ESCOLA POLITÉCNICA DA UNIVERSIDADE DE SÃO PAULO

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**Patterns of open innovation within product development: a comparative study
between Brazilian and Canadian aerospace industries**

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between Brazilian and Canadian aerospace industries**

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“Progress requires that the subject be enlarged in itself; alternation, that it be transformed into something else. The intelligence, then, the knowledge, the wisdom, as well of individuals as of all, as well of one man as of the whole Church, ought, in the course of ages and centuries, to increase and make much and vigorous progress; but yet only in its own kind; that is to say, in the same doctrine, in the same sense, and in the same meaning.”

St. Vincent of Lérins (Commonitorium, 434 A.D.)

RESUMO

A inovação aberta é uma nova linha de pesquisa que surge a partir de nova organização industrial de pesquisa, desenvolvimento e inovação (P,D&I): após um período de verticalização, a economia parece caminhar em direção a um maior nivelamento com menores barreiras para novos entrantes em um novo cenário de colaboração e disseminação de conhecimento. Neste conceito, as empresas podem e devem usar ideias externas, assim como internas, e caminhos internos e externos para o mercado, na medida em que buscam avançar suas tecnologias. O objetivo geral deste projeto é analisar a profundidade e impacto das práticas de inovação aberta, bem como identificar padrões de sua integração ao processo de desenvolvimento de produtos (PDP) com foco na indústria aeroespacial, um segmento tradicional de alta tecnologia no setor metal-mecânico. Para tal, um modelo de referência é elaborado e avaliado em diferentes contextos, em uma comparação entre as indústrias brasileira (economia emergente) e canadense (economia desenvolvida), mais especificamente os arranjos produtivos aeroespaciais em São Paulo e Quebec. A pesquisa compreende uma análise do mercado aeroespacial, bem como o estudo dos sistemas nacionais de inovação de ambos os países, apoiados por um levantamento ("survey") que mede a intensidade e a importância da inovação aberta em plantas de empresas aeroespaciais no Brasil e no Canadá. A pesquisa é realizada por meio de entrevistas presenciais em empresas com gestores de P&D, baseadas em um questionário. A amostra compreende um total de 53 plantas de empresas aeroespaciais, 22 delas no Brasil e 31 no Canadá. Através da análise descritiva dos dados da pesquisa, é possível identificar semelhanças e diferenças nos padrões de inovação aberta nos dois grupos. Entre as semelhanças destacam-se o foco no produto, o envolvimento precoce de clientes no PDP, as estratégias adotadas para proteção de propriedade intelectual (PI), a concentração de acordos colaborativos dentro dos limites da indústria aeroespacial e a baixa intensidade na utilização de ferramentas pecuniárias, tais como o capital de risco, spin-offs e/ou aquisições. Entre as diferenças, o Canadá se destaca com relação às suas políticas públicas de inovação e programas de assistência, que se mostram mais eficazes em relação aos brasileiros. Além disso, as plantas canadenses parecem ter um melhor desempenho inovador, mais próximo do estado-da-arte das tecnologias aeroespaciais e com maior relevância internacional. O levantamento também mostrou que as intensidades de abertura no Brasil e no Canadá são semelhantes, embora os padrões e motivações difiram: as plantas brasileiras estão mais envolvidas no fornecimento de serviços de P&D para produtos de terceiros sob contrato direto (e não dentro de acordos de colaboração) para clientes locais, enquanto que as plantas canadenses parecem estar engajadas em um leque mais amplo de frentes de colaboração, com maior distribuição geográfica. Além disso, as plantas brasileiras adotam com muito menor intensidade métodos formais de proteção da PI em relação às canadenses, o que dificulta (mas não impede) a adoção plena da inovação aberta no cluster brasileiro. Com base nos resultados, o texto conclui com recomendações dirigidas aos três vértices da hélice tripla em ambos os países, a saber: empresas, institutos de ciência e tecnologia e governo.

Palavras-chave: Desenvolvimento de produtos, inovação tecnológica, inovação aberta (open innovation), gestão da inovação, indústria aeroespacial

ABSTRACT

Open innovation is a new research line that emerges from a new industrial organization of research, development and innovation (R,D&I): after a period of vertical integration and accumulation, economy seems to walk towards a more plain level with lesser barriers to new entrants due to a new scenario of collaboration and knowledge dissemination. In this new mindset, firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as firms look to advance in their technologies. The general goal of this research project is to analyze the depth and the impact of open innovation practices, as well as to identify patterns of their integration to the product development process (PDP) with focus on aerospace, a traditional high-tech segment within the metal-mechanic sector. For such, a reference model is elaborated and analyzed in two different contexts, in comparison study between Brazilian (emerging economy) and Canadian (developed economy) industries, more specifically the aerospace clusters in São Paulo and Quebec. The research comprises an aerospace market analysis, as well as the study of both countries' national systems of innovation, supported by a survey that measures the intensity and importance of open innovation in Brazilian and Canadian aerospace companies' plants. The survey is carried out by means of in-company questionnaire-based face interviews with R&D managers. The sample of analysis comprises a total of 53 aerospace plants, 22 of them in Brazil and 31 in Canada. Through a descriptive analysis of survey data, it is possible to identify similarities and differences in the patterns of open innovation in the two clusters. Among the similarities one highlights the focus on the product, the early involvement of customers in the PDP, the strategies adopted regarding intellectual property (IP) protection, the concentration of collaborative arrangements within the boundaries of the aerospace industry and the low intensity use of pecuniary tools, such as venture capital, spin-offs and/or acquisitions. Among the differences, Canada stands out with respect to its innovation public policies and assistance programs, which are found to be more effective in relation to Brazilian policies. Besides, Canadian plants seem to have a better innovative performance, at the cutting edge of aerospace technologies and higher international relevance. The survey also finds that the intensities of openness in Brazil and Canada are quite similar, although the patterns and motivations differ: Brazilian plants are more engaged in providing R&D services for products of third parties under direct contract (and not within collaborative arrangements) to local customers, while Canadian plants seem to be more engaged in a wider spam of collaborative fronts in a wider geographical range. Besides, Brazilian plants are much less intense in the adoption of formal IP protection methods in relation to Canadian ones, which hinders (but not prevents) the full adoption of open innovation in the Brazilian cluster. Based on the results, this text concludes with recommendations directed to the three vertices of the triple helix in both countries, namely: enterprises, science and technology institutes and the government.

Keywords: Product development, technological innovation, open innovation, innovation management, aerospace industry.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

AFP	<i>Agência de Fomento Paulista (Brazil)</i>
BDC	Business Development Bank of Canada
BMP	Business Process Management / Business Process Map
BNDES	<i>Banco Nacional de Desenvolvimento (Brazil)</i>
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAPES	<i>Coordenação para Aperfeiçoamento de Pessoal de Nível Superior (Brazil)</i>
CBERS	China-Brazil Earth Resources Satellite
CNPq	<i>Conselho Nacional de Pesquisa (Brazil)</i>
CRIAQ	<i>Consortium de Recherche et d'Innovation en Aérospatiale au Québec</i>
CSA	Canadian Space Agency
CTA	<i>Centro de Tecnologia da Aeronáutica (nowadays DCTA)</i>
DCTA	<i>Departamento de Ciência e Tecnologia Aeroespacial (former CTA)</i>
DRDC	Defense Research and Development Canada
ECSS	European Cooperation for Space Standardization
ESA	European Space Agency
EU	European Union
FAPESP	<i>Fundação de Amparo à Pesquisa do Estado de São Paulo</i>
FINEP	<i>Financiadora de Estudos e Projetos (Brazil)</i>
FQRNT	<i>Fonds Québécois de la Recherche sur la Nature et les Technologies</i>

GETS	Global Enterprise Technology System
ICT	Information and Communication Technologies
INPE	<i>Instituto Nacional de Pesquisas Espaciais (Brazil)</i>
IP	Intellectual Property
ISS	International Space Station
JAA	Japanese Aeronautic Association
JAXA	Japanese Aerospace Exploration Agency
KM	Knowledge Management
MCTI	<i>Ministério da Ciência, Tecnologia e Inovação (Brazil)</i>
MDEIE	<i>Ministère de Développement Économique, de l'Innovation et de l'Exportation (Quebec)</i>
M&A	Mergers and Acquisitions
M&O	Maintenance and Operations
MFE	<i>Ministère de Finances et de l'Économie (Quebec)</i>
MNC	Multinational Company
NASA	National Aeronautics and Space Administration (USA)
NRC	National Research Council
NSERC	Natural Sciences and Engineering Research Council of Canada
NSI	National Systems of Innovation
NPD	New Product Development
NPS	Non-Pecuniary Support
OECD	Organization for Economic Co-operation and Development
OI	Open Innovation

OSS	Open Source Software
PARC	Palo Alto Research Center (Xerox)
PDP	Product Development Process
PINTEC	<i>Pesquisa de Inovação Tecnológica</i> (Brazil)
PLC	Product Lifecycle
PLM	Product Lifecycle Management
PM	Project Management
PNFP	Private-Non-For-Profit
R,D&I	Research, Development and Innovation
R&D	Research and Development
RFB	<i>Receita Federal do Brasil</i>
RSI	Regional Systems of Innovation
SADI	Strategic Aerospace and Defence Initiative (Canada)
SI	Systems of Innovation
SME	Small and Medium Enterprise
STI	Science and Technology Institutes
TDP	Technology Development Process
TPP	Technological Product and Process
TRM	Technology Roadmapping
TRL	Technology Readiness Level
TTO	Technology Transfer Office
SOA	Service-Oriented Architecture

UAV	Unmanned Aerial Vehicles
ULA	Ultralight Aeroplanes
VC	Venture Capital

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1 INTRODUCTION

"The very foundation of entrepreneurship is the practice of systematic innovation"

Peter Drucker (1909-2005)

1.1 Background

Innovation is more and more being recognized as a fundamental source of competitive advantage to firms. Governments from all over the industrialized world work to stimulate its entrepreneurs and firms to invest in innovation as the most straight-forward path for a nation's continuous prosperity in the globalized scenario.

Although currently relevant, the subject is not that new. Innovation has been object of studies in Economic Sciences since Austrian economist Joseph Schumpeter (1883-1950) introduced the concept of innovation as the drive of economic growth in his work **"Theory of Economic Development"** (SCHUMPETER, 1912).

As a matter of fact, since the Industrial Revolution in the nineteenth century, the dynamics of capitalism has been deeply influenced by technological development, which led to a paradigm shift in the economic development theory of his time.

1.1.1 Creative destruction

One of Schumpeter's main contributions was to observe that, opposing the neoclassical theory, technical progress within an industry is a phenomenon that is not exogenous to the market, but endogenous. That is to say that the agent that motivates and generates technical progress is mostly the firm and not public science anymore.

This paradigm shift is explained in Schumpeter's model by the theory of "creative destruction". According to this theory, the factor that allows firms to earn extraordinary profits is the introduction of technical differentiations (innovations) that would enable the destruction of an existing market structure in order to create a new situation in which, at a first moment, the firm that performed such innovation

would have a monopoly. The creation of temporary monopolies would then be at the very heart of competition¹.

These technical differentiations tend to be, sooner or later, nullified by the action of competition, which is to say that the effects of an innovation are temporary. Therefore, in order to continuously earn extraordinary profits, firms should reinvest part of the exceeding profits in the research and development (R&D) of new technologies, so that new innovations can arise, which would by their turn enable new ruptures in the market structure and new extraordinary profits. This succession of ruptures would determine the dynamics of economical growth, which happens in cycles in the Schumpeterian model, as Schumpeter would later explain in detail (SCHUMPETER, 1939). Figure 1 summarizes this cycle.

Figure 1 Dynamics of the economical growth in the Schumpeterian model

A characteristic of this model is the cumulative nature of the economy at the firm level. That is to say that economy tends to be cumulated in the long run in a few large companies, rather than in perfect competition. Schumpeter admits it in the later phase of his life in his book **"Capitalism, Socialism and Democracy"**

¹ This notion also represented a rupture with the neoclassical model, which considered monopoly as antagonist to competition (POSSAS, 2006).

(SCHUMPETER, 1943), which represents a change of mind regarding his early works, where Schumpeter attributed to the entrepreneur – in general small and new entrant – the task of innovating (SCHUMPETER, 1912).

By this new perspective, the mainstream of innovations would be observed in R&D laboratories of large firms rather than in small entrepreneurship².

1.1.2 Cumulative nature of economy at the firm level

This cumulative nature was observed by several other thinkers of the Economic Science, although from different perspectives, such as Josef Steindl (1912-1993) and Edith Penrose (1914-1996).

According to Steindl (1958), companies within an oligopoly are dimensioned with excess capacity, which allows them to absorb demand oscillations and to adopt aggressive price strategies for blocking new entrants. Steindl's model leads to the conclusion that resources tend to be accumulated in the long-term in a few large companies, which he designates as the state of maturity and stagnation of a capitalist system.

What Steindl ignores in his model is the relevance of technical changes for obtaining competitive advantages by firms, as he admitted in late writings (BLOCH, 2006). In spite of that, he managed to reasonably explain the dynamics of price determination in these markets and the cumulative nature of the economy at the firm level.

Penrose (1958) reaches a similar conclusion addressing the firm through a resource-based approach. According to Penrose, the market is not a limitation for the size of a given firm, due to the diversification of investments that this firm can perform with its capital; the limitation to a firm's growth is due to its resources and

² In the words of Sturgeon (1997: p.4): "By the time he [Schumpeter] wrote *Capitalism, Socialism, and Democracy* (1942), Schumpeter's focus had shifted from the innovative entrepreneur to innovation in the R&D laboratory, from tacit to codified knowledge, from low to high market entry barriers, and from small to large firms."

its inability to absorb/develop new business or to enhance the existing ones. In other words, accumulation to Penrose is not only in scale but also in scope.

The resources of a firm assume a central role in penrosian theory: they are the determinants of the firm as a whole (RUGMAN et VERBEKE, 2002). By resources, one shall understand both tangibles (infrastructure, equipments etc) and intangibles (knowledge, know-how, values etc). The intangible ones are the most important in penrosian model, for they contain all capabilities that the firm developed throughout its path (history).

The necessity to grow and diversify arises from the fact that the firm permanently has productive resources that are not used. These, instead of being considered a waste, are faced by Penrose as opportunities for growth, for they make room for diversification. For Penrose, a firm fundamentally grows because it has idle resources.

Still many other academics of the Economy Science noticed this cumulative nature of the economy, such as Nelson and Winter, fathers of the “evolutionary economics” theory, who assert that *“the claim that a market structure involving large firms with a considerable degree of market power is the price that society must pay for rapid technological advance”* (NELSON et WINTER, 1982: p. 278).

1.1.3 Scale and scope – the dynamics of industrial capitalism

The author that best described³ the process of vertical integration in the twentieth century was Harvard’s business history professor Alfred Chandler (1918-2007). His extensive historiographical study resulted in his book **“Scale and Scope – the dynamics of industrial capitalism”** (CHANDLER, 1990), where he contrasts the growth of the top 200 corporations in the United States, United Kingdom and Germany from 1880 to 1940.

In this book, Chandler (1990) observed that:

³ According to Sturgeon (1997) and Chesbrough (2003a).

"(...) the major innovations made in the processes of production during the last quarter of the nineteenth century created many new industries and transformed many old industries. These processes differed from earlier ones in their potential for exploiting the unprecedented cost advantages of the economies of scale and scope." (CHANDLER, 1990: p.23)

These innovations led to a deep vertical integration process in many industries, which included not only production, distribution and other activities within the supply chain, but also those related to R&D⁴.

It is the rise of the large corporative R&D laboratory.

To take advantage of the benefits of the economies of scale and scope, firms developed organizational capabilities in management and strategic planning, which aim to administrate a multidivisional structure in constant vertical and horizontal growth in the market, not to mention product diversification and expansion to new geographic markets.

This analysis also leads to the same conclusion as that of authors previously presented: that economy in the first-half (and part of the second-half) of the twentieth century tends to accumulation in the firm level.

1.1.4 The unbundling process

Things were about to change, though. Sturgeon (1997) describes the situation of manufacturing activities within large corporations by the 1990's. According to him and other authors, such as Langlois (2003), manufacturing was at that time at a speed process of outsourcing: greater focus was then being given to the activities related to innovation, relegating manufacturing activities to a new player in the market: specialized merchant suppliers.

⁴ Quoting West et al. (2006: p.285): "Chandler (1990) recounts how the key technologies of the early and mid-20th century were developed by industrial research departments within large diversified enterprises of U.S. and Europe. Such diversification, along with vertical integration from research and development through distribution, provided these firms with competitive advantage over smaller and newer rivals through economies of scale and scope"

Sturgeon defines this change as “a paradigm shift” (STURGEON, 1997). The previous paradigm consisted of vertical integration and concentration of the industrial activity within the boundaries of large firms (from R&D to distribution and sales). This paradigm served well for explaining North-American industry organization by the 50's (STURGEON, 1997).

However, changes in the world economy during the 1970's and 1980's, *“particularly the failure of large American corporations to adequately respond to new competition from Asia”* (STURGEON, 1997: p.4), provoked this paradigm shift.

In this new paradigm, companies realize that outsourcing and strategic alliances for providing fully-integrated solutions (turnkey contracts) are alternatives for keeping them competitive in the market.

This paradigm shift causes a reduction of barriers to entry for new firms (due to the transfer of capabilities to these specialized suppliers), and give greater fluidity to the market, once market-share gains are not necessarily associated with an increase in the size of firms (STURGEON, 1997).

Langlois (2003) refers to this new dynamics of market as the ‘vanishing hand’, opposing Chandler’s (1977) ‘visible hand’, which in its turn opposes to Smith’s (1776) ‘invisible hand’.

1.1.5 From manufacturing to research, development and innovation (R,D&I)

One shall understand that the motivation for such unbundling process finds its roots in the very characteristics of current economy. Shifts in the technological and economical environments led to a new market dynamics where one observes: (i) reduced life cycles of products, (ii) greater market volatility and (iii) more complex technologies with higher costs of development (CHESBROUGH, 2007a).

These factors result in increasing rates of uncertainty on investment. The firm seeks alternatives to address this new scenario, due to its natural strong aversion to risk (CHRISTENSEN, 1997). Sharing risks by sharing resources and responsibilities is

a viable alternative to decrease a firm's investment requirements. It is the logic behind the rise of specialized merchant suppliers.

Although Sturgeon's analysis focuses on manufacturing outsourcing, he realized that some sectors (such as electronics) were by that time already including other activities in turnkey contracts rather than simply manufacturing⁵.

At that time, however, manufacturing was the most relevant locus of outsourcing. As a matter of fact, since manufacture involves more standardized and replicable structures, it is relatively "easier" to be shared and outsourced than others, such as R&D. Even today, manufacturing outsourcing is more often performed than other types of outsourcing.

But there is no reason why this unbundling model could not be replicated to the innovation value chain⁶. In fact, it is already happening. R&D outsourcing, for instance, is something that is not new at all, but it is getting more and more frequent in many industries, as examples in the literature show⁷.

Activities such as R&D, manufacturing and marketing are all within this value chain, and they are all susceptible to outsourcing with varying degrees of difficulty, and consequently, of cost. However, as costs for internal implementation of a given activity go higher for no matter what reason, outsourcing may become a reasonable alternative. In product development, outsourcing arrangements occur at increasing rates (ANDERSON JR. et al., 2008).

⁵ "(...) Besides basic electronics manufacturing processes, such as circuit board assembly, most contractors have added a range of back- and front-end services, such as process R&D, design for manufacturability, product-specific process development and documentation, various forms of testing, final product assembly, final packaging, software loading and document duplication, and shipping to distribution." (STURGEON, 1997: p.12)

⁶ By "innovation value chain", it is meant something like the straight-forward three-folded linear model proposed by Hansen and Birkinshaw (2007) which explains how "ideas" (the "raw material" of innovation) are transformed into goods, services and processes. Its phases are: (i) generation of ideas, (ii) conversion of ideas and, (iii) diffusion of ideas.

⁷ See, for example, the result of the survey from Fuqua School of Business at Duke Univ. and Booz Allen Hamilton Inc., published in R&D Magazine in June 2007 (STUD, 2007), which shows the increasing trend of R&D outsourcing in American companies from many different sectors.

As a consequence, concepts, such as “core competence” (PRAHALAD et HAMEL, 1990), gradually gain importance in order to help executives of large corporations to distinguish between activities that should strategically be kept internal to those that could be outsourced, among other goals.

It is within this context that the concept of open innovation arises.

1.1.6 *Open innovation (OI)*

Common sense often considers open innovation (OI) simply as a reference model and/or methodology to external sourcing of ideas⁸.

As a matter of fact, the starting point of analysis of OI seems to be this very perspective of “innovation outsourcing”, which Gassmann and Enkel (2004) define as “outside-in process”. As it has been argued here so far, it is the unbundling process that took place from the 1980’s that enabled the rise of OI.

Chesbrough (2003a), who coined the term open innovation, follows the same line of argument in his first and introductory book on the subject, as he discusses the panorama before its rise:

“(...) Centrally organized research and development were central to companies’ strategies and were regarded as critical business investments. R&D functions were a salient feature in the knowledge landscape of the economy, relatively insulated from the universities and small enterprises, relatively unconnected to the government, and largely self-contained” (CHESBROUGH, 2003a: p.24)

However, open innovation is a concept that intends to be broader than just an “outside-in” process, although the dominance of the outside-in process is usually observed (GASSMANN et al., 2010). Chesbrough (2003a) defines it as a new “paradigm shift”:

“Open Innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external

⁸ It happens even in the specialized literature on innovation. For example, Hansen and Birkinshaw (2007) shared this opinion about OI, as discussed in a previous essay (ARMELLINI et KAMINSKI, 2009).

paths to market, as firms look to advance in their technology.”
(CHESBROUGH, 2003a: introduction, p. xxiv)

Although it is not intended here to extendedly present the concept (the literature review on open innovation is found in item 2.2), it is important to highlight that the central idea behind open innovation is that, due to the fact that knowledge is today more distributed than in the past, and being knowledge an asset that large companies cannot confine within its borders, firms shall not rely exclusively on its own internal capabilities in order to promote innovation. Instead, firms shall count on external ideas as well as external paths to market (CHESBROUGH, 2003a). That is, for enhancing internal development for use in the firm’s own markets, and for enabling internal R&D projects to be used for markets different than those of the company, where they may be more valuable.

Therefore, besides the “outside-in” process previously mentioned, other two “core process archetypes” compose open innovation: “inside-out” and “coupled” processes (GASMANN et ENKEL, 2004), being this last one a combination of both “outside-in” and “inside-out” processes, as it often happens in collaborative arrangements.

The subject is not a novelty in the innovation literature. Freeman’s (1991) review paper on networks of innovation shows evidences of interaction of in-house R&D with external partners from the 1960’s. But according to an OECD study called **“Open Innovation in Global Networks”** (OECD, 2008), the systematic approach of the “inside-out” process, along with the strategic integration of all three processes into firms’ innovation strategies is a new perspective on the subject, and constitute the major contributions of the open innovation approach to the innovation literature⁹.

⁹ “The innovation literature has long recognised that companies do not innovate in isolation but co-operate with external partners throughout the innovation process. (...) The novelty of the concept of “open innovation”, coined by Chesbrough (2003), lies especially in the fact that the open innovation process has become an integral part of companies’ innovation strategy and business model. Additionally, the concept draws attention not only to the importance of knowledge sourcing but also to the exploitation of internal innovation together with external partners (the so-called inside-out process).” (OECD, 2008: p.24)

1.1.7 Conclusion of the section

By means of a literature review that departs from a chronological analysis, this first section of the work shows succeeding paradigm shifts in the western economic behavior towards technological development and industrial organization, from the neoclassical period to the rise of open innovation, summarized in Table 1.

Table 1 Paradigm-shift timeline

Paradigm	Main scholars	Main concepts	Dominant period (approx.)
Classic / neoclassic	Smith, Ricardo, Walras	<ul style="list-style-type: none"> - Liberalism: economy self-regulated by the market (the 'invisible hand') - Technology change exogenous to the firm 	From industrial revolution to mid-20th century
Creative destruction	Schumpeter	<ul style="list-style-type: none"> - Innovation as the driving force of technical progress and economical development - Technology change endogenous to the firm - Entrepreneurs' prominent role in generating innovation. 	First half of the 20th century
Corporative R&D	Chandler	<ul style="list-style-type: none"> - Vertical integration from development to distribution (the 'visible hand') - Innovation performed mainly in corporate R&D labs 	Mid-twentieth century
Unbundling process (outsourcing)	Sturgeon, Langlois	<ul style="list-style-type: none"> - Unbundling process in course: vertical structures start to collapse (the 'vanishing hand') - Partnerships and outsourcing ("turnkey contracts") as alternative to share risks and responsibilities 	From 1980's on
Open innovation	Chesbrough	<ul style="list-style-type: none"> - Unbundling reaches strategic structures, such as R&D and Product Development. - Use of inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively 	From 1990's on

In spite of the effort to precise dates, it is not quite clear when a paradigm shift occurs, due to overlaps that are noticed in practice. Paradigm shifts happen

gradually, not suddenly, and very normally they coexist within time and space. A paradigm shift is related to cultural aspects, therefore connected to personal values and beliefs. Two employees from the same department of a given company can follow different paradigms, for instance.

What the literature points out are general “trends of change” observed in specific periods and industries, that persist in time and that are later on expanded to other industries, in proportions big enough to be considered a paradigm shift.

It is relatively easier to notice changes “post-factum”, that is, after they took place. However, it is normally of less relevance to industrial organization matters: it just shows how companies should better be organized in the past. Alone, it normally does not draw any conclusions about present or future.

Much more complex is the effort to derive a theory based on a paradigm shift that is in course. Analytical data may not be all available, and mental models have to be constructed (sometimes with a great deal of simplifications), based on analytical past data, in an effort to draw “tendency curves” that would show where changings are leading to.

In this context, open innovation (OI) arises as a new research line among scholars and innovation experts around the world. It is based on the cognition of a “tendency” in industrial organization that is well represented in Figure 2, a graph produced by Prof. de Wit for a special conference on collaborative R&D and knowledge transfer in 2004 (EIRMA, 2004).

Source: EIRMA (2004)

Figure 2 Towards greater outsource of innovation

This figure shows that after a period of vertical integration and accumulation, economy seems to walk towards a more plain level with lesser barriers to new entrants biased by a new scenario of collaboration and knowledge transfer.

Besides the aspect of innovation outsourcing, OI contributes to the literature with the perspective that spillovers from internal R&D can and should be used by the firm to leverage the innovation in different markets¹⁰.

