Hill.

Unger, D., & Eppinger, S. (2011). Improving product development process design: a method for managing information flows, risks, and iterations. *Journal of Engineering Design*, 22(10), 689-699. http://dx.doi.org/10.1080/09544828.2010.524886.

Vargas, C. A. F., Rech, I., & Santos, S. A. (2016). Fatores de competitividade empresarial em empresas instaladas em um parque tecnológico brasileiro. *Revista Gestão & Tecnologia*, 16(2), 100-126.

Vedovello, C. (1997). Science parks and university-industry interaction: geographical proximity between the agents as a driving force. *Technovation*, 17(9), 491-531. http://dx.doi.org/10.1016/S0166-4972(97)00027-8.

Vedovello, C. A., Judice, V. M. M., & Maculan, A.-M. D. (2006). Revisão crítica às abordagens a parques tecnológicos: alternativas interpretativas às experiências brasileiras recentes. *RAI: Revista de Administração e Inovação*, 3(2), 103-118.

Westhead, P. (1997). R&D “inputs” and “outputs” of technology-based firms located on and off Science Parks. *R & D Management*, 27(1), 45-62. http://dx.doi.org/10.1111/1467-9310.00041.

Woschke, T., Haase, H., & Kratzer, J. (2017). Resource scarcity in SMEs: effects on incremental and radical innovations. *Management Research Review*, 40(2), 195-217. http://dx.doi.org/10.1108/MRR-10-2015-0239.

Yin, R. K. (2005). *Estudo de caso: planejamento e métodos* (3. ed.). Porto Alegre: Bookman.

GESTÃO & PRODUÇÃO

ISSN 0104-530X (Print)
ISSN 1806-9649 (Online)

ERRATUM

Erratum

In the article “Product development in technology based firms in innovation environments”, DOI https://doi.org/10.1590/0104-530X4551-20, published in the journal *Gestão & Produção*, v. 27, n. 2, e4551, 2020, on page 1.:

Where it reads:

“Carlos Augusto França Vargas[1], Silvio Aparecido dos Santos[1], Guilherme Ary Plonski[1]

[1]Universidade de São Paulo – USP, Faculdade de Economia, Administração e Contabilidade – FEA, Programa de Pós-graduação em Administração – PPGA, São Paulo, SP, Brasil. E-mail: carlosaugusto.vargas@usp.br

How to cite: Vargas, C. A. F., Santos, S. A., & Plonski, G. A. (2020). Product development in technology based firms in innovation environments. *Gestão & Produção*, 27(2), e4551. https://doi.org/10.1590/0104-530X4551-20”

It should be read:

“Carlos Augusto França Vargas[1], Silvio Aparecido dos Santos[1], Guilherme Ary Plonski[1], Márcio Shoiti Kuniyoshi[2]

[1]Universidade de São Paulo – USP, Faculdade de Economia, Administração e Contabilidade – FEA, Programa de Pós-graduação em Administração – PPGA, São Paulo, SP, Brasil. E-mail: carlosaugusto.vargas@usp.br

[2]Pontifícia Universidade de São Paulo – PUC-SP, Faculdade de Economia, Administração e Contabilidade, São Paulo, SP, Brasil. E-mail: m_kuniyoshi@pucsp.br

How to cite: Vargas, C. A. F., Santos, S. A., Plonski, G. A., & Kuniyoshi, M. S. (2020). Product development in technology based firms in innovation environments. *Gestão & Produção*, 27(2), e4551. https://doi.org/10.1590/0104-530X4551-20”