The task of scholars engaged on researching the concept is to give conceptual basis to the facts observed in practice. As Chesbrough et al. (2006) wrote:

"It is far too soon to claim that the paradigm of Open Innovation will make an enduring contribution to our understanding of innovation, However, it is not too soon to claim that it has already made an impact on our understanding of innovation" (CHESBROUGH et al., 2006: p.4)

1.2 Relevance of the topic

Open innovation is a topic of growing interest in both academy and industry.

¹⁰ The proposal of Chesbrough's (2003) first book on OI was to show these evidences to managers of industrial innovation processes, as he explicitly admitted later on (CHESBROUGH et al., 2006).

On the behalf of industry, this interest is more evident and has been noticed in empirical studies (CHESBROUGH et CROWTHER, 2006; ENKEL et al., 2009). The clearest evidence, however, is the fact that many companies from different industrial segments are explicitly engaged in open innovation as part of their strategy: Kraft¹¹, Nokia¹², Deutsche Telekom¹³, Philips¹⁴, Siemens¹⁴, Unilever¹⁵, IBM¹⁶, Xerox¹⁶, SAP¹⁶, Intel¹⁶, Procter & Gamble¹⁶ and DOW Chemicals¹⁶, just to name a few.

On the behalf of the academy, Chesbrough et al. (2006) extensively discussed some topics in OI theory that attracts the interest of scholars, such as IP management issues, community-based knowledge creation (the so-called “peer production”), knowledge networks and collaborative arrangements (with or without university participation). Although these topics are not new to literature, the novelty lies in the integrated perspective that OI provides to such studies (OECD, 2008).

Dahlander and Gann (2010) also evidenced the growing interest of scholars in the topic after an extensive literature review. Among their findings, they noticed a rising number of papers published on open innovation in the period from 2000 to 2009 indexed in ISI Web of Knowledge database, reproduced from the original in Figure 3.

¹¹ Jusko, 2008.

¹² Dittrich et Duysters, 2007.

¹³ Rohrbeck et al., 2009.

¹⁴ Enkel et al., 2009.

¹⁵ Hague, 2010.

¹⁶ Chesbrough, 2003a.

Source: DAHLANDER et GANN (2010)

Figure 3 Number of papers published on open innovation over time

Dahlander and Gann (2010) conclude their study pointing out that important contribution has been made in the academy *“to depict and explain different aspects of the innovation process”*, and that *“it is timely to take stock of this important idea and assess whether a coherent body of literature is being developed”* (p.9).

This common interest in the topic (from both scholars and executives) derives from the observation that industrial organization towards innovation is in course of change. Indeed,

“(...) great research and development laboratories of the twentieth century have been downsized, broken up, or redirected to new purposes in the West, while new labs are springing up overseas in large countries such as India and China, as well as small countries such as Finland and Israel. Companies are shortening their time horizons for research and development expenses and are shifting money from ‘R’ to ‘D’ (...)” (CHESBROUGH, 2006: p.1)

Chesbrough (2007a) illustrates the cause for these changes by means of a “Revenue vs. Cost” chart, reproduced in Figure 4. This illustration shows that rising costs of innovation (mainly due to higher complexity of new technological discoveries) and shorter product life cycles are leading the so-called “closed model” to collapse. The open model solution includes efforts for finding new sources of revenues and reducing development costs by leveraging external sources of development.

Source: adapted from CHESBROUGH (2007a).

Figure 4 The economic pressure on innovation and the open business model solution

This open model is more likely to be successful if it is adopted as part of a firm's strategy (CHESBROUGH et APPLEBYARD, 2007). However, before it happens, single and isolated actions towards higher openness shall be able to present positive contribution to a firm's income, otherwise executives are not likely to adopt the concept.

According to Chiaroni et al. (2011), the path behind the full adoption of open innovation within a company would be to move from sporadic use (the so-called "unfreezing" process) to the institutionalization of open innovation in the formal processes and culture of the firm.

There lies the current relevance of a research project on OI: to form a coherent body of knowledge on the topic and to show its relevance in industry organization.

1.3 Scopus of the study (boundaries of research)

The subject of innovation and the impact of open innovation to industrial organization in general, as it has been presented here so far, is a theme way too vast for the purposes of a PhD research thesis and, therefore, it shall be limited.

The present work aims to analyze the contributions of openness practices to the Product Development Process (PDP) in one specific traditional high-tech industry in the metal-mechanic sector that is economically relevant in Brazil. By doing so, this paper intends to clarify whether OI should be regarded as strategic or not for this specific industrial segment.

Six constraints are highlighted in the previous paragraph, which constitute the boundaries of this work.

The first constraint is restricting the study to **“product development process”** (PDP), which is defined in this study as the

“Conjunto de atividades envolvendo quase todos os departamentos da empresa, que tem por objetivo a transformação de necessidades de mercado em produtos e/ou serviços economicamente viáveis.” (KAMINSKI, 2000: p.1)

[“Set of activities involving almost all departments within a company, which aims to transform market requirements into economically viable products and/or services.”]

By focusing the PDP, this work intends to analyze the impact of innovation (and especially its degree of openness) to the enhancement of a firm’s technology and of its organizational practices towards the development of new products and industrial processes or improvement of existing products and industrial processes. The pecuniary aspect, although important, is regarded as secondary in this work: it is just one of the factors that influence product development, although perhaps the most important one.

Besides, a recent exploratory paper from Knudsen and Mortensen (2011) highlights some negative effects of openness within the new product development process. Far from discouraging further research on the subject, these results urge other scholars to verify whether these findings are also observed in different contexts.

The second constraint is the choice for analyzing only **“one”** industrial segment. From that it follows that this work does not intend to make cross-industry analyses and comparisons, but simply investigate the impacts of OI within one industry,

following the deductive logic of analysis (from general to specific). This work aims to verify whether the theory that is being formed on open innovation can be applied to one specific chosen situation.

The third constraint is the choice of a “**traditional**” industry. It serves to counteract the majority of publications on open innovation, which generally focuses on highly innovative and dynamic sectors, such as biotechnology, software development, information technology and mobile electronics. In these segments, which Chesbrough and Appleyard (2007) name “open-dominated industry segments”, the choice of open business models seems to be more evident.

Huizingh (2011) argues that this path is common to any new concept: initial studies (based mostly on descriptive case studies) are based on successful early adopters and are later on supported by quantitative studies involving larger samples of adopters, which contribute to determining the relative importance of several factors in order to build a consistent body of knowledge about the concept.

However, the same evidences found in open-dominated segments may not be present in segments where the “erosion factors”¹⁷ of the closed model are not yet a reality. In this case, the adoption of open innovation shall not be a necessity in absolute terms, but it may (or may not) turn out to be a competitive advantage to firms in these segments. Choosing a more traditional industrial segment is a way to investigate whether open innovation is a more general tendency, rather than just a tendency for some specific industrial segments.

The fourth constraint is the choice of a “**high-tech**” industry. In spite of the efforts of some scholars to prove that the size or the intensity of technology is not a determinant for well-succeeding innovation (COHEN et LEVINTHAL, 1990; CHESBROUGH et CROWTHER, 2006; VAN DE VRANDE et al., 2009; CHESBROUGH, 2007b), this is an aspect this work does not intend to verify.

¹⁷ The term is used by Chesbrough (2003a) to designate the factors that are leading firms towards the adoption of open business models. They are presented in details in section 2.2.2.

Although discarding “open-dominated industry segments”, this research shall remain within the high-tech domain, in order to more easily find correlations between managerial actions towards innovative openness and its respective results in technology enhancement.

The fifth constraint is about the choice of the “**metal-mechanic**” sector, which is more related to the area of concentration of this work and personal interests of the researchers involved in the project.

Finally, the sixth constraint sits on the choice of an industrial segment “**relevant to Brazilian economy**”. The reason for this constraint is to allow both higher relevance to this work and larger population of enterprises within the scope of the research, so that better results be achieved.

The first boundary restrains the field of study in which this research can be framed (innovative product development). The second boundary brings implications to the research method (discussed in Chapter 5). The remaining four boundaries contribute for choosing the industry segment of study, which is discussed in the following subsection.

1.3.1 Industry segment choice: Aerospace

One industry segment that meets all the requirements previously raised is the aerospace.

As presented in details in section 4.4, the aerospace industry is one of the most prominent segments in Brazilian economy, that was responsible for 3.2% of total exports (6.1% of produced goods) of the Brazilian trade balance in 2007 (ABDI, 2009; AEB, 2009), and 4.99% in 2010 (GOMES, 2012).

One additional aspect that biased the choice of this segment is the fact that the most renowned Brazilian company in the segment, Embraer, has adopted a business model that is broadly related to openness: risk-sharing collaborative arrangements. As reported in Harvard Business School’s case about the success of Embraer’s aircraft development (HBS, 2000a), the company engaged in collaborative partnerships:

(...) so as to give risk-sharing partners responsibility for supplying entire systems instead of components, and thereby encourage the development of closer relationships with a smaller number of supplies. Bombardier, in contrast, was thought to place less emphasis on external partnerships because it was larger and more vertically and horizontally integrated, and Fairchild Dornier because financial and ownership issues had probably limited its ability to establish and maintain long-term relationships. (HBS, 2000a: pp.10-11)¹⁸

Although one cannot conclude from this excerpt that Embraer adopts open innovation in strict sense, it can be stated that the company takes advantage of an open innovation practice in order to achieve competitive advantages in the market. Through this practice, Embraer managed to reach reduced production lead-time and costs, as well as lowered development risks and costs, in relation to the competition, by sharing responsibilities (HBS, 2000a).

1.3.2 Geographical loci of analysis: Brazil and Canada

As part of the research methodology explained in details in Chapter 5, this work aims to provide a comparative study of the Brazilian aerospace industry regarding openness practices in innovation processes.

This comparative study must include one other aerospace industry from somewhere this segment is also relevant to local economy. In addition, as it is addressed in section 1.5, this region should better be situated in a well-developed economy, in order to provide a comparison that could contrast the adoption of Open Business models in a developed economy – where most of the research on OI has been performed (WEST et al., 2006) – and in an emergent economy such as Brazilian's.

A *locus* of analysis that suits these restraints is Canada, more specifically the province of Quebec, responsible for approximately 60% of Canadian aerospace production in 2008 (CRFAQ, 2010). This province also concentrated, in 2008, about 50% of the staff and 70% of the R&D of the segment in the country (MDEIE, 2010). In addition, also in 2008, aerospace is the second largest industry segment in the

¹⁸ This model is described in details in section 2.1.9.

province in terms of exports (CRIAQ, 2010), which denotes its importance to local economy.

Further information about the aerospace industry in Canada and Quebec is found in section 4.5.

1.4 Formulation of the problem of research

From all exposed, at this point the problem of research can be properly summarized and formulated into research questions, which this work aims to provide answers to.

West et al. (2006: p.289) defined that

"Open Innovation is both a set of practices for profiting from innovation, and also a cognitive model for creating, interpreting and researching those practices."

Dahlander and Gann (2010) noticed that *"this definition is inclusive for various different practices to be considered open"*, which led to *"conceptual ambiguity"*¹⁹.

This is one of the main reasons why much skepticism is found in the academy towards OI. Chesbrough et al. (2006) were aware of this, even though they noticed a growing academic interest in OI, and therefore claimed that fully developing the concept may be a fruitful path to academic inquiry.

Therefore, the first question to be asked in this research project is:

1) "What exactly does open innovation stand for?"

¹⁹ "Chesbrough et al. (2006, p.286) submit that 'open innovation is both a set of practices for profiting from innovation, and also a cognitive model for creating, interpreting and researching those practices'. This definition is inclusive for various different practices to be considered open. An unintended consequence of such a definition is that scholars use the openness construct to mean different things. Scholars have used different definitions of openness in their studies of 'open innovation'. This has led to conceptual ambiguity, with empirical papers focusing on different aspects, inhibiting our ability to build a coherent body of knowledge. At the very least, this may be detrimental to what could be useful studies by scholars outside the innovation community, who find it difficult to consider how openness links into broader debates." (DAHLANDER et GANN, 2010: pp.7-8)

Afterwards, since this research project aims to address open innovation within the Product Development Process, the second straight-forward question to be investigated in this research may be formulated as follows.

2) “What are the implications of open innovation within the Product Development Process?”

Next, a relevant issue is about the applicability of open innovation in different contexts than those investigated by Chesbrough (2003a; 2006) in his formulation of the concept.

Some possible sources of differentiation are geography and the so-called “National Systems of Innovation” (NSI)²⁰. West et al. (2006) claim that:

“(...) As most (but not all) of the prior research on Open Innovation has focused on the U.S. system, an examination of Open Innovation in the context of other National Systems of Innovation could more clearly identify both the prerequisites for and limits of Open Innovation, and make explicit the linkages between these institutions and practice.” (WEST et al., 2006: p.290)

Since this research project aims to verify the applicability of OI within Brazilian companies, a third question to be addressed in this research is whether OI is biased by these issues and how it happens. Thus, it can be defined as follows:

3) “Is open innovation applicable to emergent economies as well as to developed economies? What differences and similarities shall be observed in the approach of open innovation for both realities?”

Last but not least, one notices that OI is more evident in some industry sectors, such as electronics and information and communication technologies (ICT), than in others where some of the “erosion factors” pointed by Chesbrough (2003a), such as reduced product life cycles, are not still a reality. What it is intended to verify is whether OI is a reality in more traditional high-tech industries, such as Aerospace.

²⁰ “(...) [NSI are] the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge ... and are either located within or rooted inside the borders of a nation state.” (LUNDVALL, 1992)

In addition, the success of open innovation can differ across technologies and industries (CHRISTENSEN et al., 2005). Therefore, the fourth and last question is formulated as follows:

- 4) “How open is (and should be) innovation in more traditional high-tech industries, particularly in Aerospace?”

1.5 Research goals

In short, the **general goal** of this research project is to analyze the relation and impact of open innovation to technology development²¹ in the Product Development Process of a traditional high-tech industry segment in Brazil within the metal-mechanic sector.

Therefore, an extensive literature review on **product development** and **open innovation** shall be performed in order to reach the state-of-the-art within these two research fields, as well as to see where the studies in the two fields of study converge.

As for the specific research goals, they can be listed as follows:

- a) To present and discuss the concept of open innovation (OI). This goal is performed by means of a literature review followed by a critical analysis of the concepts;
- b) To analyze OI tools applicable to the Product Development Process (PDP). It follows from the discussion performed as the previous goal and is also performed by means of a literature review and critical analysis;
- c) To derive a conceptual model of the PDP suitable to incorporate and delineate the contribution of OI to the process. This goal also follows from the previous two, and is essentially the result of a critical review of existing models in the literature and the proposal of modifications to adapt them to a new boundary condition (OI);

²¹ It is important to stress that the primary goal in this work is to analyze the impact in the field of technology development. The economical impact analysis, although not neglected, is relegated as secondary in this research.

- d) To perform a field study of OI practices in the product development in the Aerospace industry. This study consists of a comparison between Brazilian (emergent economy) reality and a well-developed country where this industry is also important and relevant to local economy (Canada);
- e) To derive conclusions from this comparative study, with suggestions and recommendations to firms in both geographical situations.

In order to achieve these goals, besides the literature review, a market analysis overview on the Aerospace industry is required. What's more, a consistent research method must be established to investigate, analyze and discuss the subject under analysis.

1.6 Structuring of text

For fulfilling all the goals previously presented, this text is structured as follows.

Chapter 1 introduces the theme and its relevance, by means of a timeline analysis of innovation as a field of study within Economics from Schumpeter to date. It also presents the boundaries, goals and the formulation of the problem of research.

Chapter 2 presents the theoretical foundations of the research, which consists of a literature review on product development and open innovation.

Chapter 3 closes the literature overview, with the proposal of a conceptual model that serves as a framework that guides the rest of the work.

Chapter 4 consists of a market analysis overview of the aerospace industry, in three domains: global, Brazilian and Canadian markets.

Chapter 5 presents in details the research method used to address the issues of this project.

Chapter 6 shows the results obtained through the research method and performs an analysis of them.

Chapter 7 draws conclusions and suggests themes for further research on the subject.

Chapter 8 lists all references used in this work.

2 THEORETICAL FOUNDATIONS

*"Beware the man of a single book."
(St. Thomas Aquinas, 1225-1274)*

*"Better to illuminate than merely to shine, to deliver to others
contemplated truths than merely to contemplate."
(Idem)*

The foundations of this project lie on two specific topics: 1) product development and 2) open innovation and its contribution to innovation management in general. These two topics are addressed in the sections 2.1 and 2.2, respectively.

Product development and innovation management are complementary subjects, however, they are often studied separately. The literature lacks works in which these two subjects are studied together. One of the few exceptions are Paul Trott's (2011) book which embraces the two subjects in the same work, although each subject is discussed in different sections of the book.

Section 2.3 introduces the systems of innovation concept, as well as the theory of public policies for innovation, which somehow completes the discussion about open innovation performed in the previous section.

The reference material used for such consists of books and papers from the most renowned scholars engaged in the respective themes, as well as highly-referenced literature review papers, mostly from high-impact journals, which summarize and present a consistent overview of the general academic production on the themes. The works referenced in this literature overview are not presented one by one, but their concepts, findings and conclusions are diffused along the text, in order to present the reader a logical sequence to build the concepts that are relevant to this research project.

2.1 Product Development Process (PDP)

2.1.1 Introduction

The twentieth century was characterized in the social sciences as a period in which practical subjects that were not believed in the past to be eligible to be

submitted to the scientific method of analysis started to be considered as such. It happened in the study of innovation itself (POSSAS, 2006). The same happened to the study of labor division (CHANDLER, 1962), knowledge management (NONAKA et TAKEUCHI, 1995), entrepreneurship (HISRICH et al., 2001) and project management (HELDMAN, 2005), to name a few.

Product development went through the same path. Rozenfeld et al. (2006) argue that in the past it was believed that the success of companies in product development mainly depended on the genius of the professionals involved in the process, and that it was creed that management and structuring could not be successfully implemented for such activity due to uncertainties, low predictability and high creativity that are inherent to the process. However, still according to Rozenfeld et al. (2006), well-succeeded cases in the last decades led to a paradigm shift where these uncertainties not only may, but must be managed for successful product development.

2.1.2 Definition

According to ISO9000:2005 international standard, product is *“the result of a set of inter-connected or iterative activities which transforms inputs into outputs”* (ABNT, 2005: p.8). Possible outputs within this definition encompass goods or services (ABNT, 2005: p.12). Product development is the set of activities to create, modify and improve products.

Product development sits in the broader literature on innovation (TROTT, 2011), which consists of two broad areas of inquiry: one of them is attached to the economics-oriented tradition, which examines innovation on the macro level of patterns across industries and nations and its impact to the economy in general; the second, attached to organizations-oriented tradition, focuses the micro level regarding how products are developed and how this process can be more effectively structured and managed. This latter broad area is what product development is about (ADLER, 1989 apud BROWN et EISENHARDT, 1995).

In this field of study, product development is regarded as a business process. As such, it is a flow of activities that can be formalized, measured, managed and optimized (HAMMER, 2010). After all, it comprises a set of activities that aims the design of products and production processes, for their posterior manufacturing, distribution, use, maintenance and disposal (ASIMOW, 1962; KAMINSKI, 2000; ROZENFELD et al., 2006; JUGEND, 2010).

Rozenfeld et al. (2006) develop further Kaminski's (2000)²² definition of the PDP, by stating that:

"(...) desenvolver produtos consiste em um conjunto de atividades por meio das quais se busca, a partir de necessidades do mercado e das possibilidades e restrições tecnológicas, e considerando as estratégias competitivas e de produto da empresa, chegar às especificações técnicas de projeto de um produto e de seu processo de produção, para que a manufatura seja capaz de produzi-lo." (ROZENFELD et al., 2006: p.3)

["(...) product development consists of a set of activities through which one seeks, from the market needs and technological possibilities and constraints, and considering the competitive and product strategies of the company, to reach technical specifications for the design of a product and its production process, so that manufacturing is able to produce it."]

The science that deals with product development as a business process is referred to as **Product Development Process (PDP)** in the literature, although some authors also call it **New Product Development (NPD)**. Despite the employment of the word "new" in the latter, NPD also encloses the development of modifications within existing products²³. Therefore, to avoid misinterpretation of the term, and to stress the approach of the activity as a business process, this work adopts PDP nomenclature rather than NPD.

²² Cited on page 40.

²³ See, for instance, Loch's and Kavadia's (2008: p.3) definition of NPD: "New Product Development (NPD) consists of the activities of the firm that lead to a stream of new or changed product market offerings over time. This includes the generation of opportunities, their selection and transformation into artifacts (manufacturable goods) and activities (services) offered to customers, and the institutionalization of improvements in the NPD activities themselves." (the highlight is ours). Also note that this definition perfectly suits to define PDP as well.

2.1.3 History of research in the field

In order to better understand the structure of the PDP, it is important to understand how its study evolved since it became an object of academic inquiry. Many efforts to organize PDP research into frameworks is found in the literature, with some points in common and some differences as well, though. It is not surprising, since there are different perspectives in which one can regard the PDP.

In this section, some literature review papers are analyzed and compared, namely: Liyanage et al. (1999), Cooper et al. (2001), Brown and Eisenhardt (1995), Krishnan and Ulrich (2001) and Loch and Kavadias (2008). The aim behind this analysis is to search for evidences to argue that PDP research is also walking towards openness issues.

Liyanage et al. (1999) analyze the PDP from the strategic and organizational perspective, and propose a division of R&D management research in four generation models.

The **first generation**, which evolved in the early 1960's, placed great emphasis on individual creativity and the undertaking of scientific discovery with minimal bureaucratic controls for successful product development.

"In the first generation model, the scientific freedom of the researcher was considered more important than the relevance and accountability of the research itself. (...) The justification for undertaking R&D projects was argued on the basis of perceived importance of the new knowledge generation process." (LIYANAGE et al., 1999: p.376)

The description of the first generation matches the previously mentioned statement²⁴ from Rozenfeld et al. (2006) that past product development mainly depended on the genius of the professionals involved in the process, and that it was not creed that formal structures would be suitable for R&D management.

²⁴ Cited on page 42.

The **second generation** was prominent between the late 1970's and late 1980's, (LIYANAGE et al., 1999). It emphasized the multi-disciplinary nature of R&D and the need for professional project selection and management.

"While it continued to place emphasis on knowledge generation, second generation management also responded to 'market pull' and 'technology push' concepts, which reiterated the importance of having the underlying knowledge base of science and technology that yield economic returns. Researchers were compelled to select projects, which would deliver tangible results within a specified period. As a result, second generation management provided a framework for R&D at the project level and built better communication between research managers and business managers." (LIYANAGE et al., 1999: p.376)

During the 1990's, the **third generation** model for product development emerged with the proposal of linkage between corporate business strategy and R&D technology development strategy.

"Third generation management seeks to create across the business units, across divisions and across the corporation a strategically balanced portfolio of R&D formulated jointly in a spirit of partnership between general managers and R&D managers" (ROUSSEL et al., 1991 apud LIYANAGE et al., 1999: p.377)

In all three previous models, though, *"no systematic attempts were made to explore interdependence between internal R&D processes with external knowledge and technology diffusion and exploitation initiatives."* (LIYANAGE et al., 1999) Therefore, a new generation of R&D was required in order to address the following R&D management processes (LIYANAGE et al., 1999):

- To absorb and integrate external knowledge;
- To overcome the organizational inability to generate knowledge exponentially;
- To integrate complementary skills and resources for cost effective knowledge management;
- To deal with knowledge as an intellectual asset and manage this asset rather simply managing people, technology, market, organization etc.

Therefore, this new generation, the **fourth generation**, which was arising by the time Liyanage et al. (1999) wrote the article, deals with strategic management of

internal and external knowledge. As such, it deals with internal and external sources of knowledge and manages research networks, collaborative arrangements and strategic alliances, linking research, technology and innovation management.

Other renowned scholars built a similar historical background for PDP research. Cooper et al. (2001), for instance, mention a frustrated effort of scholars in the early 1970's to develop mathematical programming for optimizing project prioritization, which would constitute a first attempt to evolve to the second generation model. After this first failed attempt, the rise of the financial or economic models for evaluation of projects took place. This rise placed PDP definitely in the second generation model of Liyanage et al. (1999).

Afterwards, the rise of scoring and checklist models, probabilistic financial models and behavioral approaches progressively incorporate corporate business strategy as a factor of decision for portfolio management, placing PDP in the third generation model.

Brown and Eisenhardt (1995), in their turn, divide PDP research into three streams:

- The **rational plan stream** which focuses on measuring the financial performance to evaluate the viability of projects, for enhancing project portfolio management. According to the authors, its origin lays on studies in the early 1970's. This stream's definition is close to what Liyanage et al. (1999) classify as second generation models;
- The **communications web stream** work "concerns the narrow effects of *communication* on project performance" (BROWN et EISENHARDT, 1995: p.345). The origin also dates back to the early 1970's and focuses in product development aspects that are somehow contained in second and third generation models;
- Finally, the **disciplined problem-solving stream**, whose origin is in some studies of successful Japanese products performed in the mid

1980's, focuses mainly on organizational aspects of product development.

Brown and Eisenhardt (1995) do not intend to establish a timeline in which these streams are prominent within PDP research. According to these authors, all three streams evolve simultaneously and “offer complementary and sometimes overlapping insights to provide the basis of an integrative model” (p.365). Based on all three streams, the authors build an integrated model for product development which emphasize the organizational drivers and key players for successful product development: project team, project leader, senior management, suppliers and customers.

Finally, to conclude their paper, Brown and Eisenhardt (1995) propose an agenda for future research in the topic. For the matters of this text, it is worth mentioning the following assertions of them in this part.

- Early and extent integration of suppliers and customers are key factors for product development performance. Although the studies are almost unanimous to state that, it was still uncertain (by the time this article was written) how and when these key players are appropriately involved in the process, and they suggest these questions to be addressed in future research;
- The results in the studies within the communications web stream indicate that external communication is critical to successful product development. Internal communication is not negligible but often requires lesser organizational efforts to ensure that it happens properly. Here the authors also identify some research inquiry opportunities.

Krishnan and Ulrich (2001) classify PDP research papers in two broad categories: those whose subject is about decisions within a development project (encompassing technical and managerial issues) and about decisions for organizing and planning development projects (which include decisions related to business

strategic and organization). This division approaches the second and third generation models of Liyanage et al. (1999) as well.

The major contribution of Krishnan's and Ulrich's (2001) review paper is the research clustering analysis they perform to minimize interdependencies. It allowed the authors to identify three fundamental enablers in product development, as follows.

- **Product:** it comprises market and design and successfully identified the influence of some technological trends to product development, such as the use of virtual prototyping and computational simulation in engineering design;
- **Architect:** it encompasses product architecture and organizational issues, such as product variance, manufacturing and assembly design and supply-chain setup;
- **Portfolio:** this third cluster includes selection and prioritization decisions, technological and business strategy alignment and product platform management.

A more recent review on product development research from Loch and Kavadias (2008) identifies that earlier review papers and product development frameworks "have emphasized certain theories and phenomena within NPD [*New Product Development*], but not targeted an overall view" (p.9). These authors contribute to the literature in the field by integrating an evolutionary view to the PDP, which is done within three levels, as follows.

- **Process level:** it includes internal project organizational issues, such as creativity, project team structuring, product portfolio management, engineering design, and so on;
- **Firm level:** it comprises all issues related business strategy, technology strategy and roadmapping, marketing, among others;
- **Industry level:** here is the main source of novelty of this approach, which includes within the scope of product development issues such as:

industrial organization, vertical and horizontal differentiation, government policies, competitive analysis, cooperative development, outsourcing, network externalities, dominant design and so on.

Based in Deshmukh and Chikte (1980), Loch and Kavadias (2008) argue that PDP research until the early 1980's was basically focused on allocation of resources at the process level, which suits the second generation model. In the following twenty years, according to Loch and Kavadias (2008), PDP research was dominated by issues involving strategic management, particularly in developing different methodological approaches between short-term and long-term R&D efforts, which is exactly what third generation model is about.

As it can be inferred from all these review studies, there is a general consensus among scholars that since product development is being studied as a business process by executives and the academy, two main streams can be identified: one related to management and technology and the other related to business strategy and organization.

Besides, there is also a consensus in identifying a more recent trend to openness, collaboration and external awareness. From that we argue that open innovation is in the state-of-the-art of PDP research.

To support this argument, the next subsections analyze in detail some important aspects within PDP theory, namely: its characteristics (section 2.1.4), scope (section 2.1.5), goals (section 2.1.6) and structure (section 2.1.7). Afterwards there is a special section (2.1.8) dedicated to analyze the PDP in the aerospace industry, with examples (section 2.1.9). Finally, in section 2.1.10, one finds the conclusion of this part of the literature review, where this argument is once again presented and discussed.

2.1.4 PDP characteristics

Rozenfeld et al. (2006) list some of the characteristics that stand PDP out of other business processes within a company:

- High degree of uncertainties and risk in the results;

- Important decisions are taken in the beginning of the process, when uncertainties are even higher;
- It is difficult to change initial decisions;
- Basic activities follow a Design-Build-Test-Optimize iterative cycle;
- The requisites of the process come from many different sources, within the company or through its supply chain.

Therefore, product development processes are usually more complex to design, manage, measure and continuously improve, when compared to more routine business processes, such as manufacturing, for instance.

However, if well planned and executed, a product development strategy may result in many benefits to a firm, such as improved market position, return on R&D investments and improvement of the firm's reputation in society (CLARK et WHEELWRIGHT, 1993).

For this to occur, still according to Clark and Wheelwright (1993), the project's initial planning is a task of capital importance for the endeavor's success. The authors argue that while the ability to influence the outcome of the PDP decreases over time, normally the peaks of attention happen in the later phases of the process, when few or no changing is allowed in product itself without compromising huge amounts of time and money. This argument is summarized in the exhibit of Figure 5.

Source: CLARK et WHEELWRIGHT, 1993.

Figure 5 Timing and impact of management attention and influence

Therefore, product developers seek ways to enhance their capability of forecasting possible design problems that can occur during development, to which contribute methods such as the FMEA (Failure Mode and Effects Analysis) and, since the 1980's, the use of virtual simulation and rapid prototyping (CHOI et CHANG, 2004).

2.1.5 PDP scope

2.1.5.1 Multi-disciplinary character of the PDP

PDP scope encompasses or at least overlaps many other business processes, such as strategic planning, market analysis, sales, customer care, technical assistance, production, supply, distribution and R&D (KAMINSKI, 2000).

Rozenfeld et al. (2006) argues that in the last decades, the scope of the PDP inside a firm's operations is being enlarged: as Figure 6 illustrates, PDP is more and more penetrating, influencing and being influenced by its subjacent processes of manufacturing and strategic planning. In addition, more and more departments are being involved in PDP activities and decision making.

Source: adapted from ROZENFELD et al., 2006.

Figure 6 Growing scope of the PDP

Krishnan and Ulrich (2001) state that product development is a subject that encompasses studies in four different fields of knowledge, namely:

- Marketing;
- Organizations;
- Engineering design; and
- Operations management.

Each one of these “schools of thought” addresses the subject under a different perspective. Although distinctive one from the other, Krishnan and Ulrich (2001: p.12) argue that *“coordinated decision making requires an approach to research that is driven by the intrinsic interdependencies among decisions, rather than being driven by attempts to bridge the extant functional structure of the research community”*.

In other words, the PDP is better understood if one regards it under the optics of decision making and the interdependencies among the four perspectives previously mentioned (i.e., how a decision within marketing impacts operations, for instance), rather than attempting to create new functional structures. That is to say that PDP is intrinsically a multi-disciplinary subject, and it had better be regarded as such.

2.1.5.2 The decision perspective

Additionally, Krishnan and Ulrich (2001) observe that *“while how products are developed differs not only across firms but within the same firm over time, what is being decided seems to remain fairly consistent at a certain level of abstraction”* (KRISHNAN et ULRICH, 2001: p.3). In other words, what gives consistence in product development literature are not the particularities on the methods adopted, for they vary over time and space, but the problems they are addressed to solve.

With that in mind, the authors adopt the perspective that product development is *“a deliberate business process involving scores of (...) generic decisions”*, which they call *“the decision perspective”*. (KRISHNAN et ULRICH, 2001: p.3)

Under that perspective, they define the scope of PDP by researching the decisions that are addressed in the literature on the theme. Through an extensive literature review, they identify 34 decisions which are organized in eight groups, which in they turn are grouped into two broad categories: one concerned to the management of single projects, and the other more related to strategic issues, as the sketch of Figure 7 shows.

Source: adapted from KRISHNAN et ULRICH, 2001.

Figure 7 Product development decision groups

The first group of activities consists of more technical issues that aim the creation of new products and their introduction in the market. This group basically consists of **product design** activities, and subjacent issues related to it.

The second group is more focused on the strategic decisions in the PDP. Cooper et al. (2001), whose work is more focused in this segment of the PDP, call it **portfolio management** activities. It also encompasses project management issues, as defined and standardized by the PMI – Project Management Institute – and its PMBOK Project Management Book of Knowledge (PMI, 2000).

2.1.5.3 Product development vs. technology development

When contrasting the division of the PDP proposed in Figure 7 with the broad definition proposed by Adler (1989 apud BROWN et EISENHARDT, 1995)²⁵, one notices that Krishnan and Ulrich (2001) seems to adopt a narrower view of the PDP. As a matter of fact, in their literature review, they do not consider the process of research and technology development as part of the PDP. The single product development activities group considers only the incorporation of technologies into products and/or industrial processes, but not their development. Technology is considered an input to the process, instead.

Indeed, some scholars distinguish product development and technology development as two distinct processes (JUGEND, 2010). According to this view, the Technology Development Process (TDP) would strive for new knowledge, new technical capabilities or new technological platforms (IANSITI, 1995 apud JUGEND, 2010), while the PDP would be a posterior phase in which the output of the TDP is incorporated into products (goods and services) and/or industrial processes (PHAAL et al., 2004 apud JUGEND, 2010).

Clark and Wheelwright (1993) state that such a division is important *“to guide the firm in acquiring, developing and applying technology for competitive advantage”* (p.91). Managing a firm’s technology portfolio independently to product development itself help companies to better understand technological needs of the firm, to organize its technology portfolio and to better draw plans of action for fulfilling its needs by means of specific techniques designed for such, such as Technology Roadmapping (TRM) tools (PHAAL et al., 2001).

Although recognizing that this division brings out some advantages for the understanding of the process as a whole, this work adopts the broader concept of the PDP, by considering both technology and product development as parts of the PDP. The justification for such decision is that although the TDP may be distinguishable to

²⁵ Presented on page 50.

product development itself, it is nothing but a preliminary phase of the PDP. Usually, the reason why firms develop technology skills is to allow later incorporation in products and industrial processes. Another motivation, as selling the very result of the TDP process, is what open innovation literature call “inside-out” innovation. In this case, one can consider, as an early output from the product development funnel.

2.1.5.4 Product development vs. R&D

The Frascati Manual (OECD, 2002) is a document that was prepared and published by the Organization for Economic Co-operation and Development (OECD), whose first edition dates back to 1963. The manual is one of the most distinguished worldwide references for measuring R&D activities in industry. It aims to provide “*internationally accepted definitions of R&D and classifications*”, in order “*to serve as a standard for R&D surveys*”, and to “*contribute to intergovernmental discussions on ‘best practices’ for science and technology policies*” (OECD, 2002).

According to the manual:

“Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.” (OECD, 2002, n.63)

According to Frascati manual, R&D covers three activities: it begins with basic research²⁶ (initially “pure” and later “oriented”), which is followed by applied research²⁷, and ends up with experimental development²⁸ (OECD, 2002).

²⁶ “**Basic research** is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.” (OECD, 2002, n.64)

²⁷ “**Applied research** is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.” (OECD, 2002, n.64)

²⁸ “**Experimental development** is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.” (OECD, 2002, n.64)

Regarding basic and applied research, one can perceive the resemblance of these concepts to what has been defined as TDP in the previous section. One special attention, though, must be paid to the use of the term "experimental", always added by Frascati Manual (OECD, 2002) when referring to development.

It is worth to recall that this manual aims defining R&D in order to make it easier its measurement, as well as providing a theoretical basis to allow legislation from governments on the subject. Therefore, this manual has a particular interest in establishing limits to the R&D, especially in terms of expenditures. The authors of the manual wished to segregate those activities where there are technological risks and uncertainties ("experimental development") to those that, although an integrant part of the product development process, are routine and/or part of production start-up, which has very low or no technological risk associated to them.

In the introductory text of the sixth edition of the manual one finds:

*"Technological innovation activities are all of the scientific, technological, organizational, financial and commercial steps, including investments in new knowledge, which actually, or are intended to, lead to the implementation of technologically new or improved products and processes. **R&D is only one of these activities and may be carried out at different phases of the innovation process.** It may act not only as the original source of inventive ideas but also as a means of problem solving which can be called upon at any point up to implementation." (OECD, 2002, n. 21. Highlights are ours).*

It can be inferred from previous quotation that, on the one hand, R&D is within the scope of technological innovation, and therefore it is part of product development. On the other hand, there are other innovation activities that the manual does not consider as part of the R&D.

Regarding development itself, the very authors of the manual state the existence of two "types" of development: the "experimental" and a "pre-production" development, with a subtle border between them:

*"(...) it is difficult to define precisely the cut-off point between **experimental development** and **pre-production development**, such as producing user demonstration models and testing, and production that is applicable to all industrial situations. It would be necessary to establish a series of conventions or criteria by type of industry." (OECD, 2002, n.111)*

Still according to Frascati manual, this distinction is particularly difficult “for defense and large-scale civil industries such as aerospace” (OECD, 2002, n.110), which is the reason why the manual contains a special annex to provide additional guidance to the classification of R&D activities for these two industries²⁹.

Frascati manual adopts the rule originally laid down by the US National Science Foundation (NSF) for the exercise of judgment in difficult cases, which states that:

“(...) If the primary objective is to make further technical improvements on the product or process, then the work comes within the definition of R&D. If, on the other hand, the product, process or approach is substantially set and the primary objective is to develop markets, to do pre-production planning or to get a production or control system working smoothly, the work is no longer R&D.” (OECD, 2002, n.111)

The document from the so-called “Frascati family”³⁰ that deals with innovation in general is the Oslo Manual (OECD et EUROSTAT, 2005). In consonance with Frascati, Oslo Manual also includes “pre-productive” development as an innovation activity:

“Enterprises’ development of innovations may include a number of in-house activities that are not included in R&D as defined by the Frascati Manual. They include both the later phases of development activities and, importantly, the introduction of product and process innovations that are new to the firm, but not new to the market (or, in terms of the definition of R&D, do not increase the stock of knowledge or contain an appreciable element of novelty). Development and implementation activities for the adoption of new goods, services and processes may represent an important share of innovation activity.” (OECD et EUROSTAT, 2005, n.331. The highlights are ours)

One alternative to distinguish routine product development to innovative product development is to call upon the use of a neologism, such as Brazilian legislators did in federal law n. 11.196/2005, the so-called “lei do bem” (“goods law”), regulated by decree n. 5.798/2006. In these documents, the term

²⁹ Frascati manual’s Annex 10 is discussed in section 2.1.8.4 (p.87).

³⁰ “Frascati family” is the name given to a series of documents prepared and published by the OECD that includes manuals on R&D (Frascati Manual), innovation (Oslo Manual), human resources (Canberra Manual), technological balance of payments and patents as science and technology indicators. (OECD, 2002)

“technological innovation development” is used to refer to non-routine development. (BRASIL, 2005; 2006)

This discussion can be summarized in the illustration shown in Figure 8: there are four groups of activities that are related to research and development; however, Frascati manual, for its own reasons, excludes the so-called “pre-production development” out of the scope of R&D.

Figure 8 R&D activities

Although it is a pertinent and interesting topic for discussion, this distinction is not relevant to this work, once its objectives differ from those of the Frascati manual. This work intends to understand the whole cycle of innovative product development from the “idea” to the market, and not to distinguish the “scientific” to the “non-scientific” steps of the process.

In practice, if a company goes through experimental development, it will likely perform “pre-production” development if the experimental phase succeeds and, therefore, they are both to be performed by the company. “Pre-production” development performed without its respective previous “experimental” phase only makes sense when regarding non-innovative projects, which is out of the scope of this work.

Therefore, not contradicting Frascati’s definitions (OECD, 2002) but expanding them, when referring to R&D in this work, one shall understand this broad view of the R&D which includes all R&D activities defined by this manual plus pre-production development activities.

2.1.5.5 Conclusion: scope of the PDP in this work

Having in mind what has just been put, this work proposes that the scope of the PDP comprises:

- All the eight (8) decision groups defined by Krishnan and Ulrich (2001)³¹, and therefore is composed of both portfolio management and product design activities;
- Additionally, TDP activities are also part of the PDP, as a preliminary phase of product development;
- R&D activities are also part of the PDP, as defined in Frascati manual (OECD, 2002). Nevertheless, “pre-productive” development is also part of the PDP, and is identified with the definition of “Production ramp-up and launch”, according to Krishnan’s and Ulrich’s (2001). As a matter of fact, R&D is comprised of TDP and all activities related with product design, according to this classification, except for this particular group.

As a result, this work contributes in defining the scope of the PDP with a sketch that is presented in Figure 9.

Figure 9 Scope of the PDP

³¹ Shown in Figure 7 (p.61).

There are two main groups within the PDP.

One of them is determined by R&D activities plus production ramp-up and launch, which can be called the “technological” activities of the PDP. It departs from market needs (delivered by project strategy and planning) and comprises all steps from then until manufacturing is deployed and is operational.

The second group comprises portfolio management activities. One of them (project strategy and planning) acts as the gate between strategic planning in marketing and technology development within R&D. The other two activities consist of managerial activities related to the organization and management of development project portfolio of the firm.

This bipartite division reflects the organizational structure adopted by many companies that perform R&D. It is very common to see the PDP responsibility divided into at least two different departments: one or more R&D departments, responsible for technical issues of the PDP, and a business development department, responsible for the management of both the portfolio and project management (PMO). The names may vary from one company to another, but this division is usually present, especially in big companies, because it is logical and practical for the purposes of the PDP.

2.1.6 PDP goals

Having in mind the bipartite division proposed in the previous section, one identifies general goals for the PDP, as well as specific ones for each of the groups of activities within the PDP.

Rozenfeld et al. (2006), who also adopt the broad picture of the PDP, state that the general goals of product development are:

- Identification of market needs;
- Identification of technology alternatives;
- Product development accordingly to market’s expectations in terms of quality, lead-time and cost;

- Manufacturability of the products developed.

Clark and Wheelwright (1993) also identify four main purposes for what they call “development strategy”:

- Creating, defining and selecting a set of development projects that will provide superior products and processes;
- Integrating and coordinating functional tasks, technical tasks, and organizational units involved in developing activities over time;
- Managing development efforts so they converge to achieve business purposes as effectively and efficiently as possible;
- Creating and improving the capabilities needed to make development a competitive advantage over the long term.

Regarding now portfolio management activities, Cooper et al. (2001) identify four specific goals:

- Maximizing the value of the project portfolio;
- Seeking the right balance of projects;
- Ensuring that the portfolio is strategically aligned, and
- Engaging the right number of projects.

As for the technological part of the PDP (R&D and production ramp-up), their specific goals lie in the achievement of (ANDERL, 2008):

- Faster time to production and faster time to customer;
- Highest engineering and design quality;
- Cost efficiency;
- Fast and flexible reaction based on customer change requests and desires.

2.1.7 Structuring the PDP

2.1.7.1 PDP macro-phases

Rozenfeld et al. (2006) propose a division of the PDP in three macro-phases discussed next.

- **Pre-development**

This macro-phase aims to establish a connection between the strategic goals of the company with those of the teams in charge of product development. This macro-phase is closely related to what Cooper et al. (2001) refer to as portfolio management, as previously discussed³².

- **Development**

Once the company reaches a common understanding of what is to be developed, aligning technology development with business objectives in pre-development, in this second macro-phase the functional structures of the product are defined, in order to fulfill the needs of all stakeholders of the process: besides customers and end users, product development has also to take into consideration the boundaries drawn by suppliers, production, legislation, environment and society in general. Here is where the product design takes place.

Back in the 1960's, Asimow (1962) proposed a basic framework comprising of seven (07) stages, which is illustrated in Figure 10.

Although sequential, Kaminski (2000) proposes that these stages must be iteratively dealt with, according to the concept of the design spiral (EVANS, 1959), explained in section 2.1.7.3.

³² See page 61.

Source: adapted from Asimow (1962)

Figure 10 Product development stages

- **Post-development**

The central goals within this macro-phase is the systematic follow-up of the results of the new products in the market, in manufacturing, as well as to study prospective technologies that could be incorporated to the products in future incremental projects.

Also in this phase, the management of all product planning done in the development macro-phase must be performed, e.g., the last four stages identified by within Asimow's (1962) framework, previously shown in Figure 10.

Different methods and frameworks emerged from this simple straight-forward tripartite division. Through them, companies and experts are able to translate product development phases into business process maps (BPM), often represented by procedure flowcharts. Once translated into flowcharts, precise indicators and control variables can be established to allow effective management through traditional project management tools (HAMMER, 2010).

2.1.7.2 Linear models

The most common framework structure for PDP follows a linear or sequential pattern. A linear or sequential model is divided into activities disposed in a logical order from conception to accomplishment. Development projects must go through all applicable stages before reaching the market.

One of the most well-known linear framework models in the literature is the “product development funnel” proposed by Clark and Wheelwright (1993) reproduced from the original in Figure 11.

The “development funnel” is a linear straight-forward process which suits well to describe the *modus operandi* of the R&D performed in companies, despite of the limitations of the model.

Source: Clark et Wheelwright, 1993

Figure 11 The product development funnel

The use of the geometric shape of a funnel to represent product development is meaningful. It emphasizes the idea that firms should be very permissive in the inlet of the process, enabling creativity to provide a great number of “project ideas” (represented in Figure 11 by the white squares). Within the funnel, these “ideas” shall be progressively filtered and recombined, being narrowed down until they take the form of development projects (gray squares), which will, in their turn, result into goods and/or services that are shipped to the market. The outlet of the funnel is narrow, to show that less products are launched in relation to projects that are evaluated. All development is located in the straight part of the funnel, what is to say

that once a project reaches the development phase, there is no more recombination and/or selection. If a project is interrupted within this phase, it is often an indicator of a planning problem in the previous stages that were not able to identify this false positive before the departure of its development.

The development funnel suggests that projects have to be somehow evaluated and discarded if they do not prove to be economically and/or technically feasible or aligned with corporate business goals. In this sense, Cooper (1986) developed the stage-gate model, whose basic idea behind is to see the PDP as a linear bipartite graph, which consists of two kinds of activities: “stages” and “gates”. In order to pass from one stage to the next, the project must necessarily go through a gate, where the decision of continuing funding the project or not is typically decided by a manager or a steering committee.

The stage-gate model shown in Figure 12 is reproduced from the original.

Source: COOPER, 1986.

Figure 12 The stage-gate process model

The stage-gate model contributed to highlight the importance and to show how to implement a systematic discipline of project evaluation, integrated with decision making in strategic planning (ROZENFELD et al., 2006).

The literature on Product Development suggests many examples of companies that had designed their R&D as linear processes as funnel and the stage-gate models (CLARK et WHEELWRIGHT, 1995; COOPER et al., 2001; MANKIN, 2004; LOCH et

KAVADIAS, 2008). The product development process at Xerox's PARC (Palo Alto Research Center) reproduced in Figure 13, is a good example of that.

Source: Chesbrough, 2003a

Figure 13 XEROX's PARC development funnel in 1996

Consistent to Clark's and Wheelwright's (1993) model, XEROX's funnel has a great inlet of "opportunities", i.e. of "ideas", which are analyzed by "innovation councils". These councils, consistently to Cooper's (1986) model, play the role of "gates" as evaluation rounds, represented in Figure 13 by vertical dashed lines. On the one hand, these "gates" progressively discard "ideas" that are less viable or less interesting to the firm's strategy and, on the other hand, they develop the business concept for the "ideas" that are selected, as they go through the "stages" of the funnel. At the end of the process, remaining "ideas" have been specified and conceived in the shape of product development projects, which are then incubated in one of the business units of the company, for internal development, or licensed/spun out if it is not related to the firm's business core (CHESBROUGH, 2003a).

As it happens to all models, which are nothing but approximate representations of reality, linear models incur limitations. The two major limitations are:

- Linear models do not show knowledge feedbacks that often occur in product development. It just show the straight-forward path that product development projects go through from conception to the release in the market;

- Knowledge about the market and/or product characteristics may not be available in the early stages of planning, prejudicing decision making (MANKIN, 2004);
- As Chesbrough (2003a) points out, linear models were designed to avoid false positives, i.e., to restrain bad projects from going to the market. However, they do not take false negatives into consideration, i.e., that projects that could have success in a scenario different from that of the analysis, and may be cut out of funds inadvertently.

2.1.7.3 Iterative models

In order to compensate the limitations of linear models, some scholars propose an iterative approach to product development (EVANS, 1959; KAMINSKI, 2000; MANKIN, 2004). In reality, what happens is a combination of both methods.

Source: adapted from Evans, 1959

Figure 14 A design spiral for the development of a ship

Yet in the late 1950's, Evans (1959) proposed an iterative procedure suitable for complex design projects in naval engineering, the so-called **design spiral** shown in Figure 14. The idea behind it is that the starting point for a product design sits on

rough estimates of the main variables and/or features of the final product. Later on, they should be refined and re-entered into the solution as the design is carried on, until all performance characteristics and features fall into desired standards.

Very often, PDP models combine linear and iterative steps. For instance, Mankin (2004) proposes an iterative process consisting on controlled releases of the product in order to involve customer feedback not only for product improvement, but also for product definition and specification. However, the author proposes the use of a linear stage-gate decision framework within each loop of the spiral.

Mankin (2004) argues that, for emergent markets where customer needs are often not clear, faulty assumptions that could be made within a straight-forward decision making process within a “gate” could kill a good market opportunity. According to the author, the use of iterative loops would be a way to test alternatives, and to let customers decide the features or the very use of the product.), Mankin’s (2004) process would be then an alternative to avoid false negatives in product development.

Figure 15 illustrates this proposal, also represented by a spiral.

Source: Mankin, 2004

Figure 15 Iterative product development process

It is relevant noticing that Mankin's (2004) model takes into consideration external collaboration (mostly from lead users) as a relevant part of the process, which shows a tendency towards openness of the PDP.

2.1.7.4 Overview of PDP tools

Using different combinations of linear and iterative methods, many firms, consultants and scholars have developed specific tools suitable for specific needs and/or environments for product development. Nowadays, there are many hundreds of different PDP management tools. Liyanage et al. (1999) made reference to more than 200 by the late 1990's.

The tools may differ from the coverage of the PDP: some are more directed to one macro-phase³³ of the PDP, others are suitable for the whole product lifecycle (PLC). The approach may differ depending upon who is the "target audience" of the tool: some are more suitable for hardware engineers or software design, others for business strategy professionals, who might have no technological background at all.

For exemplification purposes, some of the most widespread tools adopted by technology firms in the market are presented and analyzed next.

1) Stage-gate method

This method, described in section 2.1.7.2, is essentially a linear model useful for screening and selection of projects within a product portfolio. It became one of the most used by firms all around the world after Cooper presented it in 1986 (MANKIN, 2004; CHESBROUGH, 2003a).

It covers all three macro-phases of the PDP, with greater emphasis for the "pre-development" macro-phase and is directed to managers involved with product portfolio and business development strategy.

³³ See section 2.1.7.1 in p. 69.

2) Technology Roadmapping (TRM)

TRM is a technique that can be either applied within a company, for establishing short-term and long-term needs for technology development, or in the industry level, to help stakeholders within an industry to determine technology needs for the industry itself to evolve (GARCIA et BRAY, 1997).

The final document delivered by the TRM process is the technology roadmap, which:

"(...) identifies (for a set of product needs) the critical system requirements, the product and process performance targets, and the technology alternatives and milestones for meeting those targets. In effect, a technology roadmap identifies alternate technology 'roads' for meeting certain performance objectives." (GARCIA et BRAY, 1997)

TRM process is normally divided in three phases, disposed in linear sequence (PHAAL et al., 2001), as follows.

- **Preliminary phase** – responsible for defining the scope and boundaries of the TRM project by satisfying essential conditions and providing leadership/sponsorship for the project;
- **Development phase** – consists of seven steps that aim identifying the product and establishing technology alternatives and their timelines;
- **Follow-up phase** – final phase where the roadmap generated in the previous phase is critiqued, validated and accepted (or not) by the group that will be involved in the implementation of the TRM. Additionally, periodical reviews are recommended in order to generate eventual updates in the roadmap, due to changes in the technology scenario.

As it can be seen, it is a tool directed to the “pre-development” macro-phase of the PDP. As for the stage-gate method, this tool is more useful for business development strategy personal, for it determines the strategy of technological development of the company in order to reach specific strategic goals. However, it requires the involvement of technological departments due to its technological-oriented approach.

3) V-Model

The V-Model (also known as the systems engineering “V”) is a methodology that is often employed in Systems Engineering³⁴. It consists of a linear model that shows the whole lifecycle of an “engineering system”³⁵ from conception to abandonment (retirement). The steps are disposed in a V-shaped diagram, reproduced in Figure 16, that shows how a system is initially decomposed and defined (as it goes down the “V”), for later implementation (at the vertex of the “V”) and posterior testing, validation and integration, as it goes up the “V” (USDT, 2007).

Source: USDT, 2007

Figure 16 V-model for systems engineering

Integration follows the inverse order of specification: while specification goes from general to specific, integration and testing goes from specific to general (USDT, 2007). The model also specifies that documentation is required to formalize the

³⁴ “Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem.” (INCOSE apud USDT, 2007)

³⁵ An engineering system is any engineering integrated solution. It can either be a product, a process or any internal system that involves the application of technology and systematic engineering approach to be designed/accomplished.

results of a specific stage, before proceeding to the next (USDT, 2007). The model covers all three macro-phases of the PDP, but with higher emphasis in the second phase (development). It is then oriented to technological personal of the company.

4) Want-find-get-manage® (WFGM) approach

Slowinski (2005) proposed the WFGM approach, which is used by companies such as Unilever³⁶ to integrate external technology scouting to the PDP.

It describes a fully-integrated approach from the definition of technological needs (“want”), search for internal and external alternatives (“find”), the acquisition and incorporation of the solution (“get”) and the organization (“manage”) of its integration into products and services.

This product development approach is explicitly an open innovation tool (SLOWINSKI, 2005) that intends to integrate its concepts to the PDP. It covers all three macro-phases of the PDP, with greater emphasis for the “pre-development” macro-phase and the first steps of the development phase, and is directed mostly to managers involved with product portfolio and business development strategy.

2.1.8 *PDP in the aerospace industry*

This section presents an overview of PDP frameworks, metrics, tools and methodologies designed for aerospace and defense, in order to show particularities of product development within the aerospace industry.

2.1.8.1 *Technology Readiness Level (TRL)*

According to Mankins’ (1995) white paper:

“Technology Readiness Levels (TRLs) are a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology.” (MANKINS, 1995)

³⁶ Hague, 2010.

This system was developed by the National Aeronautics and Space Administration (NASA) in the 1980's (SADIN et al., 1988), and later on adopted by other U.S. government agencies, such as the Department of Defense (USDOD, 2011), with some minor adaptations of the terms.

TRL classification system serves as a support for project portfolio management, to better distribute resources according to the level of maturity of each technology. Many companies in the aerospace industry use this system to classify internal R&D projects and, likewise, to better manage their project portfolios. Embraer, for instance, uses TRL to internally distribute R&D projects among its departments and to organize R&D budget accordingly³⁷.

TRL scale goes from 1 to 9. A lower TRL means that the technology is less mature, i.e., is still under investigation in more basic levels of research. Higher TRL means that the technology is closer to real application in products, services or processes. One way to see TRL is that the higher the level, the closer the technology is from the outlet of the development funnel presented in Figure 11³⁸.

Table 2 Comparison between TRL and R&D classification according to the Frascati manual

TRL	Maturity level	R&D stage (Frascati manual)
1	Basic principles observed and reported	Basic research
2	Technology concept and/or application formulated	Basic to applied research
3	Analytical and experimental critical function and/or characteristic proof-of-concept	Applied research
4	Component and/or breadboard validation in laboratory environment	
5	Component and/or breadboard validation in relevant environment	Applied research to experimental development

³⁷ Verbal information given by an Embraer employee.

³⁸ See p. 64.

TRL	Maturity level	R&D stage (Frascati manual)
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)	Experimental development
7	System prototype demonstration in a space environment	
8	Actual system completed and “flight qualified” through test and demonstration (ground or space)	Experimental to “pre-productive” development
9	Actual system “flight proven” through successful mission operations	Maintenance and Operations (M&O)

Source: the author, using data from Mankins (1995).

Table 2 is an attempt of this text to establish a parallel between the maturity levels defined by Mankins (1995) and the R&D phases according to the Frascati manual (OECD, 2002), discussed in section 2.1.5.4 (p.69).

In short, the importance behind the adoption of TRL systems is to support strategic decisions within portfolio management such as project prioritization and funding.

2.1.8.2 Pre-competitive R&D

Pre-competitive R&D classification is an alternative to the TRL classification, which is connected not to the technology maturity level itself, but to the commercial stage of a project.

Pre-competitive R&D projects are not connected to any particular product or process, but to general technologies that can be later on used in product development projects.

Embraer uses this classification in order to differentiate internal projects within the civil aircraft development process, according to Resende (2008). As Figure 17 shows, pre-competitive R&D is not accounted as part of the aircraft development. If

it were, the average time to develop a civil aircraft would go from 6 years to about 20 years (RESENDE, 2008).

Source: adapted from Resende, 2008.

Figure 17 Embraer's civil aircraft R&D Model

Besides, what one can also infer, when comparing the information provided in Table 2 with Figure 17, is that precompetitive projects encompass TRL from 1 to 4, and in some cases TRL 5, that is, basic and applied research, or some incipient experimental development, at most.

This is exactly what happens in the Consortium for Research and Innovation in Aerospace in Quebec (CRIAQ), which is discussed in the next section.

In short, this classification has a close relation to the TRL levels presented in the previous section; however the focus is on the commercialization of technologies, not the maturity level from the technological point of view.

2.1.8.3 Research consortia

Research consortia are a new form of organization in which governments can actively collaborate towards innovation, by promoting a favorable environment for the discussion, establishment and execution of R&D collaborative projects between companies and universities. In the worldwide aerospace industry, there are some such consortia, namely: the previously mentioned CRIAQ, in Quebec (Canada), the Ohio Aerospace Institute and the Arizona Aerospace and Defense Collaboratory, the last two located in the USA (AÉROMONTRÉAL, 2012b). In order to explain the dynamics behind these consortia, we perform here a brief explanation of CRIAQ, which has been the subject of a previous paper of ours (ARMELLINI et al., 2011a).

CRIAQ is a non-for-profit consortium that comprises aerospace companies, universities, research laboratories and governmental agents from the Province of Quebec, in Canada, whose goal is *“to promote and perform collaborative pre-competitive industry research projects primarily at universities”* (FORTIN, 2010: p.1). By “precompetitive”, one shall understand research projects that comprises TRL from 1 to 5, as the consortium webpage³⁹ asserts.

The idea behind CRIAQ’s focus on pre-competitive technologies is that in this field companies are eager to collaborate with others (even competitors) in order to reduce innovation costs, and are not too worried about secrecy issues. Besides, in this kind of research project universities and other science and technology institutes (STI) have better conditions to collaborate with industry players. Linking to the discussion of the previous subsection (2.1.8.2), one realizes, in Figure 17, that Embraer also consider pre-competitive projects the appropriate locus for collaboration with universities, research institutes and industry players.

The consortium was launched in 2001, and since its beginning counted with the support and participation of the main players of the local aerospace industry, in all

³⁹ http://www.criq.aero/Projets_de_recherche. Retrieved: 2012/11/23.

three vertices of the triple helix, that is, from the industry, the government and STI⁴⁰. At the end of 2010 CRIAQ had 58 active projects (either in progress or in the preparation phase) and 21 closed projects, distributed in four project rounds and international agreements, not to mention the 48 potential projects that resulted from CRIAQ's 5th research forum that took place in 2010 (CRIAQ, 2010). The rising number of members and projects are undoubtedly indicators of the acceptance of the model from both companies and STIs.

Bazergui (2007) proposes a way to understand CRIAQ's positioning through the "innovation triangle", reproduced in Figure 18.

Fonte: adapted from Bazergui (2007)

Figure 18 CRIAQ positioning in the "innovation triangle"

The idea behind this triangle is to map how different agents are placed in relation to the trinomial "knowledge-technology-product", that is, the intensity of the participation of a particular agent in the generation of each one of these factors. For instance, firms are more likely to be closer to the "product" vertex, while universities are closer to the "knowledge" vertex and research centers strive to place themselves equidistantly from all three vertices. As Figure 18 illustrates, CRIAQ aims at positioning itself exactly within the common field in which companies, universities and research centers act (FORTIN, 2010).

⁴⁰ The triple helix theory is presented in section 2.3

The ordinary mechanism for the generation of research projects is a workshop called “research forum”, organized by the consortium board every two years (FORTIN, 2010). All local companies in the aerospace value chain are welcome to join the forum, regardless of whether they already are CRIAQ members or not. All participants are encouraged to share their technology needs, which are discussed and analyzed. From the discussion, project opportunities are raised and formulated for later discussion in specific committees formed by parties interested in the project. For the opportunities in which there is viability, relevance and interest, research projects are formulated. All research projects formulated within the forum are included in its executive summary. The next steps for the project launch are the submission to the NSERC (Natural Sciences and Engineering Research Council of Canada) and, upon approval of the project by the latter, the signature of a cooperation agreement by all participating entities (FORTIN, 2010).

For the funding of projects of the consortium, participating companies have committed themselves to cover 25% of all research expenses, the remaining 75% to be financed by Quebec governmental funds. The collaboration structure for financing projects follows the scheme illustrated in Figure 19. According to this scheme, one observes that CRIAQ acts as the intermediary among all agents in the funding process.

Source: adapted from Fortin (2010)

Figure 19 Project financing

All funding originated from Provincial sources, as well as the counterpart provided by participating companies is paid to the consortium, which in turn distributes it to the project teams. Besides those resources, the universities generally count on other grants, including those from federal sources, which are applicable to consortium research projects. Projects are headed by university staff, which may include professors, post-doc researchers, graduate and undergraduate students (BAZERGUI, 2007).

It's worth mentioning that in order to be part of the Consortium, a project requires at least two interested companies and two universities involved (BAZERGUI, 2007). This rule's purpose is to guarantee that CRIAQ's projects are of more general interest to the industrial sector, and do not aim solely at solving specific problems of a particular company (FORTIN, 2010).

Besides funding the project, the participating firms' role is to follow up projects in which they are involved, by taking part into follow-up and technical meetings and, in some cases, by transferring technologies and proprietary know-how required to the executive teams, which are essentially formed by academic staff (FORTIN, 2010).

This is, in brief, the *modus operandi* of the Consortium for research and innovation in aerospace in Quebec, which is the research consortium studied within the scope of this research project.

2.1.8.4 Classification of large R&D projects in defense and aerospace industries

It is worth mentioning that Frascati manual (OECD, 2002) contains an annex, more specifically the Annex 10 (pp. 226-37) which provides supplementary guidance on the classification of large R&D projects in defense and aerospace industries.

As the introduction of the text clarifies, the purpose of the annex is to aid governments and companies "*on differentiating between the concept of R&D as defined by the manual and related activities that do not count as R&D*" (OECD, 2002: p. 226).

According to the OECD (2002), what happens, in practice, is that usually the expenditure on R&D reported by defense ministries is higher than the amount claimed as received from government for R&D by the defense industry. There would be numerous causes behind this distortion, according to the OECD (2002), but one of them would be due to misinterpretation of OECD's definitions, led by differences in terminology adopted by these two industries.

Therefore, in this annex, the OECD (2002) compares the categories and terminology used by aerospace and defense industries in the United Kingdom, the United States and France, and compares them to Frascati manual's own terminology. This comparison can be summarized in Table 3.

Table 3 Current classification of French, UK and US terminology in the Frascati manual

Frascati Manual	United Kingdom	United States	France
RESEARCH AND DEVELOPMENT			
Basic research	Basic research	Basic research	Basic research
			Upstream studies
			* (see also below “Research work” and “Research”)
Applied research	Strategic applied research	Applied research	Applied research
	Specific applied research		Demonstration project
			Demonstration model
			Exploratory development
			Development
			General research
			Preliminary project
			Proving project
			Proving model
			Research work
			Systems-oriented research
Experimental development	Experimental development	Advanced technology development	Development
		Demonstration and validation	Defined development
		Engineering and manufacturing development	Prototype
		Management support	Pilot plant
		Operational systems development	

Frascati Manual	United Kingdom	United States	France
NON-R&D ACTIVITIES			
Pre-production development	Scientific and technical innovation		S&T services
	Other related scientific and technical activities		S&T training and development

Source: adapted from OECD, 2002.

More important than regarding the terminologies themselves, the importance of this analysis from the OECD (2002) is to show that however diverse and complex, there are similarities in the way products are developed in different countries and contexts, and it is possible to draw a parallel among them and Frascati's general R&D framework.

2.1.9 Examples of PDP in the aerospace industry

The following list of topics is not intended to exhaust the subject, but likewise section 2.1.7.4, serves just to exemplify and present some models adopted by firms in the sector.

2.1.9.1 Embraer's risk-sharing partnership model

Embraer is the largest aerospace company in Brazil and one of the global leaders in regional jets market. In the field of product development management, the company is internationally known for its so-called risk-sharing partnership (RSP) model that the company developed for the design of aircrafts.

Basically, the model involves a strong involvement of equipment suppliers in the development that goes beyond the standard procedure of specification, order and development-on-demand. Suppliers are called to be partners of the development, which includes sharing risks, responsibilities and results (HBS, 2000a).

As asserted in a previous quote (HBS, 2000a: pp.10-11), through this model Embraer aimed at giving responsibility to risk-sharing partners to supply entire systems, so that the company could develop closer relationship with a smaller number of suppliers (HBS, 2000a).

According to Resende (2008), the model was first applied for the development of the development of the ERJ-145 family of aircrafts in the 1990's. For this aircraft, Embraer counts with four (4) risk-sharing partners and 350 suppliers. Through this practice, Embraer was able to develop an entire aircraft within the outstanding lead-time of four years and reduced development costs (FIGUEIREDO et al., 2008).

The RSP model was so successful, in a win-win relationship, that in the development projects that followed this one the numbers of partners has increased: for the EMBRAER 170/190 family, the company counts with 16 partners and a total of 22 suppliers (RESENDE, 2008). Another evidence of the success of the model (and benefit to the partners) is that the bids from the suppliers interested in become a risk-sharing partner were higher and more aggressive in comparison with the ERJ-145 family (HBS, 2000a).

The main benefit of this model⁴¹, from the engineering design perspective, is that through this practice product development managers get rid of the trap of common direct contract for development. Specification changes is an inescapable reality, due to the design spiral (EVANS, 1959) model previously mentioned⁴². Every time specifications have to change in an ongoing project, the company had to re-negotiate with all suppliers, bearing all additional costs from this operation, which is passed on to the aircraft final cost. On the other hand, in the RSP model, suppliers are deeply involved in the design, and committed with the project outcome as much as Embraer, once the partnership involves a participative sharing in the project, with rights to future sales income of products (FIGUEIREDO et al., 2008).

The model also demanded management modifications in the PDP. Figure 20 shows the general stages for establishing a development project with RSP.

⁴¹ According to a verbal source from Embraer.

⁴² See section 2.1.7.3 in page 67.

Sources: Adapted from HBS (2000a) and Figueiredo et al. (2008).

Figure 20 Product development phases within Embraer's risk-sharing partnership model

The main difference between this process and usual development frameworks, such as Asimow's (1962)⁴³, is the fact that suppliers are contacted in early stages of development, more precisely, something in-between late pre-development and early development, according to the tripartite division proposed by Rosenfeld et al. (2006), discussed in section 2.1.7.1. Partners are contacted after general product definition is finished. After a process of qualification and selection of partners, all partners are called to participate at a phase called Joint Definition Phase (JDP), highlighted in red in Figure 20.

During the JDP, all partners are gathered together in the headquarters of Embraer, in São José dos Campos for basic design activities, such as system and interface specifications and procurement (HBS, 2000a; FIGUEIREDO et al., 2008). These meetings make broad use of Information Technology tools, which includes a Virtual Reality Center that helps to integrate various aircraft systems under specification (FIGUEIREDO et al., 2008). After the JDP is finished, all development activities are performed in-house by the respective partners, under the supervision of

⁴³ Presented in Figure 10, in page 64.

Embraer engineering staff, which is responsible for the project coordination and system integration. Periodical meetings are needed, though, which guarantees a close relationship between Embraer engineers and their partners.

Another aspect worthy of note is that Embraer encourages its partners to take part in client services activities (FIGUEIREDO et al., 2008). The company takes advantage of the international presence of its partners to leverage its post-sales infrastructure.

The RSP model has pros, but it also has potential cons. The main pros, previously mentioned, are the reduction of development lead-time and costs, which allowed Embraer to reach the leadership position in the regional jets market (HBS, 2000a), the sharing of risks and costs that are inherent to product development and the use of RSP infrastructure to customer services.

On the other hand, some negative points can be also pointed. One of them, noticed by Figueiredo et al. (2008) is that risk-sharing partners are potentially indirect competitors of Embraer in areas where they acquired know-how, or may use acquired knowledge to collaborate with direct competitors.

Another negative point, stressed by Niosi et Zhegu (2005), is that by the RSP model, the knowledge is spread among the partners and, due to their global presence, reduces the importance of local knowledge flows and prevents the Brazilian cluster from being self-sufficient. Figure 21 illustrate this point by showing the division of responsibilities for the case of the ERJ-170/190 program. Analyzing Embraer's supply chain, one realizes that 95% of its suppliers are located abroad: international suppliers are responsible for over 60% of aircraft final cost (CASSIOLATO et al. 2002, apud NIOSI et ZHEGU, 2005).

Source: Figueiredo et al. (2008).

Figure 21 Risk-sharing partnership for the ERJ-170/190 program

2.1.9.2 Boeing's Global Enterprise Technology System (GETS)

Boeing is undoubtedly one of the main aeronautic companies in the world. Founded in 1916, Boeing is a North-American company with headquarters in Chicago/IL, manufacturing plants in Washington/DC and Seattle/WC and global presence that includes local offices in 15 other countries⁴⁴.

In order to structure its worldwide spread R&D, Boeing developed an approach for managing innovation that is called Global Enterprise Technology System (GETS). GETS is a strategically-driven approach that combines information and insights from several departments and plants into a unique technology system (LIND, 2006).

GETS process is a model composed of (04) stages, also known as "the four D's", namely: (1) discover, (2) decide, (3) develop and (4) deploy. Although there is a logical cause-effect sequence among these stages, they "operate continuously at various

⁴⁴ Information retrieved from Boeing's website (www.boeing.com) on 2012/11/26.

levels" (LIND, 2006: p.39). Each stage emphasizes a different type of logical thinking, as shown in Figure 22.

Source: adapted from Lind, 2006.

Figure 22 Boeing's Global Enterprise Technology System (GETS) approach

Each stage encompasses a series of PDP tools already discussed in this text, as follows.

- 1) "Discovery" activities involve highly creative, exploratory and non-standardized thinking, and are usually associated with experimentation, typical of research projects. Therefore, within this stage strategic planning methods are often used (LIND, 2006), such as TRM tools (PHAAL et al., 2001).
- 2) "Decision-making" processes involve critical analysis of discoveries in order to build a strategically-aligned R&D portfolio that balances near-term value creation with long-term opportunity exploration (LIND, 2006). Tools for selection and prioritization of projects, such as Cooper's stage-gate method (COOPER, 1986) or portfolio management tools (COOPER et al., 2001) are the most suitable for this stage.
- 3) "Development" processes comprise linear straight-forward activities that transform specifications into technologies, products, and processes. Project

management best practices from the PMBOK (PMI, 2000) and engineering design methods (ASIMOW, 1962; KAMINSKI, 2000; ROZENFELD et al., 2006) are the central theme within this stage.

- 4) “Deployment” involves running the operation and making sure that innovations developed are delivered and adds value to Boeing’s customers. Quality assurance tools and continuous improvement techniques are in order for this stage.

In addition, besides strategically-driven, GETS is also based on a systems engineering logic. That is to say that every step involves either the establishment of requirements, during the definition phase (“discover” and “decide”) or test of requirements, during the integration phase (“develop” and “deploy”). To illustrate that, Lind (2006) maps “the four-D’s” onto a systems engineering “V”, reproduced in Figure 23.

Source: Lind, 2006

Figure 23 Systems Engineering “V” applied to Boeing’s GETS approach

Regarding collaborative aspects, Boeing’s model does not have at first sight anything exceptional concerning openness, but it is externally aware. Actually,

according to Lind (2006), one of the key objectives in GETS approach is to be *“highly collaborative, drawing many types of participants together in the innovation process”* (p.37) and one of the key challenges in this effort include *“how to appropriately leverage external sources of technological innovation”* (p.37).

2.1.9.3 Space R&D standard ECSS-M-ST-10C

The European Cooperation for Space Standardization (ECSS) has developed a standard (ECSS, 2009) for space design project that present an interesting framework for product development. Although this work is focused on the Brazilian and Canadian aerospace industry, this standard is pertinent since INPE⁴⁵, part of the Brazilian space Agency, adopts a design methodology based on this standard and, consequently, all its suppliers are also impelled to adopt it as well (ARMELLINI, 2006; PEREIRA, 2009; YASSUDA et PERONDI, 2010).

The ECSS-M-ST-10C standard gathers together a number of known project management good practices, such as the WBS (Work Breakdown Structure) organization, product tree, and, what is most remarkable in this standard, project reviews: there is a total of 13 formal project reviews throughout the process (ECSS, 2009).

The framework resembles what have been previously presented as Cooper's (1986) “stage-gate” model. However, since the stress of the standard is in the engineering design process, most project reviews that serve as “gates” are mainly technical reviews, others are management milestones reviews. That is to say, marketing and financial analyses are relegated to the background, when not neglected. That is reasonable, since space design projects usually do not aim the market, but fulfilling technical specifications that serve a mission's purpose. The very space agency that specifies the product is the user.

According to ECSS (2009), the space product lifecycle is composed of seven phases, as follows.

⁴⁵ National Institute of Spatial Research in the acronym in Portuguese.

- **Phase 0 - Mission analysis/needs identification**

In this preliminary phase, the very necessity of the project is inquired, the system requirements are identified and the overall organization of the project is established.

- **Phase A - Feasibility**

This phase's goal is to prove the feasibility of the concepts and of the mission as a whole.

- **Phase B - Preliminary Definition**

Using Asimow's (1962) framework previously presented⁴⁶, the basic design is accomplished in this phase.

- **Phase C - Detailed Definition**

This phase correspond to what Asimow (1962) denominates "detailed design". At the end of this phase, all subsystems have a first complete model, although not tested or qualified. These are called "**engineering models**".

Virtual prototyping and testing may be required in this phase, according to the project philosophy.

- **Phase D - Qualification and Production**

In this phase, all engineering models are tested individually and, once qualified they are integrated in the so-called "**qualification model**". This model is then submitted to exhaustive testing and validation, in order to verify its performance under different environmental and stress conditions. Modifications in this model are performed when design problems are identified in the course of the validation.

This phase is essentially comprised of laboratory physical ground testing. Virtual tests may be also required, according to the project philosophy.

Once qualified, the project moves on to process design, when all arrangements for production and delivery of the product are organized.

⁴⁶ See section 2.1.7.1 on page 69.

The “**flight model**” (the actual system that shall be launched) and the process for its production is the final result of this phase.

- **Phase E –Utilization**

This phase encompasses launching, on-orbit operations and ground support activities management. In this phase, the disposal plan is also finalized.

- **Phase F – Disposal**

It consists of the implementation of the disposal plan, once product end-of-life is achieved.

Each of these project phases includes end milestones in the form of project reviews, listed in Table 4. There may be more than one review at the end of a phase. Design reviews take place at the end of the phase, and are used to judge whether the project is ready to move on to the next phase. If problems are found in the review board, they have to be fixed and a new board is scheduled to a new round of revisions. If the system in revision is outsourced, the board is composed by members of the upper level customers (up to the final user).

Table 4 Design reviews in the ECSS-M-ST-10C standard

Project review	Acronym	Phase	Description
Mission definition review	MDR	0	Verifies whether the mission is clearly defined in its objectives and requirements, and evaluates aspect related to the organization of the project.
Preliminary requirements review	PRR	A	Aims at accepting the overall project planning (schedules, outsourcing strategies etc) and evaluates the technical feasibility of the overall system’s concept.
System requirements review	SRR	B	Evaluates the requirements for each system that composes the products, as well as the interface requirements among them.
Preliminary design review	PDR	B	Evaluates the basic design as a whole, by means of analytical procedures (and/or virtual simulation).
Critical design review	CDR	C	Evaluates the executive design as a whole, by means of analytical procedures (and/or virtual simulation).

Project review	Acronym	Phase	Description
Qualification review	QR	D	Evaluates the qualification model, by means of laboratory physical tests.
Acceptance review	AR	D	Evaluates whether the flight model is free of manufacturing problems, prior to delivery.
Operational readiness review	ORR	D	Evaluates whether the flight model is fully operational and compability to flight systems, prior to delivery.
Flight readiness review	FRR	E	Evaluates whether the flight model is fully operational, prior to launch.
Launch readiness review	LRR	E	Re-evaluates whether the flight model is fully operational, immediately prior to launch.
Commissioning result review	CRR	E	Analysis of system performance, held after completion of the on-orbit commissioning activities.
End-of-life review	ELR	E	Analysis of mission, held at the completion of the mission
Mission close-out review	MCR	F	Analysis of disposal procedures, held after system's disposal.

Sources: adapted from ECSS (2009) and from Yassuda and Perondi (2010)

Figure 24 is a contribution of this work to the theme, which combines ECSS standard definitions with Cooper's (1986) stage-gate model.

An interesting remark on project reviews is that the first four reviews (from MDR to PDR) are "top-down", that is, they are originated from the top-level customer to the lower-level supplier. The other revisions (from CDR to MDR), the sense is opposite ("bottom-up"): it is originated from the lower level supplier to the higher level customer (ECSS, 2009).

That is to say that the first reviews aim at verifying and accepting the very planning and conceptualization of the project, while the others are meant to verify whether the design process is carried out accordingly. Thus, one can assert that this methodology is designed for R&D outsourcing, mainly after the PDR. This is what happens in practice, at least for INPE's reality, since the agency outsources the development of most subsystems of the products they develop, launch and operate (PEREIRA, 2009).

Figure 24 Stage-gate model for the space project framework

2.1.10 Conclusion: PDP and collaboration

As a conclusion for this section, one realizes that collaboration is a tendency in PDP research identified by many scholars in the field.

First of all, Brown and Eisenhardt (1995) identify the involvement of customers and suppliers as key factors for the success in product development.

Besides, recapitulating the classification of PDP research provided by Liyanage et al. (1999), fourth generation models for R&D management must be concerned with network linkages and (internal and external) knowledge exploration, and be very active in establishing collaboration links for higher efficiency in product development.

Moreover, Kirshman and Ulrich (2001) also indentify *“an excellent opportunity for research in the area of product development supply chains that enable development teams to decide on outsourcing product development”*.

In addition, recent methodologies incorporate collaboration and other external sourcing tools for product development (MANKIN, 2004; SLOWINSKI, 2005; LOCH et KAVADIAS, 2008).

In aerospace product development, this work has identified and described, in section 2.1.8, several methods and frameworks that are designed for R&D outsourcing and collaboration, or at least allow the practices.

Finally, within product design engineering, recent studies (e.g. STELZER, 2008; MAHLER, 2008; KLAMANN, 2008) show a tendency for the development and/or adaptation of design tools, such as CAD (Computer-Aided Design), CAE (Computer-Aided Engineering), PLM (Product Lifecycle Management) and SOA (Service-Oriented Architecture) platforms, in order to allow and/or enhance collaborative design.

All these evidences point that this work is well-situated in the state-of-the-art of the research in the topic.

2.2 Open innovation (OI)

The first thing that have to be noticed about OI is that, according to Chesbrough (2003a), it is not just a theory or a framework for R&D outsourcing, but it is about a new paradigm, a new mindset that companies should adopt for managing innovation.

The contemporary meaning of the word “paradigm” was given by Thomas Kuhn (1922-1996) to refer to the set of practices that define a scientific discipline at any particular period of time. A paradigm shift happens when a phenomenon cannot be explained by a current the universally accepted paradigm, and requires an alternate approach for being understood. The paradigm, in Kuhn's view, is not simply the current theory, but the entire universe in which it exists, and all of the implications which come with it (KUHN, 1962).

In this sense, OI theory proposes that innovation should be seen and dealt with in a different way it used to be. Gassmann et al. (2010) suggest nine different

perspectives in which OI should be considered and analyzed, namely: (1) spatial, (2) structural, (3) user, (4) supplier, (5) leveraging, (6) process, (7) tool, (8) institutional and (9) cultural perspectives.

An approach to comprehend this new paradigm and its implications is to understand how the paradigm shift happened. That is the intention of the next subsection, based on Chesbrough's (2003a) analysis.

2.2.1 *The closed model*

The closed innovation model, created to suit the environment of economies of scale and scope (CHANDLER, 1990), was characterized by R&D being performed mostly in large companies R&D labs, with few or no collaboration. Chesbrough (2003a) uses the development funnel (CLARK et WHEELWRIGHT, 1993) to explain this model.

Source: adapted from Chesbrough. 2003a

Figure 25 The closed innovation model

Two characteristics of this closed model representation stand out in the present analysis (CHESBROUGH, 2003a):

- The funnel represents the boundaries of the firm, which is determined by its business model. Any development projects that do not fit the firm's business are likely to be eliminated in the process;

- R&D spillovers are considered an inefficiency that is inherent to the process.

2.2.2 *Erosion factors of the closed model*

After many years of success of this closed innovation model, in the last years some “erosion factors” are leading it to collapse. Chesbrough (2003a) points out some of them.

2.2.2.1 Increasing mobility of skilled workers

It is more difficult nowadays to keep an internal knowledge within the firm’s boundaries, as skilled workers change jobs much more frequently nowadays than in the past.

2.2.2.2 High-quality research in universities

Bright ideas are being generated outside large firm’s R&D labs. It is quite difficult for a company to keep the hegemony of knowledge within a technology field nowadays. Additionally, universities get much more funding from companies today than in the past, and are then likely to perform research on subjects of interest to the industry.

2.2.2.3 Venture capital (VC) market

As Hellmann and Puri (2002) empirically prove, VC plays a role beyond the traditional roles of financial intermediaries. Chesbrough (2003a) states that VC is one of the causes for breaking the virtuous business cycle of innovation (Figure 26) in large R&D labs, giving key-engineers an alternative for developing internal technologies that were discredited as “spillovers” in the closed model, as it happened to many emerging technologies developed in the Xerox’s PARC (Palo Alto Research Center).

Source: adapted from Chesbrough, 2003a

Figure 26 Closed innovation virtuous cycle broken

2.2.2.4 Relevant knowledge generated outside big companies

According to data from the American National Science Foundation (NSF), small companies are now performing much more R&D activities than it used to do thirty years ago, when most of the R&D expenditures came from large companies (Table 5). It does not mean that big companies are not performing R&D anymore, but that now small companies are also engaged in R&D, and therefore, good ideas are likely to be found outside big companies' boundaries.

Table 5 R&D expenditures in the USA by size of company

Company size	1981	1989	1999	2005
< 1,000 employees	4.5%	9.0%	22.5%	23.5%
1,000-4,999 employees	6.0%	7.5%	13.5%	15.1%
5,000-9,999 employees	6.0%	5.5%	9.0%	8.7%
10,000-24,999 employees	13.0%	10.0%	13.5%	15.0%
> 25,000 employees	71.0%	67.5%	41.5%	37.7%

Source: adapted from Chesbrough (2003a) and NSF (2010)

2.2.2.5 North-American hegemony decrease

As previously introduced, Sturgeon's (1997) study identified the rise of Asian firms in the market as one of the factors that led to the unbundling process in course since the 1970's. Also Doz et al. (2001) have identified that global companies, in order to win in the knowledge economy, should move from global to metanational, in the sense that they should learn to innovate by using skills from all over the world, instead of performing all R&D within the headquarters.

Likewise, Chesbrough (2003a) identifies the aggressive rise of international players in the market as one of the "erosion factors" of the closed model, for these companies brought with them different traditions in industrial organization practices that ended up changing market dynamics as a whole.

2.2.2.6 Increasing costs for R&D

Finally, Chesbrough (2003a) argues that rising costs for R&D (due mainly to increasing complexity of new technology discoveries) and lower return on R&D investments (mostly due to higher competition and shorter product lifecycles) are biasing lower attractiveness for companies to engage R&D activities.

2.2.3 *From closed to open – a mindset shift*

All these erosion factors are driving the closed innovation model to collapse.

The collapse is not uniform to all industrial sectors in terms of intensity and timing, though. To some industrial sectors, this collapse has already happen. To others, though, these erosion factors are not relevant issues, for the time being. To some sectors, the collapse may never happen.

Nevertheless, regardless of whether these changes constitute a paradigm shift in the kuhnian sense of the word, Chesbrough (2003a) has identified some significant shifts in the way innovation management ought to be dealt with, which can be summarized in the comparative chart of Table 6.

Table 6 Contrasting closed and open mindsets

Closed innovation principles	Open innovation principles
The smart people in our field must work for us.	Not all of the smart people work for us, so we must find and tap into the knowledge and expertise of bright individuals outside our company.
To profit from R&D, we must discover, develop and ship it ourselves.	External R&D can create significant value; internal R&D is needed to claim some portion of that value.
If we discover it ourselves, we will get it to the market first.	We don't have to originate the research to profit from it.
If we are the firsts to commercialize an innovation, we will win.	Building a better business model is better than getting to market first.
If we create the most and best ideas in the industry, we will win.	If we make the best use of internal and external ideas we will win.
We should control out IP, so that our competitors don't profit from our ideas.	We should profit from others' use of our IP, and we should buy others' IP whenever it advances our own business model.

Source: Chesbrough, 2003b

The development funnel in the open innovation model looks like the illustration in Figure 27. In this model, internal ideas that may not be useful in the firm's own business model can be used in other firm's funnel by means of licensing and other technology transfer agreements. Additionally, external ideas can be adapted to the internal development projects of the firm.

Source: adapted from Chesbrough, 2003a

Figure 27 The open innovation model

2.2.4 Definition and scope of open innovation

There are several definitions for open innovation in the literature. OECD's (2008: pp.19-20) study on open innovation, for instance, cites nine definitions from different authors, in order to illustrate how the very notion of OI varies among scholars and executives engaged on innovation, which denotes the novelty of the concept.

Among them, the definition that best suits the vision of this research, and which is also the most used definition in latest studies is the one that asserts that:

Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively. (CHESBROUGH et al., 2006: p.1)

And elsewhere:

Open innovation means that companies should make much greater use of external ideas and technologies in their own business, while letting their unused ideas be used by other companies. This requires each company to open up its business model to let more external ideas and technologies flow in from the outside and let more internal knowledge flow to the outside. (CHESBROUGH, 2006: preface, p. xiii)

These two excerpts highlight the following aspects:

- Openness occurs in two directions, from the inside to the outside and the other way around;
- These flows are **purposive**, that is, accidental spillovers are not to be accounted as open innovation;
- 'Knowledge' and 'technologies' are the 'matter' that is shared;
- Open innovation implies in business model modifications, what is to say that it requires redesign of internal business processes and cultural changes.

In consonance with that definition, Gassmann and Enkel (2004) identify three archetypes or core processes that delineates OI scope from the process perspective. The three core processes are:

(1) The 'outside-in' process: Enriching the company's own knowledge base through the integration of suppliers, customers and external knowledge sourcing can increase a company's innovativeness.

(2) The 'inside-out' process: earning profits by bringing ideas to market, selling IP and multiplying technology by transferring ideas to the outside environment.

(3) The 'coupled' process: coupling the outside-in and inside-out processes by working in alliances with complementary partners in which give and take is crucial for success. (GASSMANN et ENKEL, 2004: p.6)

This three-folded division is of great importance for this work, since we adopt this typology throughout the research to classify and analyze OI activities in the survey described in Chapter 5.

Likewise, Lichtenthaler (2008) divides open innovation in two opposing technology transactions: external technology acquisition (or exploration) and external technology exploitation. The first embraces all activities with respect *"to the absorption of external technologies"*, while the latter *"refers to commercializing technology assets exclusively or in addition to their internal application"* (p.148). It is evident the relation between these two transaction and what Gassmann and Enkel (2004) call outside-in and inside-out, respectively.

Source: Lichtenthaler (2008)

Figure 28 Cluster analysis with respect to openness

The contribution of Lichtenthaler (2008) to the literature is that, according to the extent of each transaction within a given scale, the author was able to identify some clusters that allowed him to group the companies targeted in his research within six (6) clusters, as Figure 28 illustrates.

To contrast this classification based on the flow direction, which is behind Gassmann's and Enkel's (2004) and Lichtenthaler's (2008), the Netherlands Advisory Council for Science and Technology (AWT, 2006 apud OECD, 2008) developed another typology for defining and classifying open innovation, which takes into consideration not the direction, but **for whom** the company is open. According to this classification system, there are three types of OI:

- **Purchasing-based open innovation** – companies interact with other parties as they purchase inputs for their innovation process;
- **Collaborative open innovation** – companies set up partnerships to innovate together in view of a common goal;
- **Open access innovation** – companies allow anyone to contribute to the innovative process.

AWT's (2006, apud OECD, 2008) system is not used in this work, but is presented here to show that there are different ways to classify OI, and divergences of scope may occur. For instance, AWT's (2006, apud OECD, 2008) system would consider open source software (OSS) development intrinsically as part of open innovation scope (as an open access innovation), while according to West and Gallagher (2006), OSS should only be considered open innovation if there is a business model behind it that allow value capture besides creation, as explained in section 2.2.5.1.

As a matter of fact, defining the extent of the domain of OI is still one of the tasks for scholars in the field (WEST et al., 2006). An overview of the released material on OI is presented in the next section, in order to provide the reader some of the concepts under discussion among OI scholars.

2.2.5 OI in the innovation literature

As previously mentioned, the subject of collaboration, networking and use of external sources is not a novelty in academic and specialized literature about innovation management. For instance, Freeman (1991), in a review paper in the early 1990's, has shown evidences that the use of formal and informal R&D networks and other kinds of collaborative arrangements is in order since before World War II. Freeman (1991) also states that the growth of structured networks of innovators, in the same sense of Chesbrough (2003a), would date from the 1980's.

In spite of that, the fact is that the coining of the term "open innovation" has brought to the literature a binding perspective of a number of existing practices, and a necessity to structure such practices into firms' strategy. That would be, according to the OECD (2008), the two main contributions of OI to the literature on the topic.

The question that remains is where the boundaries of open innovation would be. In other words, in which extent open innovation impacts currently available literature on innovation. Is it different from the impact of PDP in the literature?

In order to answer this question, one should analyze the very definition of the word “innovation”. This present work adopts the guidelines of the 3rd edition of the Oslo manual (OECD et EUROSTAT, 2005) for defining such term. According to this manual, there are four types of innovation:

*“A **product innovation** is the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics. (n.156)”*

*“(...) A **process innovation** is the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software. (n. 163)”*

*“(...) A **marketing innovation** is the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing. (n.169)”*

*“(...) An **organizational innovation** is the implementation of a new organizational method in the firm’s business practices, workplace organization or external relations. (n.177)” (OECD et EUROSTAT, 2005)*

Product and process innovations comprise the concept of technological innovation, the so-called technological product and process (TPP) concept. Organizational and marketing innovations are then called non-technological innovation (OECD et EUROSTAT, 2005).

Enlightened by the definitions presented, one notices a difference in the scopes of PDP and OI research; while the first deals with TPP issues, the latter embraces all four types of innovation, i.e., OI mindset impacts innovation in all its facets at the firm level.

Another difference of scope between OI and PDP lies on the level of analysis. While PDP is focused mainly at the firm level, with some implications at the industry level (BROWN et EISENHARDT, 1995), OI research impacts firm, industry and macro economical levels (WEST et al., 2006; OECD, 2008).

OI concepts are broadly applicable to many different fields under the subject innovation. Indeed, OI literature comprises studies relating its concepts to many other fields, such as:

- Innovation within small and medium enterprises (VAN DE VRANDE et al., 2009);
- Strategy and business model (e.g. CHESBROUGH et APPLEBYARD, 2007);
- R&D management and tools (e.g. ENKEL et al., 2009; SLOWINSKI, 2005);
- Funding and investments (e.g. CHESBROUGH, 2003b; FERRARY, 2010);
- Technology intelligence (e.g. VEUGELERS et al., 2010);
- National and regional systems of innovation (e.g. OECD, 2008; BELUSSI et al., 2010);
- Knowledge management (e.g. SPITHOVEN et al., 2010);
- Globalization and internationalization (e.g. LI et KOZHIKODE, 2009; OECD, 2008).

It is not within the scope of this work to perform a literature review on each one of these topics. Nevertheless, there is one that must be addressed, since one of the hypothesis⁴⁷ of this work make an analogy to the finding within this topic: it is about the effect of openness within small and medium enterprises (SME). There is a research line to address this topic that, to our knowledge, dates back to the 1980's, which may be even longer. During these years, many scholars were able to identify that SMEs have different challenges for innovation management, in comparison to big companies. Several studies (e.g. QUINN, 1985; ACS et AUDRETSCH, 1990; VOSSSEN, 1998) analyze strengths and weaknesses of SMEs towards innovation. These studies are generally consistent in asserting that if, on the one hand, SMEs lack enough resources for adopting formal structures and tools to innovate under a more regular basis, on the other hand, they work under more flexible procedures, count with proactive employees, have lesser bureaucratic barriers and a more direct communication link between operational staff and the top management, which all together provide a favorable environment for the emergence of innovations (QUINN, 1985; VOSSSEN, 1998).

⁴⁷ More specifically, hypothesis H8 from Table 21 (p.172).

In regard to the scope of open innovation research, what such studies assert is that SME often rely on networking in order to fill knowledge gaps that prevent them from fully meeting their clients' needs (VAN DE VRANDE et al., 2009). To verify that, Van de Vrande et al. (2009), using Lichtenthaler's (2008) classification system⁴⁸, performed a survey with SMEs in the Netherlands to measure the motives and challenges in the adoption of open innovation. In this survey, it was found that SMEs are also engaged in many open innovation practices, and increasing during the previous seven years. As for the motives, the survey found that SMEs pursue OI primarily for market-related motives rather than by science-driven motives, as it often happens in large companies. Based on these findings, Van de Vrande et al. (2009) conclude that because SME lack enough structure to produce all innovation in-house, they are engaged in several collaborative fronts. These findings contribute to the more general literature about innovation in SME, showing that also within openness SMEs have particularities with regard to big companies.

2.2.5.1 Relation of OI with contiguous theories and practices

It is important to stress the relation and differences between OI and some contiguous theories and practices that often cause confusion in understanding the concept.

- **User innovation**

User innovation is the term coined by Eric Von Hippel to designate a series of practices that aims the integration of the user in the innovation process (VON HIPPEL, 1986). According to OI, user innovation advocates that companies should look for external paths to the market, by revealing internal technologies and allow external creativity to make use of it.

The major difference between user and open innovation lies in the focus that is given to the use of the concept. While user innovators give great emphasis to **value**

⁴⁸ Lichtenthaler (2008) proposes a division of open innovation practices into two groups: external technology acquisition and external technology exploitation, presented in section 2.2.4.

creation and the **revealing** (with special attention to free revealing), open innovation is more about building business models that optimize **value capture** and **IP commercialization**.

From the point of view of scope, another difference between both theories is that OI is broader in the analysis, by considering users as one of various other external sources that could be involved in the innovation process.

Although different in the approach and scope, there are many conceptual similarities between both theories, and one's tools and findings are often applicable to the other's. One example is the **lead user method**, a different approach for collecting information about both needs and solutions from the leading edges of the target market and from analogue markets, markets facing similar problems in a more extreme form (VON HIPPEL, 1986). This practice, along with the toolkits that follows it, is perfectly in line with OI principles and is often listed as an OI practice.

- **Open source software development**

Open source software (OSS) development is a widespread set of practices for software development in free collaboration, in which the source code is openly available. It is not only the source code that is important but also the right to use it. The practice emerged as a reaction to the proprietary software model, reflecting an attempt by customers to reduce their dependence on software vendors. The dissemination of software development tools and the internet contributed to the rapid rise of open source in the late 1990's (WEST et GALLAGHER, 2006).

The use of the term "open" in OSS designates royalty-free technologies. This is not necessarily true in OI: depending on the business model, the distribution of the technology may still imply payment of (significant) license fees. That constitutes a primary distinction between open source and OI (OECD, 2008).

OSS is a collaborative, community model based on a philosophy that does not allow any contributor's ownership to intellectual property (IP) on the code developed. Open source can be open innovation if it is associated to an open business

model that enables value capture (WEST et GALLAGHER, 2006). In other words, in the OI mindset, companies will engage in OSS development if they are able to create value from their IP over and above what they give away (OECD, 2008).

Some examples of open business models that uses OSS as part of their strategy (OECD, 2008):

- companies profit from customer services (installation, customization, maintenance, and support);
- integrating the software with other parts of the IT infrastructure;
- providing proprietary complements.

West and Gallagher (2006) identify four possible open source strategies for OI:

- **Pooled R&D** – complementary development for the development of a common platform, aiming the application by companies of the different natures and different commercial purposes;
- **Spin-outs** – transforming internal technologies that are not creating value into externally visible open source projects so that it creates to the company by the generation of demand to products and services that the company still sells;
- **Selling complements** – revealing the core innovation in order to create demand to complements that remain proprietary technologies;
- **Donated complements** – profiting from the selling of the core innovation, but allowing and encouraging users to develop their own complements.

In short, one should not take open source as an open innovation practice just because of the use of the word “open”, but only if there is a business model behind it that allow value capture from OSS development.

- **Other peer production practices**

Commons-based peer production, or simply **peer production**, is the general name popularized by law professor Yochai Benkler to designate any new way of

producing goods and services that relies on self-organizing communities of individuals who come together to produce a shared outcome (BENKLER, 2005).

Confronting this definition to what has just been said about OSS development, one infers that open source is an example of peer production practice.

Other practices that are becoming popular, such as **crowdsourcing** (HOWE, 2006) and **open design** (VALLANCE et al., 2001; VAN ABEL et al., 2011) also fall under the general definition of peer production.

Peer production is about mass collaboration practices to the generation of knowledge (TAPSCOTT et WILLIAMS, 2006). They normally are enabled by the internet, where these self-organizing communities are gathered together.

About the relation of all these concepts and practices to OI, extrapolating the argument from West and Gallagher (2006), they can only be considered OI if they are attached to an open business model that aims the value capture for a firm. It cannot be considered OI if the goal is not directly or indirectly pecuniary, for example, if the goal is humanitarian or based on an ideology or philosophy.

2.2.5.2 Open innovation and strategy

The clear conclusion after comparing OI to the contiguous theories and practices, performed in the previous item, is that the element that stands OI out from all of them is the existence of a business model whose goal is to claim part of the value that is being generated to the firm engaged in the open business strategy.

Indeed, the importance of the business model is crucial within OI. In the words of Chesbrough (2003a):

"There is no inherent value in a technology per se. The value is determined instead by the business model used to bring it to the market. The same technology taken to the market through two different business models will yield different amounts of value. An inferior technology with a better business model will often trump a better technology commercialized through an inferior business model." (CHESBROUGH, 2003a: introduction, p.xxx)

Chesbrough and Appleyard (2007: p.73) define that an "open strategy balances value creation with value capture". Analyzing data from the OSS industry, the authors

argue that although companies are more and more striving for externally aware models, they can only be considered open innovation if they are connected to a strategy that seeks to capture part of the value created within the openness initiative.

Accordingly, Chiaroni et al. (2011) observed that companies normally adopt some of the practices and tools that are being labeled as open innovation, even when they do not adopt it strategically. The challenge would be to move from sporadic use (“unfreezing”) to the institutionalization of open innovation in the formal processes and culture of the firm. Chiaroni et al. (2011) identified a path of adoption of OI for firms willing to incorporate an open strategy that comprises three aspects: dimensions, processes and managerial levers, illustrated in Figure 29.

Source: Chiaroni et al., 2011.

Figure 29 Open innovation journey

Accordingly, Van de Vrande et al. (2009), analysing specifically SMEs, identified a similar sequence of adoption of open innovation,

(...) starting with customer involvement⁴⁹, following with employee involvement⁵⁰ and external networking⁵¹, and ending with more ‘advanced’

⁴⁹ “Directly involving customers in your innovation processes” (idem, p.428)

⁵⁰ “Leveraging the knowledge and initiatives of employees that are not involved in R&D” (idem, p.428)

⁵¹ “Drawing on or collaborating with external network partners to support innovation processes” (idem, p.428)

practices like IP licensing, R&D outsourcing⁵², venturing⁵³ and external participations⁵⁴. (VAN DE VRANDE et al., 2009, p.435)

One notes that, although there is a variation in the naming between Van de Vrande's et al. (2009) and Chiaroni's et al. (2011) works, in both works it is clear that:

- 1) Openness begins inside the company's network (e.g. clients) that expands as the company moves forward in the adoption of open innovation;
- 2) Initially, open innovation is regarded exclusively as an outside-in process, with later adoption of inside-out practices;
- 3) Companies at first become externally aware, which provokes a cultural change within the company that causes later on the institutionalization of OI inside the company, which allows the adoption of the "more advanced practices", using the words from Van de Vrande et al. (2009).

2.2.5.3 Innovation practices related to openness – an exploratory review

A picture that is often used in OI books and presentations is found in Figure 30. This figure combines the concepts of the development funnel and the spiral, to show that iterative loops are likely to occur inside a stage-gate process of combination and selection of development projects. Additionally, external links are represented by arrows. Outside-in practices are represented by arrows that cross into the funnel while arrows that cross outwards the funnel stand for inside-out practices.

The visual representation of Figure 30 diverges from the original proposal of Gassmann and Enkel (2004)⁵⁵, for it lacks the representation of the coupled core process. In fact, if one assumes the tripartite division, "joint business development" and "venturing" are more properly classified as coupled activities rather than outside-in.

⁵² "Buying R&D services from other organizations, such as universities, public research organizations, commercial engineers or suppliers"(idem, p.428)

⁵³ "Starting up new organizations drawing on internal knowledge"(idem, p.428)

⁵⁴ "Equity investments in new or established enterprises in order to gain access to their knowledge or to obtain other synergies"(idem, p.428)

⁵⁵ See p.107.

Figure 30 also lacks the representation of non-pecuniary practices within OI such as technology sourcing and revealing (DAHLANDER et GANN, 2010), but just the some formal mechanisms through which technologies can be traded, such as licensing.

Additionally, Figure 30 does not represent funding and investment practices, such as corporate VC, that are often linked with open business model strategies (CHESBROUGH, 2003b; FERRARY, 2010).

Source: De Jong (2007) apud De Backer, 2008.

Figure 30 Open innovation practices

According to Dahlander and Gann (2010), the very difficulty in performing a literature review on OI lies in the fact that the literature is fragmented, as they proved by the bibliographic analysis they performed over the *ISI Web of Knowledge* database. The disadvantage of this is that comparing empirical findings is difficult.

Therefore, in order to give consistency to OI literature, and based on the literature review performed, Dahlander and Gann (2010) propose a classification of OI studies based in two variables: in one axis, inbound or outbound innovation; in the other axis, pecuniary or non-pecuniary interactions. Four different forms of openness arise from this approach, as shown in Table 7.

Table 7 Structure of different forms of openness

	Inbound innovation	Outbound innovation
Pecuniary	Acquiring	Selling
Non-pecuniary	Sourcing	Revealing

Source: DAHLANDER et GANN, 2010.

To close this section, another way to classify OI practices can be done as proposed by the OECD (2008) study on OI. This proposal classifies OI modes (practices and strategies) according to the familiarity of the firm with the technologies and markets related, as shown in Table 8.

Table 8 OI modes: Technologies and markets

MARKETS	Unfamiliar	Joint venture Contract R&D	Venture capital Internal venture fund	Spin-off Sell
	Non-core	Joint development Acquisition	Licensing Equity stake	Venture capital Internal venture fund
	Core	Acquisition Internal development	Internal development Licensing Acquisition	Joint venture Contract R&D
		Core	Non-core TECHNOLOGY	Unfamiliar

Source: EIRMA (2004) apud OECD, 2008.

All these tables and figures show similarities and differences in defining the scope of OI. In Chapter 5, this material is used to draw boundaries for OI for the matters of this research project. This analysis can be considered a contribution of this work to this discussion.

2.2.6 OI within PDP

As the discussion on the last topics show, OI impact is broader than the limits defined by PDP research. OI mindset proposes a shift in virtually all domains of innovation research, from which PDP is one of the topics.

Nevertheless, it is within the PDP that one of the first insights of OI has arisen: Chesbrough's (2003a) analysis of Xerox's PARC product development funnel played an important role in academic and business communities to show the importance of an open mindset for benefiting from knowledge created inside and outside a firm. The first essays on OI were virtually all regarding technological innovation, which gave a false initial perception that OI was a theory that regarded exclusively technology development (CHESBROUGH, 2007b). From a certain point of view, one can state that OI research arose from PDP.

Within the PDP theory, the immediate consequence of the paradigm shift advocated by OI is the need for a new framework for product development. Chesbrough (2003a) criticizes the development funnel reference model, for it does not look outside the firm's boundaries neither for searching for external sources of knowledge or for looking for external alternatives for the knowledge generated within the boundaries of the firm.

Mankin (2004) proposes that for emerging markets where customer needs are not yet clearly defined, assumptions *a priori* within closed linear product development should be replaced by open iterative loops that allow user interaction and product definitions, which might lead to alternative applications for products than those of the firm's own business model.

These examples show that PDP models urge to be revised, in order to incorporate openness to them. That is the motivation for the discussion in the next section.

2.3 Systems of innovation

Prior to defining a conceptual framework for this research, one additional relevant concept for the purpose of this work shall be introduced: why and how government contribute to the innovation process that takes place mostly within private-for-profit organizations?

To discuss this point, we shall introduce the theory of systems of innovation, which presents the approach in which governments normally see and study the innovation process. This theory states that the flow of knowledge, technologies and information among institutions is critical to the success of innovation in local firms of a given region or country.

The concept of systems of innovation is a theme that has been present in the specialized literature since the mid-1980's, when Lundvall (1985), Freeman (1987; 1988) and Nelson (1988) published a series of studies whose proposal is to analyze how the local environment contributes for the encouragement of the innovation in firms of a given geographic location. More precisely, Freeman (1987; 1988) devotes himself to the study of the Japanese system of innovation; Nelson (1988), in his turn, takes the USA as the object of his studies; as for Lundvall (1985), he approaches the theme under a more theoretical point of view, adopting the evolutionary econometric model to raise the hypotheses that systems of innovation evolve from client-supplier interactions, using as background the economic transformations that took place in Europe to illustrate the concept.

Later on, these pioneers performed similar analyses, along with other scholars, within different contexts and with different approaches (e.g. LUNDVALL, 1992; NELSON, 1993; WONG, 1999; ANDERSEN, 1999). All these studies contributed for the formulation of a concise conceptual model that suggests that firms do not innovate alone; on the contrary, they depend on a complex institutional framework and strong ties with several other actors to innovate. When approached generally, this theory is named "systems of innovation" (SI); however, when applied to specific regions, it is also known as "regional systems of innovation" (RSI) or "national systems of innovation" (NSI) when it analyses the theme within the economy of a whole country. Nowadays, the SI theoretical model is considered a very mature one, properly verified in the scientific and specialized literature, as can be noticed in various works of explanatory nature on the subjects (e.g. OECD, 1997; LASTRES et al., 2005).

Although this theory is relatively recent, the idea is much older. As Freeman (1995) admits, back in 1841 Friderich List created the concept of a “national system of political economy” to explain how Germany could overcome the United Kingdom in industrial organization at his time, and had proposed public policies for the local support of the industrial development of non-industrialized regions. Therefore, modern SI theory contains conceptual elements that predate the model, whose main contribution is an integrated vision.

Another preexisting idea that is incorporated to the SI model is the triple helix concept, which is a term already used in the 1960's by Sábato and Botana (1968). What the triple helix advocates is the necessity of interaction between the productive structure (firms), the technological-scientific infrastructure (universities and other STI), the first as the agent that promotes innovation in the market and the latter as the agent that generates and holds the scientific and technical knowledge required for such innovations. Since these agents differ (and even diverge, sometimes) in their goals and methods, they do not normally interact with the required intensity. For that reason, the aid of a third agent, the government, is required to serve as a “catalyst” for the STI-enterprise relationship, by means of incentive policies, investments in local research and development (R&D) infrastructure and, ultimately, as the purchaser of cutting-edge technology, as it often happens in the case of technology development contracts in strategic sectors such as defense, aerospace and energy. Figure 31 illustrates these interactions as a triangle whose vertices are the three agents, namely: firms, government and STI. The sides of the triangle represent the flows of information, knowledge and resources that are critical for the proper functioning of the local SI, according to this theory.

Source: adapted from Sabato and Botana (1968)

Figure 31 Triple helix

2.3.1 Public policies for innovation⁵⁶

Public authorities from all over the world recognize that innovation is paramount to continued prosperity. Although recognizing its economical importance for society as a whole, the government cannot have total control over the innovation performed in-house, since innovation is fundamentally a market phenomenon, whose main locus are private-for-profit companies. Therefore, what the government can and actually does is to create a favorable environment for innovation by means of public policies that serve as catalysts, which stimulate the successful accomplishment of innovations on the behalf of the companies located in their territories.

In order to build the argument to justify the importance of government intervention in the economy of innovation, one must have in mind that, in the process of allocating scarce resources, economic agents (e.g. firms) tend to prioritize the provision of such resources to more advanced stages of the technological

⁵⁶ This discussion, as well as the introduction of Brazilian and Canadian innovation policies (respectively presented in sections 4.4.2 and 4.5.2) were originally presented in the 22nd International Conference on Management of Technology (IAMOT) (ARMELLINI et al., 2013).

innovation process, due to their risk perception: mature technologies usually offer more tangible perspectives and lower-term return over investment than technologies in early stages of development, that is, lower Technology Readiness Levels (TRL), borrowing NASA's standard for the technology classification (MANKINS, 1995). Furthermore, economic activities within more structured and better known businesses and technologies, in which the agent has a history of performance, are also likely to be prioritized for resources allocation (CHRISTENSEN, 1997).

These two factors (risk perception and history) therefore cause companies to delay or underestimate the necessity of investment in R,D&I activities, even though the agent often acknowledges the importance of these activities in the medium and long term. Thus, one can conclude that the promotion of technological innovation, although fundamental for the socio-economic development, is not prioritized by the economic agents responsible for innovation.

Government measurement towards innovation, such as funding, financing, sector funds, tax incentives, aim at enhancing the competitive edge of agents that they cannot guarantee by themselves (BOSCHMA, 2004). In short, according to this principle, the government can and should create mechanisms to promote innovation within its territory. Such instruments should foresee the needs of the various spheres of scientific and technological development of a region or nation, serving as a catalyst to economic development.

There is a number of different ways in which the government can support innovation within its territory. According to Edquist (2001: p. 220), innovation policy is a "public action that influences technical change and other kinds of innovations", which includes "elements of R&D policy, technology policy, infrastructure policy, regional policy and education policy".

Analysing Edquist's (2001) definition, one denotes that it is inclusive of many political actions that, although fundamental for the innovation performance in a territory, are not directly aimed at it. One example is the promotion of high-quality

education at all levels: the effects on that over innovation performance is actually a spillover, it is not the original goal intended by the policy.

At other times, the government is also a key player in the innovation system as a technology purchaser, as it often happens in the aerospace industry. Then again, although relevant for innovation in general, it is not part of what is being considered an innovation policy here. For the purposes of this work, a “public policy for innovation” is a public action directly aimed at enhancing the innovative performance of firms within a territory.

Initially, it involves the promulgation of laws and decrees that officially establish the incentive policy. Once promulgated, these legal documents require modifications in the government organizational structures in order to respond to the new policy. Government agencies are then created or assigned for managing a specific support program, which may involve budgets, require specific procedures of accountability, personnel for training, support and supervision, among others. This is the moment when the government agent actually takes shape and becomes a real player in the innovation system. These players and their “products” (the support programs) are the object of study of this research.

There are several ways to classify the possible types of government support for innovation. Choosing the most adequate classification system is something that depends on the perspective on which one regards such policies. For instance, CGEE and ANPEI (2009), in a study whose goal is to present to Brazilian firms the existing opportunities of financial support for innovative projects, divide such programs into five categories, namely: tax incentives, funding, financing, venture capital and seed capital. In contrast, FIESP (2009), an industry association in the state of São Paulo (Brazil) that congregates firms from different industry sectors and activities, makes a primary classification according to the destination of the support (infrastructure investment, technology, exports and services), and within each one of these four destinations, the study subdivides the programs according to the type of support (funding, financing, sector funds, venture capital, tax incentives, human resources, direct contract etc). Finally, Industry Canada (2011), in a report ordered by

governmental agents, classifies such programs according to the type of expenses these programs incur in public budgets: tax waivers, direct spending programs, venture capital investments and federally performed R&D.

Having in mind the particularities of each study previously mentioned, and taking into account the specific goals of the present work, this paper proposes the division of such policies into four groups, according to Table 9. Three of them consist of financial (pecuniary) support, namely: tax incentives, funding and financing. The fourth group gathers together all initiatives that do not involve the direct inflow of cash to the firms, but are more related to the improvement of important skills that firms should have for being more innovative, such as networking, organizational, or knowledge-management capabilities. The next two sections present existing policies in Brazilian and Canadian systems of innovation that are applicable to the aerospace industry.

Table 9 Classification of public policies for innovation

Policy type	Description	Examples
Tax incentives	Reduction of tax load for innovative companies	Exemption or reduction of specific tax rates Granting of tax credits proportional to R&D expenses
Funding	Non-refundable pecuniary support	Grants for internal innovative technology projects Grants for collaborative projects with STI Sector funds Scholarships, fellowships and awards
Financing	Refundable pecuniary support	Loans with lower interest rates ("soft loans") for internal innovative projects or for investments on R,D&I infrastructure Seed, angel and venture capital Private equity

Policy type	Description	Examples
Non-pecuniary support (NPS)	Other government support policies that do not involve direct money support, but focus on enhancing networking, organizational or knowledge capabilities.	Technology support and assistance programs Cluster organization / technological parks / incubators Research consortia Training

Source: adapted from Armellini and Aquino (2012)

From this classification system, one is able describe any country's public policies for innovation. This research project uses it to analyze Brazilian and Canadian policies in sections 4.4.2 and 4.5.2, respectively.

3 TOWARDS A PRODUCT DEVELOPMENT FRAMEWORK FOR OPEN INNOVATION

*“Knowledge is justified true belief”
(Socrates, “Meno”, V century B.C.)*

After the literature review, this chapter presents a discussion that aims at integrating all issues presented in the last chapter, with additional considerations taken from the knowledge management (KM) literature, in order to define a framework and some fundamental concepts to this work, which is a first original contribution of this work to the topic.

3.1 A preliminary discussion about the concept of “idea”

In this section, whose end is to propose a conceptual model that integrates OI to the PDP, a discussion of fundamental concepts has to be raised⁵⁷.

Creativity is the human capability behind innovation and product development. Without it none of these fields of research would make sense. Behind creativity, there is a fundamental element called “idea”.

But what is an idea, anyway?

The etymology of the word “idea” comes from the Greek word ἰδέα (idéa) or εἰδέα (eidéa), whose root εἶδος (eidos) means “image”.

The origin of the term dates back to the classical Greek philosophy ages. Plato (V century B.C.) has introduced the current of **idealism**: conception that beyond the sensible world – the reality that the senses realize – there would be the world of the Ideas. This world would be composed of perfect, eternal and immutable entities (the Ideas), whose existence would be independent from men’s will. All material things would be nothing but ephemeral and imperfect reflexes of the Ideas, the only existing beings in reality. According to this theory, the perception captured by the senses would be to reality as shades on a wall are to the objects that produced them,

⁵⁷ This discussion has been originally presented in the 21st International Congress of Mechanical Engineering (COBEM) (ARMELLINI et al., 2011b).

as Plato explains in the famous myth of the cavern in the VII book of the "Republic" (HESSEN, 2003). Only Philosophy could give true knowledge, which could be able to release men from the cavern of the senses to the true world: the world of the Ideas. (FRANCA, 1965)

Against this current arises the theory of **realism**, whose most prominent names are those of Aristotle (IV century B.C.) and, much later on, Saint Thomas Aquinas (1225-1274), which asserts that the world captured by the senses is the real world, indeed. Idea, in its turn, would be an entity of reason that, although immaterial, exists in reality in the intelligence of rational beings, not in a contiguous existence as idealism claims. According to realism, ideas are seized by the senses by means of observation and abstraction from the real world. Knowledge is related, thus, to this capability of abstracting true and universal laws from the material world. (FRANCA, 1965)

A more contemporary definition of the philosophical concept of "idea" is found in the **Dictionary of Philosophy and Psychology** of the Encyclopædia Britannica, compiled by James Mark Baldwin between 1901 and 1905. According to Baldwin and Stout (1905), authors of the text which explains the entry in this dictionary, idea is *"the reproduction with a more or less adequate image, of an object not actually present to the senses"* (BALDWIN, 1905).

Not going further into the philosophical discussion, which does not matter to this work, what is relevant to highlight is that, with the advent of the modern idealism in the Modern Age, whose exponent is French philosopher René Descartes (1596-1650), different meanings for the word "idea" have arisen besides that of mental images of universal beings. This changing of meaning was perceived by English writer Samuel Johnson (1709-1784), whose life is known by means of his biography by the also English writer James Boswell (1740-1795), who wrote:

"He [Samuel Johnson] was particularly indignant against the almost universal use of the word idea in the sense of notion or opinion, when it is clear that idea can only signify something of which an image can be formed in the mind. We may have an idea or image of a mountain, a tree, a building; but we cannot surely have an idea or image of an argument or proposition."

Yet we hear the sages of the law 'delivering their ideas upon the question under consideration;' and the first speakers in parliament 'entirely coinciding in the idea which has been ably stated by an honourable member;' – or 'reprobating an idea unconstitutional, and fraught with the most dangerous consequences to a great and free country.' Johnson called this 'modern cant'." (BOSWELL, 1791: p.130-131)

What Dr. Johnson considered eccentric to the XVIII century is currently common sense. Nowadays, the word “idea” has many different and equivocal meanings. Often, ideas are conceived as representations (images) of existing things, as the classical definition sustains. However, as Dr. Johnson realized, idea can nowadays be a synonym for notion or opinion. Yet, it can also mean a suggestion, a concept or it can even designate anything that comes into one’s mind.

Within the field of innovation and product development, “idea” is a word that is constantly employed, but rarely defined. And since it is a word that can bear so many equivocal meanings, it urges to be clearly and precisely defined.

In order to do so, the following section (3.2) proposes a theoretical model for PDP that not only defines “idea”, but also relates it to some adjacent concepts, such as “datum”, “information” and “technology”, fundamental to this research project.

3.2 Building a conceptual model

The starting point to the construction of the conceptual model of this work is the well-known product development model proposed by Clark e Wheelwright (1993), known as “development funnel”, previously presented in Figure 11 (p. 78).

The goal here is to build a conceptual model that incorporates other concepts to this funnel, in order to indicate the process of “maturation” of an “idea” within the funnel. The ultimate goal in doing that is to give a conceptual approach to inbound and outbound flows that characterize OI processes.

Initially, the funnel shall be regarded as a tripartite process, with three well-distinguished stages, according to division of R&D proposed by Frascati Manual⁵⁸:

⁵⁸ Discussed in section 2.1.5.4 (p.63).

basic research, applied research and experimental development (OECD, 2002). Figure 32 shows these three phases inside a funnel that represents the PDP as a whole.

Figure 32 Division of the R&D funnel, according to the Frascati Manual

The placement of these three processes within the funnel-like figure is meaningful. The narrowing represents the processes of selection, combination and filtering that take place in the investigatory phases of the PDP, that is, within basic and applied research. The straight end of the funnel represents the final phase of the PDP (development itself), where 100% efficiency is sought: every project that gets in the development stage is intended to result in a specific product or process.

Taking advantage of the discussion in section 2.1.5.4, in this framework the word “experimental” is suppressed when referring to development. That is to say that this model embodies both “experimental” and “pre-productive” development into one single development stage. Figure 33 illustrates this incorporation into the development funnel presented in Figure 32 and the junction of both development stages into one general “development” phase. This merger aims to facilitate the classification of activities within the funnel and to avoid the difficulties highlighted in Frascati manual to segregate these two types of development activities (OECD, 2002).

Figure 33 Incorporation of “pre-production” development into Frascati’s framework

After defining the three phases of the funnel, the next step is to define the inputs and outputs of each stage.

Frascati manual defines basic research as:

“experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.” (OECD, 2002: n.64)

It is evident from the definition itself that the primary output of basic research is **knowledge**. As for the inputs, since basic research is fundamentally a learning process, the primary input shall be the “raw materials” of knowledge, which in this work are called **data** and **information**.

These terms shall be understood in this work according to the definitions of the Australian standard HB 275-2001 (STANDARDS AUSTRALIA, 2001 *apud* VEYBEL et PRIEUR, 2003), the first standard in the world exclusively dedicated to Knowledge Management – KM (VEYBEL et PRIEUR, 2003).

According to this standard:

*“Une donnée se réfère à des bits et des caractères dans un système informatique ou dans d'autres manifestations physiques de la communication, comme le son ou la température” (STANDARDS AUSTRALIA, 2001 *apud* VEYBEL et PRIEUR, 2003: p.84)*

[“Datum refers to bits and characters in an information system or in other physic manifestations of communication, such as sound or temperature”]

In relation to the concept of information:

"L'information est une donnée contextuelle pouvant servir à une prise de décision. Une donnée est habituellement mise en forme pour fournir un sens à l'observateur. Il s'agit plutôt d'un texte, mais peut être une image, une séquence de vidéo, une conversation ou tout simplement le signal d'occupation d'une ligne téléphonique." (STANDARDS AUSTRALIA, 2001 apud VEYBEL et PRIEUR, 2003, p.85)

["Information is contextual datum that can be useful for decision taking. Data is normally organized in order to make sense to the observer. It's rather a text, but it can be an image, a video sequence, a conversation or even the busy sign of a telephone line"]

Finally, the standard also defines:

"La connaissance est la nature même de la compréhension et représente ce qui est mentalement construit par les individus." (STANDARDS AUSTRALIA, 2001 apud VEYBEL et PRIEUR, 2003: p.85)

["Knowledge is the very nature of understanding and represents what is mentally constructed by individuals."]

In short, one can assume that the mainstream within basic research is the transformation of data and information into knowledge, as Figure 34 illustrates.

Figure 34 Main knowledge transformation within basic research

It does not mean that basic research cannot make use of technologies and/or previous knowledge in order to construct new knowledge. This model just indicates, as the caption in Figure 34 points out, the main knowledge transformations inside the funnel development model that is being constructed.

Next, as to applied research stage, once again quoting Frascati manual:

"Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective." (OECD, 2002: n.245)

From this definition, one can infer that the same inputs of basic research (i.e., **data** and **information**) are inputs here as well, although it is also important to consider **knowledge** as input, especially the knowledge generated within basic research. As for the output, the result of applied research is applied knowledge, which is assigned as **technology**, according to Merriam-Webster dictionary:

"Technology: The practical application of knowledge especially in a particular area; a capability given by the practical application of knowledge"
(Merriam-Webster Online, retrieved 2010/09/13)

Based on that, Figure 35 illustrates the main transformation that occurs within applied research, from knowledge (along with information and data) to technologies.

Figure 35 Main knowledge transformation within applied research

Jugend (2010) provides another definition of technology, which suits the PDP better:

"(...) pode-se definir tecnologia como o conjunto de conhecimentos teóricos e práticos aplicados ao desenvolvimento de produtos, processos, serviços ou novo método voltado para a gestão de uma empresa." (JUGEND, 2010: p.9)

[...] technology can be defined as the set of theoretical and practical knowledge applied to the development of goods, processes, services or a new management method.]

By this definition, **technology** is, thus, an input to the development process, where the outputs of research efforts (basic and applied) are transformed into products (goods and services) to the market. This conclusion is consistent with the very definition of experimental development given by Frascati Manual:

“Experimental development is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.” (OECD, 2002: n.249)

In the conceptual model that is being built, development gathers technologies together with more information, data and knowledge originated or not from practical experience, always aiming their incorporation into products (goods and services) for the market. Figure 36 illustrates this mainstream.

Figure 36 Mainstream of idea maturation within development

It is important to stress that development is considered in its broad sense in this conceptual model. By incorporating “pre-production” development, it has the following characteristics:

- It aims at the attainment of product and/or processes that are new or substantially improved in relation to what the company had before;
- It involves significant technological risk;
- It comprises a non-routine (“experimental”) phase;
- It includes later phases of development (“pre-production”) technical activities, up until it is put into operation (for the case of processes) or it is introduced in the marketing (for products).

An advantage of this approach is that the end of the funnel is a product in operational production, ready for the market. This model can be summarized in the conceptual schema of Figure 37.

Figure 37 PDP conceptual model

In this conceptual model, the “material” that flows inside the funnel is an intellectual asset that changes throughout the process: it can be called datum, information, knowledge or technology, depending on its degree of maturity.

It is not intended, in Figure 37, to illustrate all possible connections among these different types of intellectual assets. However, it is drawn so that to highlight some aspects within the PDP, namely:

- Data and information are everywhere, either inside and outside the firm, and it is used throughout the PDP;
- Although knowledge can be created in at any stage, this is more prominent (and is the main goal) within basic research;
- Applied research aims at converting knowledge into technologies;
- Technology is development’s main input;
- Innovative products are the result of the creative combination of different kinds of intellectual assets;
- Knowledge and technologies are stable stages in this maturation process that can constitute finished intangible assets that are eligible for trading: a firm’s development funnel can use knowledge and technologies

generated internally, as it can internalize external knowledge and technologies. Likewise, a firm can profit from other firm's use of its own knowledge and technologies generated internally.

The difficulty to make correlation between frameworks from different authors in the specialized literature (academic or not) lies in the name that is given to this "intellectual asset". Some authors call it "knowledge"⁵⁹ or "technology"⁶⁰, when these terms designate different stages of maturity of this "intellectual asset". Others designate as "ideas" the elements that flow through the funnel⁶¹, when in reality, according to the conceptual model of Figure 37, ideas are the elements that combine different kinds of intellectual assets in order to form new "intellectual assets", as well as products (goods and services) and processes.

3.3 Concluding the discussion about the concept of "idea"

With this conceptual model in mind, let us go back to the initial question of this subsection: what are ideas after all?

The concept of idea within the literature on product development and innovation seems to refer to a faculty related to the very human ability to create. It is part of the creative being to have many ideas. And what else is generated in the creative process but ideas?

Ideas, as well as creativity, are not exclusive to any of the three phases of the funnel modeled previously. On the contrary, they are part of all of them. It is men's ability to create that biases the investigation of new possibilities of combination and/or use of available knowledge, information and data in a fashion not previously

⁵⁹ The whole literature on Knowledge Management (KM) uses the word "knowledge" either to designate it generically or within the specific maturity level that defines knowledge (VEYBEL et PRIEUR, 2003; LIYANAGE et al., 1999).

⁶⁰ That is the case of the Technology Readiness Level (TRL) approach, for instance (MANKINS, 1995).

⁶¹ See, for instance, Chesbrough (2003; 2006; 2007a) and Hansen and Birskinshaw (2007). In fact, due to the influence of Chesbrough's works in OI literature, many papers in the field employ the word "idea" in this sense, as for example Dittrich and Duysters (2007).

conceived. It is within this process that innovation arises. On the other hand, ideas are not something that can be sold or borrowed, for they do not constitute a finished state of knowledge.

Under this view, ideas serve, therefore, as the **catalyst** that transforms data, information, knowledge and technologies (the “intellectual assets”) into new knowledge, technologies, which ultimately will become products, services and production processes.

Based on that, this work proposes a formal definition for the term as follows:

“Ideas are creative impulses that allow the combination of existing data, information, knowledge and technologies into new knowledge, technologies, products and/or processes.”

According to this definition, it is creativity that generates ideas that produce knowledge, technologies and products, in their turn. The activities within the three-phased PDP are nothing but systematic tasks aiming the creation and validation of such ideas.

3.4 Advantages and limitations of the conceptual model

As a linear framework, this conceptual model incurs the limitation of this kind of models, not representing feedbacks that can happen in the knowledge maturation process in all steps of the funnel. Secondary knowledge and technologies can and are generated, for instance, during development.

It is a fact that research also makes use of technologies, for example, those incorporated into the equipments used for research purposes. Those technologies are not represented in the framework, which constitutes another limitation of the model.

Nevertheless, the framework presented in Figure 37 has the advantage of successfully representing the mainstream of knowledge maturation within the PDP.

One additional benefit of this model is that it allows the identification of the three OI core processes (GASSMANN et ENKEL, 2004) within the funnel. Indeed:

- An outside-in process happens when knowledge and/or technologies enter a firm's funnel. It is normally formalized by licensing or other IP agreements or by an acquisition;
- An inside-out process happens when knowledge and/or technologies leaves a firm's funnel to be used by another firm. Likewise, it is normally formalized by licensing or other IP agreements or by a selling;
- A coupled process happens when collaboration arrangements uses knowledge and/or technologies from two or more institutions, with benefit to all institution funnels. It is formalized by mutual collaboration agreements, and likewise by licensing or other IP agreements.

Notice by this conceptual model that the new “marketable assets” within OI are knowledge and technologies. Ideas are not exchangeable things if they are regarded accordingly to the previous definition.

In order to do so, companies should have their technologies and knowledge somehow formalized and protected. From that follows the importance of IP protection in OI, which allows the company to build a portfolio of intangible assets that can be commercialized by means of an openness process (CHESBROUGH, 2003a).

It is within this conceptual model that this work is structured. It is used in the questionnaire structures as described in Chapter 5. Figure 37 is included in the questionnaire and was explained to each interviewee prior to the questions about open innovation. Besides, whole structure of the questionnaire afterwards is intended to cover all structures of this conceptual model.

4 AEROSPACE MARKET OVERVIEW

*"In the struggle for progress, only success is worth."
Alberto Santos Dumont (1873-1932)*

This research is intended to the aerospace industry. Therefore, prior to presenting the research methodology, the structuring of the survey and, particularly, the questionnaire that based it, one should understand this industry. It allows one to adapt open innovation issues to the terminology and the reality of aerospace R&D managers.

The aerospace industry is a high-technology⁶² sector characterized by strong governmental support and competition at global level.

Because this sector is closely connected to matters of national sovereignty, there is a strong governmental interest, mainly military, in local industry development for this segment. That is to say that the sector's trajectory is often driven at global level by regional government intervention aimed at dominating the whole product lifecycle, as well as all aerospace technologies (GOMES, 2012). For the same reason, secrecy and IP protection are often in aerospace R&D managers' agendas.

Despite the sovereignty strive, the fact is that regional technological poles are rarely self-sustaining and need complementary competencies from other countries. Since aerospace products comprise several different technologies and involve a number of different kinds of expertise that hardly can be comprised in one only place. That is even more evident when one regards civil and commercial aeronautics apart from military and space: market dynamics has led the industry to global level competition, with the rise of technological poles spread around the globe and specialized in some (but not all) critical technologies. The cluster might even have companies within all critical technologies, but they are likely not to be all global leaders within their sectors at the same time.

⁶² According to the OECD (2010), the high technology sectors are aerospace, information and communication technology (ICT), electronics and pharmaceuticals.

According to ABDI's (2008) report, competition in the sector is closely related to generating and financing technological innovations. The growing complexity of aerospace systems also increases the requirement for investments, which is leading the industry to an equity restructuring in the last 20 years, characterized by associations, mergers and acquisitions (M&A). The report exemplifies this assertion with civil aviation M&A, illustrated in Figure 38.

Source: adapted from ABDI (2008).

Figure 38 Civil aviation M&A

Besides M&A, another current trend in the sector is the establishment of joint ventures for specific large projects. Examples of that are the AMX International (GUILFOIL, 2012), a joint venture among Alenia, Aermacchi and Embraer to modernize the AMX ground attack air fighter⁶³, or Advanced Atomization Technologies, LLC, a recently announced joint venture between GE Aviation and Parker Aerospace to develop and manufacture fuel nozzles for commercial aircraft engines (PARKER, 2012).

⁶³ Since Alenia and Aermacchi merged in 2012, the joint venture nowadays is between Embraer and Alenia Aermacchi.

It follows that aerospace market, at the international level, is organized as an oligopoly, and no single country detains a market with magnitude and/or dynamism to afford the costs for the development of new aircrafts, forcing them to act globally (ABDI, 2008). This is more evident in the aviation market, but is also a reality in defense and space segments (FERREIRA, 2009). A clear example of that is the International Space Station (ISS), a joint venture from five space agencies, namely: NASA (USA), the Russian Federal Space Agency, the Japanese Aerospace Exploration Agency (JAXA), the European Space Agency (ESA) and the Canadian Space Agency (CSA) (KITMACHER, 2010).

4.1 Aerospace industry organization

The aerospace industry comprises three segments, namely, aeronautics, defense and space, described in Table 10.

Table 10 Aerospace segments

Segment	Description
Aeronautics	Design and manufacturing of air flight machines and parts as well as flight security and flight control systems, for civil and commercial purposes.
Defense	Research, development and manufacturing of airborne artillery, electronic warfare equipment as well as flight defense and communication systems, such as surveillance and tracking radars, flight control and airspace monitoring equipment (onboard and ground).
Space	Research, development and production of equipments for use in the space: satellites (including the payload), spacecrafts, sounding and launching rockets and launching facilities.

Source: adapted from Ferreira (2009).

For market analyses, the aeronautic segment is in general divided into its two main products: airplanes and helicopters. Aviation is then again split into three, according to its application: military, commercial and regional. Helicopters, in their turn, are divided into two: civil and military (IMAP, 2011). Within defense, it is normal to consider a two-folded division between artillery manufacturers and

communication equipment developers (Ferreira, 2009). Finally, the space segment, being the less complex in terms of variety of systems, is often considered as a whole, with no subdivisions. Putting all this information together, one draws the industry organization chart shown in Figure 39.

Source: the author, using information from Ferreira (2009); IMAP (2011).

Figure 39 Aerospace industry structure

There are advantages and disadvantages in grouping all three segments into one industry. The main advantage is that, since technologies are complementary, it is very common that companies act in more than one segment. However, grouped analyses tend to bias the industry by the dominant segment. For instance, in Brazil it is very normal to reduce the local aerospace industry to Embraer and its supply chain, since it is the most important segment, in terms of revenues⁶⁴. However, by doing so, one neglects different existing structures from the other segments, which narrows the general comprehension of the industry and prevent policy-makers to draw strategies that also cover the specific needs of these smaller niche segments.

For that reason, market analyses sometimes embrace all three segments, sometimes not. Combined analyses are found, for instance, among OECD studies (e.g. OECD, 2007; 2010), and a number of industry associations around the globe, such as the American Aerospace Industries Association (AIA, 2012) and the Canadian AéroMontréal (2012a), not to mention academic and/or government

⁶⁴ In 2007, for instance, the aeronautic segment was responsible for 92.9% of aerospace revenues in the Brazil (FERREIRA, 2009).

mandated market studies, such as Ferreira's (2009) in Brazil and Emerson's (2012) in Canada.

At other times, though, depending on the specific goals of the study, some segments are focused over others. ECORYS (2009), for instance, issued an industry overview study focused only on the aeronautics segment, mandated by the European Union (EU). Another example, the Japan Aeronautic Association (JAA) issues annually a market analysis on Civil Aviation, since military development in the country is restricted since World War II⁶⁵.

Regarding the two clusters on focus in this research: in Brazil it is relatively easy to find market analyses for the aeronautic segment (e.g. ABDI, 2009; MONTORO et MIGON, 2009; BNDES, 2012), since this is the most prominent segment in Brazilian aerospace industry, but very few encompasses all three segments, such as Ferreira's (2009). In contrast, in Canada aerospace is often analyzed according to this three-fold division. Therefore, one must pay close attention to the scope of studies before establishing comparisons among them.

In spite of that, industry studies are fairly constant in proposing a four-fold division of the industry value chain according to Table 11, namely, (1) end users, (2) prime contractors, (3) equipment manufacturers and (4) subcontractors and product manufacturers. End users are account merely as clients within the industry; their business is not considered part of the industry.

Table 11 Aerospace value chain

Value chain position	Description
End users	Primary client within the supply chain. Includes airlines, the Air forces, independents pilots and private aircraft owners in the aeronautic and defense segment, for instance.

⁶⁵ According to the JAA website: <http://www.aero.or.jp/>. Retrieved: 2013/01/28.

Value chain position	Description
Prime contractors	Core player in the industry from which the end user usually acquires finished aerospace products, and which has the full responsibility for its completion. This category encompasses aircraft integrators and complex system integrator/manufacturer (e.g. turbo jets or flight simulation systems).
Equipment manufacturers	Usually large companies capable of supplying complete subsystems. This category also includes small aircrafts manufacturers (e.g. Unmanned Aerial Vehicles – UAV and Ultralight aeroplanes – ULA).
Subcontractors / Product manufacturers	Companies of all sizes, with predominance of SMEs, holders of specific technical knowledge and skills that are useful for equipment manufacturers and/or prime contractors. This field encompasses a large range of firms, from machining services to R&D service suppliers.

Source: the author, gathering information from ABDI (2009); IQ (2009); AéroMontréal (2012a); AIA (2012).

It is a consensus among market studies NOT to include the airline transportation business as a part of the aerospace industry. Airlines are regarded within the aerospace industry as end users, and their business is subject of specific market studies (e.g. VALOR SETORIAL, 2010).

Finally, this work shall adopt a system to classify aerospace companies according to their technical/technological specialization. To that effect, this project proposes a division within 14 groups, based on AQA's⁶⁶ list of aerospace technologies, which comprised 36 technical specializations. Table 12 correlates this 14 groups with AQA list.

⁶⁶ AQA (Quebec Aerospace Association, in the French acronym) merged with AéroMontréal in 2012 and is now defunct.

Table 12 Aerospace technologies

Technology groups	Aerospace technologies (AQA)
Aircraft	Aircraft
	Cabin equipment
Aircraft parts	Engines and accessories
	Interior finishing
	Landing gears / floats
Defense equipment	N/A ⁶⁷
	Avionics
	Control towers
Electronics / avionics	Electronic / electrical components
	Electro-optics
	Ground communication / navigation
	Ground support equipment
Information and communication technologies (ICT)	Information technology / software
Instrumentation / automation	Hydraulics / pneumatics / automation
Maintenance, repair and overhaul	Maintenance, repair and overhaul
Materials	Composites and thermoplastics
	Raw materials
	Casting
	Contouring
	Fasteners / springs
	Machining / programming
	Parts processing
	Rapid prototyping
Mechanical manufacturing / machining	Sheet Metal / welding
	Shot peening
	Specialized containers
	Sub-assemblies
	Tooling and tools
	Test / inspection equipment
	Machinery
Satellites and components	Satellites and components
Simulation equipment	Simulation
Speciality chemicals and lubricants	Speciality chemicals and lubricants
	Design / calculation / certification
Technical consulting	Models
	Test / inspection
Other services and products	Other services and products

Source: the author, using information from the defunct AQA website: <http://www.aqa.ca>. Retrieved: 2010/09/25.

⁶⁷ "Defense equipment" is not part of AQA list of technologies, which is added here for the sake of completeness.

Since there is a wide variety of technologies, each one with its own product lifecycle, it is expected that the innovative performance of the industry players shall vary accordingly, that is, firms from more dynamic technological fields, such as electronics, avionics, simulation equipment and ICT, should have shorter innovation cycles. Thus, the technology segment is a fundamental variable of analysis that should be taken into consideration in the analysis of that data generated in this research.

The following subsections perform a brief overview of the aerospace market in three spheres: global (section 4.3), Brazilian (section 4.4) and Canadian (section 4.5). Before that, though, a brief history of the industry is presented in section 4.2.

4.2 Aerospace industry history

The birth of the aerospace industry is bonded to the rise of flying machines, whose invention is credited to a number of inventors and pioneers: Frenchman Henri Giffard performed in 1852 the first engine-powered flight on an airship (or dirigible); also Frenchmen Charles Renard and Arthur Constantin Krebs performed the first fully controllable free flight in 1884; American brothers Orville and Wilbur Wright performed the first fixed-wing self-propelled flight in 1903; three years later, in 1906, Brazilian Alberto Santos Dumont designed and flew the 14-Bis, the first fixed-wing self-propelled aircraft also capable of taking off under its own power, without the need of skids or catapults (MACKWORTH-PRAED, 1990).

The boost of the industry happened a few years later: military aviation began during the First World War (1914-1918), with the effective use of aircrafts in battle. A great development of the aeroplane followed this adoption of the vehicle as a war machine.

“The aeroplane started the [First World] war as an aerial intelligence agent or scout, for visual and then photographic reconnaissance – it was soon fitted with radio – and then added spotting for the artillery as another of its tasks. (...) As anti-aircraft fire improved, speed and climbing became growingly important, qualities which became even more vital when the machines had to defend themselves from attack by other aircraft (...) And so, out of the fast single-seat scout there was born the single-seat fighting-scout, or simply the ‘fighter’. When bombing was introduced, it was at first carried

out by the slow reconnaissance machines and later by the specialised medium and long-range bombers. But in between these categories, and superseding the old two-seat reconnaissance type, arose the general purpose machine (...) which could spot, spy, fight, 'strafe' targets on the ground and, in a small way, bomb. In addition, certain more specialised types were produced for special duties." (GIBBS-SMITH, 1960: p.88)

Commercial air transportation services began at about the same time, carried out at first by airships, though. The first airline on record is German DELAG⁶⁸, founded in 1909. The development of airplanes for air transportation purposes started later on, making use of the technological improvements of military aircrafts from World War I. In the 1920's the first commercial aircrafts were developed, such as the Dutch Fokker F.VII, capable of carrying eight (8) passengers. Nevertheless, civil aviation boost only happened after the 1937 disaster with the LZ 129 Hindenburg Zeppelin, which marks the decline of the use of airships for passenger transportation. The rise of the air jet airplane, in the 1950's, in replacement to piston-powered engines, allowed longer-distance nonstop flights and an increase in the number of passengers, which reduced the average air ticket price, which represented a second boost in the commercial flight sector (GIBBS-SMITH, 1960; MACKWORTH-PRAED, 1990).

Another relevant aircraft market within aerospace is that of helicopters. The origin of this air vehicle, as we know it today, took advantage of certain features in the development of airplanes during World War I that had become widespread since 1919. One might consider the starting point of the helicopter industry in 1942, with first flight of Sikorsky R-4, the world's first mass-produced helicopter. Sikorsky R-4 was the improvement of earlier experimental aircrafts on development since the 1930's (MACKWORTH-PRAED, 1990).

The defense segment is a little bit harder to characterize in historical terms, since part of its technologies existed prior to flight. One should analyze the history of every single technology within the segment, which would divert this text from the focus. Regarding the genesis of the defense industry within the aerospace domain,

⁶⁸ Deutsche Luftschiffahrts-Aktiengesellschaft

though, it is fairly reasonable to assert that it is closely related to the technology improvements of both Great Wars. Airborne artillery was first used during the First World War (GIBBS-SMITH, 1960). Flight communication systems just became an issue after flying was possible. Radar technology, which evolved from the sonar technology, was developed in the late 1930's, just before the Second World War, in order to prevent the UK from a possible airborne attack from German forces (SKOLNIK, 1990). Electronic warfare equipment development follows from the discoveries within radar and sonar technologies (USA, 2007).

Finally, regarding the space segment, its starting point is undoubtedly the so-called "space race" between the USA and the USSR during the so-called "cold war" (1947-1991), whose exponents were the launch of Soviet Sputnik I in 1957, the first manned moon landing in 1969, by the American Apollo 11, and NASA's space shuttle program during the 1980's (ANDERSON JR., 2008). More recently, it is worth mentioning the International Space Station (ISS) joint venture launched in 1998 (KITMACHER, 2010).

4.3 Current global aerospace panorama

The aerospace is an industry sector whose worldwide trades reached in 2009 US\$920.6 billion, and has gone through a growth of 8.7% from 2005 to 2009 (IMAP, 2011). Even though one must bear in mind the impact of the international economical crisis to the sector from 2009 to 2010, these numbers show that the industry comprises large amounts of resources, and is ascending to higher levels. In this section, the industry current situation is analyzed by segment, in consonance with the chart presented in Figure 39 (p.150).

Firstly, regarding the aviation sector, and considering the previously mentioned three-folded subdivision (commercial, regional and military), Table 13 describes each sector and lists its main players.

Table 13 Main global prime contractors in the aeronautic segment

Sector	Description	Main players
Commercial	Airplanes with capacity to more than 130 seats.	Boeing EADS Airbus
Regional	Airplanes, with capacity to 120 seats at most.	Bombardier Embraer ATR
Military	Use of airplanes for military purposes	Boeing Lockheed Martin EADS Airbus Dassault Aviation SA Finmeccanica (Alenia) SAAB ⁶⁹

Source: adapted from IMAP (2011); Gomes (2012).

Proceeding to the next sector, a general picture of today's helicopter industry market share is shown in Table 14, following the division between civil and military.

Table 14 Main global prime contractors in the helicopter segment

Sector	Description	Main players
Civil	Use of helicopters for civilian purposes.	EADS Eurocopter Agusta Westland (AGW) Bell Helicopter Textron UTC Sikorsky
Military	Use of helicopters for military and police purposes.	EADS Eurocopter Russian Helicopters Bell Helicopter Boeing

Source: adapted from IMAP (2011).

Besides complete aircrafts, the aeronautic segment also comprises large companies or groups that dominate the market at specific niches. Product niches within aeronautics may refer to relevant subsystems in terms of its contribution to the total cost to produce a large vessel (Figure 40), or to specific types of aircrafts (e.g. UAV or ULA).

⁶⁹ Just for information, although both Embraer and Bombardier, the two main players within the clusters under focus in this study, have military vessels, their names are not listed as market share leaders in this segment.

Within defense, once again it is hard to delimitate the boundaries of this industry, since defense companies are rarely comprised within aerospace, normally also integrating naval and army technologies, as well as private security systems. It is possible, though, to point some specific niches within aerospace defense.

Source: adapted from IMAP (2011).

Figure 40 Average components value as a percentage of total aircraft cost

Finally, the space segment is a segment still under scientific exploration and little commercial interest. The only activity within the space segment with relevant commercial interest is satellite launching and operation. But then again, it is normally performed by space agencies, which detains the expertise for such, which in their turn provide services to private-for-profit companies interested in exploiting the possibilities from satellite communications. Due to its commercial interest, the satellite industry is the largest niche within the segment.

Telecommunications companies and weather-services providers, for instance, are regarded here as end users of space technologies, and not as part of the industry. For that reason, space product development is government-oriented, through space agencies that perform most of the R&D expenditures in the segment. Space agencies are, thus, the prime contractors in the segment, which concentrate around them several equipment suppliers and subcontractors.

Assembling all together, Table 15 lists several product⁷⁰ niches and their respective global leaders, including aeronautic, defense and space niches.

Table 15 Prime contractors within other aerospace product niches (includes defense and space)

Sector	Description	Main players⁷¹
Composite materials	In search for light-weight structures, aerospace companies have turned their attention to the use of composite materials to replace metallic materials (aluminum and iron, mainly). It is normally done through the development of local suppliers.	Many
Propulsion	Propulsion systems are responsible for generating force to move aircrafts. The two major competing future concepts are the geared turbofan and the open rotor.	General Electric (GE) Rolls-Royce UTC Pratt & Whitney
Landing gears	Landing gears are mechanical systems used during takeoff, landing and ground taxing (when applicable).	Safran group Liebherr Goodrich Heroux Devtek
Fuels	Fuel suppliers are exploiting possibilities of alternative for aerospace applications.	Many
Avionics	Avionics is the term to designate all onboard electronic systems, including navigation, communications, monitoring displays and supervisory systems.	Northrop Grumman Thales Raytheon Honeywell Rockwell Collins BAE Systems
Simulation equipment	Flight simulation systems provide a virtual but realist environment for the purpose of training pilots.	CAE EADS Defense & Security SAAB
UAV	Unmanned Aerial Vehicles	Many
Airborne artillery	Airborne artillery comprises missiles, bombs and all other onboard artillery for aircrafts.	General Dynamics Co. ATK
Radars and communication	Radar and communication (onboard and/or ground) systems comprise all electronic devices aimed at proportioning higher flight security, as well as locating nearby aircrafts.	Raytheon Thales Finmeccanica (Alenia)
Electronic warfare	Electronic warfare refers to any action involving the use of the electromagnetic spectrum or directed energy to control the spectrum, attack an enemy, or impede enemy assaults via the spectrum.	Raytheon Thales Finmeccanica (Alenia) ITT

⁷⁰ Due to the focus of this study, we are not including here service niches, such as ICT services and aircraft maintenance and overhaul services, although we DO include them in the survey.

⁷¹ "Many" indicates segmented niches with no significant main players at global level.

Sector	Description	Main players ⁷¹
Satellites and components	This niche comprises companies that develop satellites and parts, normally through direct contract to space agencies.	Many

Source: the author, using information from OECD (2007); USA (2007); IMAP (2011).

As for the worldwide distribution of the industry, according to Ferreira (2009), the main countries within the aerospace industry are (in decreasing order of importance⁷²): USA, EU (mainly the UK, France, Italy, Germany, Sweden and Spain), Canada, Russia, Japan, Brazil, China and India. Table 16 presents the main characteristics of each mentioned cluster.

Table 16 Global market structure

Industry	Characteristics	Main cluster(s)
USA	Leader in the industry since World War II in all three segments. In civil aviation, Boeing had no match until the creation of the Airbus in the 1970's. In defense and space, the cold war made USA and Russia stand out from the rest of the world in terms of expenditures in R&D in these two segments, with American hegemony, though.	Seattle (WA) Wichita (KS) Dallas/Houston (TX) Los Angeles (CA)
EU	The weakness of European nations that followed the destruction caused by World War II made Europe lose its hegemony in aerospace to the USA. The solution found by Europeans to overcome the deficiencies of the local aerospace industry is to promote a consolidation of national champions into nationwide and continental conglomerates, with strong government intervention. The result is the establishment of large aerospace holdings, such as EADS (owner of Airbus), BAE Systems, Finmeccanica and Thales.	Bristol (UK) Toulouse (France) Bordeaux (France) Seville (Spain) Hamburg (Germany) Campania (Italy)
Canada	The Canadian cluster has grown especially since the Second World War. The cluster's most prominent segment within the industry is within civil aviation, highlighting Bombardier, a leader in the regional jets market. Defense and space activities are less intense, focused on high-technology niches supplied mainly to U.S. based companies.	Montreal (QC) Toronto (ON)
Russia	The Russian aerospace industry today is the legacy of USSR investments during the "cold war" period. A profound crisis followed the fall of the soviet government in 1991, and nowadays, public efforts are directed to resurrect the industry in the country.	Moscow Ulyanovsk Taganrog Komsomolsk-on-Amur

⁷² In terms of total revenues in 2007.

Industry	Characteristics	Main cluster(s)
Japan	The Japanese aerospace industry was paralyzed after the country's defeat in World War II. Afterwards, Japanese companies engaged in manufacturing aerospace systems of American design, under license from the U.S. government. Nowadays, the Japanese cluster is specialized in the development of aerostructures (e.g. wings, fuselage) and avionics.	Nagoya
Brazil	The Brazilian cluster is centered in São José dos Campos, induced by government facilities established in the vicinities. A few companies emerged from this environment; the most important is Embraer, a leader in the regional jets market.	S.José dos Campos (SP)
China	Until 1999, Chinese aerospace industry was concentrated in one only state-owned holding, the Aviation Industry of China (AVIC). Nowadays, the industry is distributed in four state-owned companies, one for civil aviation, one that serves as the space agency, one for large vessels and the fourth for medium-size aircrafts and helicopters. China's aerospace capabilities grow sharply every year and begin to defy the global industry leaders.	Nanjing Shanghai Suzhou
India	The Indian aerospace industry is primarily focused on the military and space segments. The aeronautic segment is centered in the state-owned Hindustan Aeronautics Limited (HAL), whose main business is in the production of military aircrafts under licence or designed by its own. India and China are the new entrants that most grow in the last years.	Bangalore

Source: the author, using information from Niosi et Zhegu (2005); Ferreira (2009); ECORYS (2009); Emerson (2012); Gomes (2012).

Regarding the genesis of such clusters, although each trajectory is unique, one notices that there are basically two sorts of clusters: induced and spontaneous clusters. Induced clusters are those whose genesis is connected to a government action. Examples of induced poles are the Brazilian aerospace cluster in São José dos Campos/SP area (discussed in section 4.4), the French cluster in Toulouse area or the Dallas/Houston cluster in the USA. In contrast, spontaneous poles are at birth private initiative with later government support; those are normally rooted on a person, a company or particular historical circumstances. Examples of spontaneous poles are the Canadian poles in Toronto and Montreal areas (discussed in section 4.5), or the American pole in Seattle area.

All this information provides a very general panorama of the aerospace industry, enough to allow one to conclude that it is a very hybrid and heterogeneous sector. With that general picture in mind, let us now move on to the two clusters on focus in this study, i.e., Brazil and Canada.

4.4 Brazilian aerospace industry pole

4.4.1 Market overview

A striking paradox in Brazilian aerospace industry is that, although the country is proud to have a Brazilian-born inventor among the pioneers of flight (Alberto Santos Dumont), the establishment of the industry has happened much later, and did not occur spontaneously, but by means of government intervention in the creation of the Brazilian aerospace cluster in São José dos Campos/SP, strategically located in between São Paulo and Rio de Janeiro, the two largest metropolises in the country.

The creation of the public research laboratory *Centro Tecnológico de Aeronáutica* (CTA) in 1946⁷³, and its establishment in São José dos Campos in 1950 along with the public higher education institute ITA⁷⁴, are the cornerstone of the aerospace industry in Brazil (FERREIRA, 2009; GOMES, 2012). Later on, in 1971, the establishment of INPE in São José dos Campos (BRASIL, 1971) consolidated the city as the aerospace cluster in Brazil.

The rise of aerospace companies is largely connected to these public institutes: when one investigates the individual history of many of the aerospace companies in the cluster, one finds that the founder, the owners and/or the main engineers are either graduated from ITA or former researchers from DCTA or INPE, when it is not both things. That is the case of Embraer, Mectron, Orbital and Neuron, to name a

⁷³ Nowadays DCTA (Departamento de Ciência e Tecnologia Aeroespacial)

⁷⁴ Instituto Tecnológico de Aeronáutica

few. This trajectory allows one to assert that the Brazilian aerospace cluster is an **induced** one, according to the discussion raised in the previous section.

The aerospace industry is one of the most prominent segments in the Brazilian economy. In 2010, it employed over 22,600 people, generated US\$6.7 billion in revenues, from which 73.8% are exports, and was responsible for 4.99% of Brazilian trade balance total exports (GOMES, 2012). It is the only high-technology industry segment in which the country has an outstanding performance at the global level⁷⁵ (FERREIRA, 2009).

The main segment within the Brazilian aerospace market is aeronautics, more specifically within the regional jets market, with its main player, Embraer, a global leader in the segment. In 2007, for instance, the aeronautic segment was responsible for 92.9% of total revenues in the Brazilian aerospace market, of which 84.5% is attributable to Embraer (FERREIRA, 2009), as shown in Figure 41.

Source: adapted from Ferreira (2009).

Figure 41 Brazilian aerospace market share in 2007

Although the country has a distinguished competence in this industry globally, the cluster is very dependent on foreign knowledge, even for the prime contractor Embraer. When analysing Embraer's supply chain, one realizes that 93% of its

⁷⁵ According to OECD (2010), a high-technology industry is one in which the output is a high-technology product. One may argue that other industry sectors in Brazil, such as Oil&Gas or Mining, have an even better performance than aerospace in terms of R&D achievements, however, these industries are not considered high-tech according to OECD classification.

suppliers are located abroad (FIGUEIREDO et al., 2008), since all risk-sharing partners are foreign companies with few or no local operations (FERREIRA, 2009).

Still within the aeronautic segment, another relevant niche market is exploited by Helibras, a subsidiary of EADS Eurocopter, the only helicopter manufacturer in Latin America. Helibras' business model is based on the manufacture, sale, overhaul and maintenance of aircrafts developed by Eurocopter, a member of the EADS holding that also controls Helibras (FERREIRA, 2009). However, recent announcements (e.g. NAKAMURA, 2012) state that the Brazilian subsidiary has established technology transfer agreements with the matrix in Europe and is now in charge of the development of the EC-725 and EC-225 models. In order to correspond to its new responsibility, Helibras is boosting its R&D capacity, through investment to increase internal resources, and also by means of collaborative alliances with local suppliers and STI (GOMES, 2012). And even the AS350 Esquilo, the model that Helibras has been manufacturing for several years, it is now being improved by Helibras R&D engineers, in collaboration with local partners (TECNODEFESA, 2010).

In the defense segment, the Brazilian productive structure is highly segmented, with small and medium enterprises acting in very specific niche markets (FERREIRA, 2009). As a result, players in this segment have very small economies of scale and scope, which makes it difficult for them to invest in self-dependent R&D infrastructures. One of the few alternatives for survival in this scenario is collaborative product development arrangements, such as the Atech-Omnisys joint venture for the development of the first 100% national S-band weather radar, which resulted in the establishment of the spin-off Atmos Systems (SILVEIRA, 2005), or Mectron's collaborative arrangement with Brazilian and South-African enterprises for the development of the fifth-generation missile A-Darter (SILVEIRA, 2009). One could argue that establishing joint ventures for specific programs is a worldwide trend within aerospace, even among world leaders. However, there is a striking difference in terms of scale and scope between international joint venture programs,

such as the AMX⁷⁶, and Brazilian defense joint ventures, such as Atmos. While the first was established to combine expertises, seeking a globally competitive product, the latter was established to develop an innovation at country's level, mostly to fill knowledge gaps, resembling Van de Vrande's et al. (2009) argument⁷⁷ about why SMEs perform open innovation.

Still within the defense segment, recent announcements (REUTERS, 2008; NERY, 2010) that the federal government is interested in purchasing fighter aircrafts in exchange of technology transfer agreements to Brazilian firms have attracted the interest of new players to the market. One such type of new entrants are foreign aerospace companies investing in infrastructure for R&D and manufacturing in the country, such as the French company Thales, which controls the Brazilian firm Omnisys since the acquisition of 51% of the company in 2005 (MILESKI, 2011), or the Swedish company Saab, which launched R&D facilities in Brazil in 2011 (PEDROSO, 2011). Another type of new entrants are Brazilian holdings from other industrial sectors that wish to enter the aerospace market by acquiring and reinforcing smaller local companies, in order to enhance their capabilities of responding to global competition. One example is the recent acquisition of Mectron by Odebrecht, the largest Brazilian company in the construction sector (ROLLI, 2011).

Finally, in the space segment, the least important in terms of its contribution to total revenues in the Brazilian industry, the development is biased by the modest Brazilian Space Program managed by INPE.

Among some failures and successes in the last 40 years, the space segment managed to develop two sounding rockets between the 1960's and 1970's (the SONDA and the VS-30 models), to implement two operational rocket-launching centres (in the cities of Natal/RN and Alcântara/MA) that provide launching services for Spatial Agencies from all over the world, given its privileged tropical geographical position, and to develop and produce a few satellites. In terms of

⁷⁶ See p.140

⁷⁷ Presented and discussed in section 2.2.5.

international collaboration, it is worth mentioning the CBERS (China-Brazil Earth Resources Satellite), a cooperative program between Brazil and China established in 1988 for developing, launching and operating Earth observation satellites that is currently developing its fourth spacecraft (CBERS-4) forecasted to be launched in 2014 (MARQUES, 2009). All these programs managed by INPE count on the collaboration of local and foreign firms through direct R&D contracts and are highly dependent on public resources for their accomplishment.

As a matter of fact, the role of the government is central to the funding and supporting of product development projects, and is a common characteristic for all three segments. This is the result of the effort from the local authorities to structure the national aerospace industry, a strategic segment for the national development plan. This topic is discussed in the following section.

4.4.2 The Brazilian innovation system and the aerospace industry

Brazilian policies for innovation are relatively recent, since the legal milestones that allowed governmental agents to promote innovation in private organizations are new. One can consider that the starting point for the kind of innovation public policies that are within the scope of the present work is the federal law n. 10.973/04, known as “innovation law”, issued in 2004 (BRASIL, 2004). Based on the French law on the same theme (FRANCE, 1999), this law established the principles on which government agents (federal, state or city) can promote innovation within their territories. The main themes of the law are the following (BRASIL, 2004).

- Establishment of environments for specialized and collaborative innovation (e.g. technological parks);
- Mechanisms to stimulate public STI to take part in the innovation process in collaboration with private-for-profit companies, including the commitment that all public STI should have an internal agency or department (the so-called Technological Innovation Cores, or NIT⁷⁸, in

⁷⁸ Núcleo de Inovação Tecnológica

the Portuguese acronym), responsible for managing all issues related to collaboration and intellectual property in the institute;

- Granting permission for benefits to stimulate in-house innovation in firms, such as tax incentives, issued in the following year (BRASIL, 2005);
- Supporting independent inventors;
- Granting permission to the creation of investment funds with public resources to finance innovation.

Before the innovation law, public agents were legally forbidden from giving any pecuniary support to private-for-profit companies. This fact limited the government capability to support innovation. There were some indirect ways to fund innovation, such as financing R&D projects in collaboration with public STI (universities or public laboratories). But even so, in this case, the resources had to be directed to the STI, never to the company. The innovation law is then the legal resource that enabled the government to issue public policies to directly benefit private-for-profit companies.

Since Brazilian public policies are new, they are still in the process of modification and adaptations to best suit the needs of Brazilian firms. Nevertheless, it is possible to brush a general portrait of the public policies for innovation in the aerospace industry. Table 17 draws such a picture for a typical aerospace company residing in the cluster in São José dos Campos, in the state of São Paulo.

One can infer from Table 17 that the main federal agencies responsible for granting innovation benefits are FINEP⁷⁹ (for funding programs), BNDES⁸⁰ (for financing programs), CNPq⁸¹ (for the fellowship grants program) and the Brazilian federal revenue agency (RFB⁸²), responsible for managing and supervising tax

⁷⁹ Financiadora de Estudos e Projetos

⁸⁰ Banco Nacional de Desenvolvimento

⁸¹ Conselho Nacional de Pesquisa

⁸² Receita Federal do Brasil

incentives. CAPES⁸³ should be added to these agencies, except for the fact that its programs are directed exclusively to academic projects, this agency does not manage any program eligible to innovative firms.

⁸³ Coordenação de Aperfeiçoamento de Pessoal de Nível Superior

Table 17 Main innovation public policies for the Brazilian aerospace cluster in São José dos Campos/SP

Policy type	Source (agency)	Program	Description
Tax incentives	RFB (federal)	“Lei do Bem” (BRASIL, 2005)	Set of tax incentives for companies that perform R&D activities, including: income tax credits proportional to expenses and investments on R&D; reduction of federal sales tax rate (IPI) for the acquisition of equipments for R&D; tax exemption for expenses related to registration and maintenance of intellectual property rights (e.g. patents) abroad.
Tax incentives	RFB (federal)	Special taxation rules for the aeronautic sector – RETAERO	Exemption for PIS/COFINS federal tax for selling or importing aeronautic parts and components (includes R&D).
Funding	FINEP (federal)	“Subvenção econômica”	Grants for radical innovation projects within specific strategic topics for companies of any size. It is the largest public funding program in Brazil.
Funding	FINEP (federal)	Sector funds	CT-ESPACIAL and CT-AERO are sector funds for investments on collaborative R&D projects between public STI for space and aeronautic firms, respectively.
Funding	CNPq (federal)	RHAE program	Fellowship grants for researchers to perform R&D projects within private-for-profit innovative companies.
Funding	FAPESP (state)	PIPE program	Grants for radical innovation projects for small and medium enterprises (SME).
Funding	FAPESP (state)	PITE program	Grants to STI that perform R&D projects in collaboration with firms of any size.
Financing	BNDES (federal)	“Capital Inovador” “Inovação Tecnológica” “Inovação Produção” “Programa Juro Zero”	Set of financing programs from federal agency BNDES that provides soft loans for innovation. “Capital inovador” is aimed at financing investments on R,D&I infrastructure while the other three allow a mix of costs including investments and expenses.
Financing	AFP (state)	“Fundo de inovação paulista” (FIP)	Soft loans for innovative technological start-ups in the state of São Paulo.
NPS	SPTec (state)	Technological Park of São José dos Campos (PqTec)	PqTec is a place for residing aerospace technology firms along with research laboratories and academic laboratories. Residing companies benefit from the proximity to STI, as well as a deduction in some state taxes rates.
NPS	SENAI (PNFP)	Training and specialization courses	SENAI is a private non-for-profit (PNFP) institute of public interest that offers technical and technological specialization courses of interest for the local industry.
NPS	ITA/DCTA (federal)	Aerospace training	Military research and high educational institute ITA performs specialized research in the field and offers technical courses to professionals in the aerospace cluster.
NPS	CECOMPI (PNFP)	Brazilian Aerospace Cluster	This cluster, managed by the a PNFP organization CECOMPI is intended to gather together firms of the aerospace value chain and organize the aerospace cluster.
NPS	Many	Technology incubators	São José dos Campos counts with four incubators for start-ups, mostly focused (but not limited to) aerospace companies: UNIVAP, REVAP, INCUBAERO and INSJC.

Source: the author, using information from CGEE and ANPEI (2009); FIESP (2009); <http://www.receita.fazenda.gov.br>; <http://www.finep.gov.br>

In the state sphere, the agencies vary. Particularly for the state of São Paulo, the main agencies are FAPESP⁸⁴, mainly responsible for managing state grants for academic projects, and AFP⁸⁵, the state bank assigned for managing public loans for firms residing in the state, also responsible for the soft loans programs aimed at innovative businesses in São Paulo state.

Non-pecuniary support (NPS) for innovation is often given by STI (public and private) and/or private-non-for-profit (PNFP) organizations of public interest that usually count with some governmental support to subsist. A remarkable aspect is that aerospace and defense are often regarded as strategic for public policies in Brazil. Evidence is found in the “Subvenção Econômica” program from FINEP (mentioned in Table 17): since the program’s launch in 2006, defense and aerospace have been present in all editions of the program (which is intended to happen annually) to date. Besides, this industry counts on two (2) sector funds (also mentioned in Table 17), out of a total of 14 existing sector funds, not to mention the existence of technological parks and incubators dedicated to companies in the sector.

4.5 Canadian aerospace market

4.5.1 Market overview

Aerospace is an important industry sector for Canadian economy as a whole. According to Emerson (2012), in 2010, among top aerospace powers, Canada ranked 5th in terms of total revenues. However, when regarding it as a share of the total gross domestic product of the country, Canada ranked 2nd, just behind the USA. This information highlights the importance of the industry to national economy as a whole. In spite of that, aerospace is not a science and technology priority for the Canadian government, still according to Emerson (2012).

In 2010, the aerospace industry in Canada employed over 66,000 people, generated US\$ 22 billion in revenues, exported 80% of its output (EMERSON, 2012).

⁸⁴ Fundação de Amparo à Pesquisa do Estado de São Paulo

⁸⁵ Agência de Fomento Paulista

Canada is one of only a handful of nations with a full range of aerospace design and manufacturing capabilities. Even though a number of leading companies in the Canadian aerospace industry are subsidiaries of foreign corporations, in most cases they have been assigned on mandates to manufacture for the world market (GARNER et LALONDE, 2002).

The birth of aerospace in Canada is linked to the first pioneers of flight. Alexander Graham Bell, known for his contribution to telecommunications, also contributed for the flight industry. While in Canada, Bell turned his genius to kite design. In 1907, Bell formed the Aerial Experiment Association, responsible for the design of the Silver Dart, the first airplane to fly over the Canadian sky (EMERSON, 2012).

The history of the cluster is closely related to Bombardier, Canada's principal aircraft manufacturer and, along with Boeing, EADS Airbus and Embraer, one of the only four civil aircraft manufacturers in the world today. Bombardier originated from the incorporation of two longstanding companies: Canadair, which started in the 1920s as the Aircraft Division of Canadian Vickers Ltd in East Montréal; and Toronto-based De Havilland, active in Canada since 1928 (GARNER et LALONDE, 2002).

Both companies have taken advantage of the expertise of Bell's association,, which was first established by private initiative: in its early years, what allows one to classify the Canadian cluster as an **spontaneous** cluster.

Both Canadair and de Havilland benefitted from World War II to boost. As a matter of fact,

In 1938, the Canadian aerospace industry employed about 4,000 workers and produced 40 planes a year. (...) At the peak of wartime production, the industry employed some 120,000 men and women and produced 4,000 aircraft a year. (EMERSON, 2012: p.11)

Before the war, Canadair designed and manufactured a series of airplanes, starting with the Vedette, the first Canadian flying-boat design; during World War II it fell under federal ownership, and played an important role in the production of

military aircrafts for the Allied Forces; Toronto-based de Havilland, originally a subsidiary of the de Havilland Aircraft Company of England, sold and serviced aircraft designed in the UK. Manufacturing started during World War II (GARNER et LALONDE, 2002).

In 1974 the government purchased de Havilland to secure the development and production of the Dash 7 and the continued operation of the company as an aircraft manufacturer in Canada (GARNER et LALONDE, 2002). In 1986, both de Havilland and Canadair were privatized. Bombardier, at the time a ground transport company with no previous expertise in aerospace, bought Canadair and a few years later, in 1992, acquired de Havilland, which was first bought by the Boeing Commercial Aircraft Company (EMERSON, 2012), forming the Bombardier Group as we know it today.

The Canadian aerospace cluster has also shown, since the early years of aviation, a vocation to propulsion design. In that direction, the government contributed in 1944, when the National Research Council (NRC) of Canada established Turbo Research Ltd in the Toronto suburb of Leaside. Pratt & Whitney Canada Inc (PWC), the 2nd largest aerospace company in Canada is a subsidiary of Pratt & Whitney established in Canada since 1929, which has grown during World War II, due to the substantial use of Pratt & Whitney engines by the Allied Forces during the war (GARNER et LALONDE, 2002). Currently, there are more than 49,000 PWC engines in service on more than 28,000 aircrafts in 200 different countries (EMERSON, 2012).

This historical overview of the industry would be incomplete without reference to Canadian Aircraft Electronics (CAE). It was founded by Mr. Ken Patrick, an ex-Royal Canadian Air Force (RCAF) officer, and has grown from a fledgling post-war electrical and electromechanical repair and overhaul service in Montréal to become the world's leading supplier of full-motion simulators of commercial and military aircraft (GARDNER et LALONDE, 2002).

The 3rd largest company in the industry is Bell Helicopter Textron Canada, headquartered in Mirabel, in the Montréal metropolitan area. Bell's operations in Canada began not a long time ago; its Mirabel facility opened in 1985, when production of the Bell 206 was moved from Texas. Afterwards, noticing the benefits from the Canadian aerospace cluster, Bell has shifted design and production of its complete line of civil helicopters to Canada (GARDNER et LALONDE, 2002).

These four companies (Bombardier, PWC, CAE and Bell) constitute the four prime contractors of the cluster, around which several equipment manufacturers and subcontractors establish a complex and varied network of companies that form the cluster (AÉROMONTRÉAL, 2012a).

In space-related activities, Canada's industry is modest by comparison with the USA, Russian and European industries, but Canadian capabilities are world class in selected niches. Among the famous successes it is worth mentioning the Alouette I, a sounding satellite developed jointly with NASA in the 1950's and launched in 1962; the landing gear used in the Apollo lunar module "Eagle" that first landed on the moon, manufactured by Héroux, nowadays Héroux-Devtek, a Quebec-based company; the Remote Manipulator Arm (known as Canadarm) developed for the US space shuttle program in the 1970's; the second generation Canadarm and SPDM "space hand" that is being used to build the ISS (GARDNER et LALONDE, 2002; KITMACHER, 2010).

Although the cluster's genesis was spontaneous, it is clear that government support was fundamental to its development. Next, the text takes a closer look at Canadian public policies to foster innovation.

4.5.2 The Canadian innovation system and the aerospace industry

In comparison to Brazil, Canadian innovation policies are more mature. According to Bibbee (2012), making Canada a global science and technology leader has long been a policy objective. Support for innovation ranks very high on the list of government priorities. R&D and innovation policies have been in place in Canada for several years. Tax policies for R&D, for instance, are in place since 1944 (MADORE,

1989), nearly 20 years before the OECD issued the first edition of the Frascati Manual, which defined the standard for the classification and measurement of R&D activities and expenses, in 1963 (OECD, 2002).

Canadian R,D&I policy strategy is not to privilege some strategic technology sectors, but to support market-oriented innovation (BIBBEE, 2012). Despite the advantages and disadvantages of such a strategy, the fact is that most of the public policies are not aimed at specific industries and technologies, but are transversal to any technological segment.

In relation to other OECD countries, Canada has the second most generous tax credit program, after France, whereas direct funding of business innovation is one of the lowest (BIBBEE, 2012). The Scientific Research and Experimental Development (SR&ED) tax credit program, which is not limited to any specific sectors or technologies, costs the federal government approximately CAD\$3.53 billion, which represents roughly 55% of the total expenditure of the government in support of business R&D in 2010-11 (INDUSTRY CANADA, 2011). This is not to mention the CAD\$1.5 billion expenditure to the provinces and territories due to the top ups that they in general provide, with their own variants, in which Quebec's is one of the most generous (BIBBEE, 2012).

In spite of this evident preference for "neutral support" towards innovation, there is a smaller but significant budget for sector-specific programs. For instance, sector agencies may have a budget to have their own incentive programs. In the case of aerospace, the Canadian Space Agency (CSA) and the Defense Research and Development Canada (DRDC) are examples of agencies that offer grants for R&D projects in their area (INDUSTRY CANADA, 2011).

According to Emerson (2012), the largest aerospace-specific program to support innovation in the sector is the Strategic Aerospace and Defence Initiative (SADI), a refundable financing program to aerospace companies that has disbursed more than CAD\$400 million since its creation in 2007.

Nevertheless, according to Bibbee (2012), the most valuable support that Canada offers to its residing companies is a rich supply of knowledge, which is achieved in part by strong support to public research institutes and high-impact academic production. Furthermore, Emerson (2012) asserts that, for the aerospace sector, the National Research Council (NRC) has five laboratories through which it works in collaboration with universities and the industry.

Table 18 summarizes the main public policies opportunities available for a typical aerospace company residing in the Montreal cluster. Federal government support is given mainly via the NRC and the three granting councils: NSERC, SSHRC and CIHR for the natural, social and health sciences, respectively (BIBBEE, 2012). Financing services are entitled to the Business Development Bank of Canada (BDC). However, as Table 18 highlights, there is a number of other government agencies that also contribute to business innovation within the Canadian system of innovation. Industry Canada (2011) asserts that this panorama comprises more than 100 programs and institutes.

In the state sphere, it is worth mentioning the funding programs of the now defunct MDEIE, which sponsored a number of funding programs directly or through provincial public agencies, such as the FQRNT (AÉROMONTRÉAL, 2012b). It is also through provincial initiative that programs such as the aerospace cluster AéroMontréal and CRIAQ research consortium are supported.

Nevertheless, since Canada's philosophy for supporting innovation does not aim at strategic sectors, the outcome is that aerospace R&D is supported roughly at the same intensity of other industrial segments. This fact distinguishes Canada from other OECD countries: while more than 60% of business aerospace R&D performed in the USA is funded by the government and about 40% in Germany, in Canada only 16% of business R&D in aerospace is funded by public resources (EMERSON, 2012).

Table 18 Main innovation public policies for the Canadian aerospace cluster in Montréal/QC

Policy type	Source (agency)	Program	Description
Tax incentives	CRA (federal)	Scientific Research and Experimental Development (SR&ED)	Income tax credits and/or refunds proportional to expenses and investments on R&D activities.
Tax incentives	RQ (provincial)	Scientific Research and Experimental Development (SR&ED)	Provincial top up to federal SR&ED tax credit program.
Funding	NSERC (federal)	Collaborative Research and Development (CRD)	Grants program for collaborative R&D projects between STI and firms.
Funding	NSERC (federal)	Industrial R&D Fellowships (IRDF)	Fellowship grants for researchers to perform R&D projects within private-for-profit innovative companies.
Funding	CSA (federal)	Space Technologies Development Program (STDP)	Financial and technical support granted by the Canadian Space Agency to Canadian organizations (industry and academia) to perform R&D on breakthrough technologies of interest for the space industry.
Funding	DRDC (federal)	Technology Demonstration Program (TDP)	Grants program for collaborative R&D projects between STI and firms in the defense sector.
Funding	MDEIE (provincial)	“Programme d'appui à l'innovation” (PAI)	Grants program aimed at technological start-ups and at the commercialization of technological innovations (for companies of any size).
Funding	FQRNT (provincial)	“Fonds Québécois de Recherche sur la Nature et les Technologies”	FQRNT is a Quebec government agency that provides funds for academic research, with or without industry collaboration.
Financing	IC (federal)	Strategic Aerospace and Defense Initiative (SADI)	Repayable financing to innovative projects at aeronautic, defense and space firms.
Financing	BDC (federal)	Technology Financing	The Business Development Bank of Canada (BDC) is entitled by the federal government to provide financial support, which includes soft loans, venture capital and consulting services to entrepreneurs.
NPS	NRC (federal)	Industrial Research Assistance Program (IRAP)	Federal government program that provides funding, management and entrepreneurial advisory and networking support.
NPS	CRIAQ (provincial)	“Consortium de Recherche et d'Innovation en Aérospatiale au Québec”	Research consortium, involving aerospace firms, universities, research laboratories and governmental agencies for defining, funding and implementing precompetitive R&D projects of interest for the industry.
NPS	AéroMontréal (provincial)	AéroMontréal aerospace cluster	This cluster is intended to gather together firms of the aerospace value chain and organize the aerospace cluster.
NPS	Montréal (city)	Technologic Parks	Montreal counts with four (4) technological parks for high-tech industries (includes aerospace): Technoparc, Pointe-St-Charles, Angus and Cité Scientifique.
NPS	Many	Technology incubators	Montreal counts with many incubators for start-ups, mostly focused (but not limited to) aerospace companies.

Source: the authors, using information from Industry Canada (2011); AéroMontréal (2012b); Bibbee (2012); Emerson (2012)

5 RESEARCH METHOD

*"The scientific method can teach us nothing else beyond how facts are related to and conditioned by each other."
Albert Einstein (1879-1955)*

In the previous chapters a discussion of all relevant issues to this research were discussed, namely: product development (section 2.1), open innovation (section 2.2), systems of innovation (section 2.3) and the aerospace industry (Chapter 4). Besides, in Chapter 3 a conceptual model is presented, which drives the survey comprised in the research method that is the subject of this present chapter.

The first step to define a research method is to properly classify the research.

Gil (2002) proposes that a research project shall be classified within two different dimensions: according to its goals and according to its method. This is the discussion in the first two sections in this chapter. After that, the following three sections detail the methodology adopted for the research.

5.1 Research classification

Depending on its goals, a research project can be classified as exploratory, descriptive or explanatory (GIL, 2002). According to Gil (2002: p.42), a descriptive research *"has as primary goal the description of the characteristics of a given population or phenomenon or, yet, to establish relation among variables"*.

As previously presented in section 1.5, this research project's goal is "to analyze the relation and impact of open innovation to technology development in the product development process of a traditional high-tech industry segment in Brazil within the metal-mechanic sector" (p. 52). Then, it aims at describing some characteristics (i.e. the degree of openness within innovation management) of a given population (i.e. an industry sector), and to establish relation among variables. Therefore, this research can be classified as a **descriptive research**.

5.2 Research method choice

As to its “method” or “technical procedure” adopted, a research project can be classified as literature search, documentary, experimental, *ex-post facto*, cohort study, survey, case study, field study or participatory action research (GIL, 2002).

Some research methods are simply not applicable to this project. This statement is true for documentary research, *ex-post facto* research, cohort study, field study or participatory action research.

Since OI is a relatively new theme in the literature on innovation, one believes that a literature search very likely would not lead to any conclusive findings, given the goals of this project. Very few articles refer to OI in the aerospace industry, and it has not been found any work that performs a systematic and extensive investigation of OI practices in the industrial sector.

An experimental research project would require the capability of influencing and testing variables within a considerable number of aerospace firms. Although it is theoretically possible to be done, in practice it would only work if the initiative came from the firms, and not the other way around.

The two research methods left are case study and survey, which constitute the two of the most used methods in industrial engineering and operations management research (NAKANO, 2010).

Initially, this research project was intended to perform a case study of open innovation in an aerospace firm in Brazil. Later on, with the opportunity to perform a comparative study in Canada with the collaboration of the industrial engineering department of *École Polytechnique de Montréal*, this initial plan was changed.

Nevertheless, a case study very likely would not provide the research any conclusive findings about the aerospace industry in general, due to the wide range companies specialized in different types of technologies that probably changes the innovation environment (hypothesis).

For all exposed, the research method adopted in this project is the **survey**, which, in the words of Gil (2002: p.50), *“is characterized by the direct inquiry of people whose behavior one desires to understand.”*

5.3 Propositions and hypotheses

According to Gil (2002), when a research goal is linked with the description of a population or a phenomenon, hypotheses are usually implicit and cannot be formally expressed. On the other hand, hypotheses are often clear when a study aims to establish the relation among variables. This research project combines both types of goals and, therefore, has implicit and explicit hypotheses. The importance of establishing hypotheses is to determine what is to be inquired by the research (GIL, 2002).

Since previous works in the literature exploring the adoption of OI practices in aerospace were not found, the idea behind the survey is to provide a general overview of OI practices in the PDP of aerospace companies. It aims at performing an extensive investigation in order to verify whether OI tools, concepts and values are adopted in aerospace product development. The three core processes (GASSMANN et ENKEL, 2004) are the starting point for the structuring the survey questionnaire. Through an extensive search in OI literature, this research was able to identify a few papers (namely: ENKEL et al., 2009; VAN DE VRANDE et al., 2009; DE JONG, 2007 apud DE BACKER, 2008; DAHLANDER et GANN, 2010), from which a list of pertinent issues associated to each one of the core processes could be extracted. This list is presented in Table 19.

Table 19 Issues within OI core processes

Core process	Issues associated
Outside-in	External knowledge/ technology sourcing
	Integration of the customer and/or user in the innovation process
	Integration of the supplier in the innovation process
	Licensing in
	Spin-ins, mergers and acquisitions (M&A)
Inside-out	IP portfolio activity
	Licensing out
	Spin-offs
	Spin-outs and divestments
	R&D outsourcing
Coupled	Co-development (with other companies)
	Collaboration with Universities and other STI
	Venture Capital (VC)

Additionally, Gassmann et al. (2010) identify nine perspectives needed to develop an open innovation theory more fully, namely: (1) spatial, (2) structural, (3) user, (4) supplier, (5) leveraging, (6) process, (7) tool, (8) institutional and (9) cultural perspectives.

Correlating the issues of Table 19 with the perspectives that are applicable to each one of them resulted in the matrix shown in Table 20.

This matrix served as a checklist for the first version of the questionnaire, in the sense that the inquiry on one specific issue should cover all perspectives that are relevant to it. In fact, after the questionnaire was made, the process vs. perspective matrix was filled with the numbers of questions that relates each applicable

perspective to the respective issue. This matrix with the question numbers is located in APPENDIX A.⁸⁶

Table 20 Core process vs. perspective matrix

Core process	Issues associated with the core process	Perspectives								
		Spatial 1	Structural 2	User 3	Supplier 4	Leveraging 5	Process 6	Tool 7	Institutional 8	Cultural 9
Outside-in	External knowledge/technology sourcing	X	X				X	X		X
	Integration of the customer and/or user in the innovation process			X			X	X		X
	Integration of the supplier in the innovation process				X		X	X		X
	Licensing in	X	X	X	X		X	X	X	X
	Spin-in and M&A						X	X	X	X
Inside-out	IP portfolio activity					X	X	X		X
	Licensing out	X	X	X	X	X	X	X	X	X
	Spin-offs and divestments					X	X		X	X
	R&D outsourcing	X	X			X	X			X
Coupled	Co-development (with other companies)	X	X	X	X	X	X	X	X	X
	Collaboration with Universities and other STI institutes	X	X				X		X	X
	External funding		X			X	X	X	X	X

However, before starting the confection of questions, some suppositions *a priori* were established in order to give an initial direction to the survey questionnaire. As a research that intends to verify the applicability of OI concepts, its hypotheses are derived from OI literature findings in other industrial sectors. Later on, after testing and validation of this questionnaire (described in section 5.4), three new hypotheses

⁸⁶ The question numbers in Appendix A correspond to the numbering of questions presented in Appendix B.

(H6, H7 and H8) were identified as relevant to the present research and added to the list. Table 21 presents the final list of hypotheses to be verified in this work.

Table 21 List of hypotheses

Seq	Hypothesis	Variables involved
H1	Collaborative companies are more innovative	- Innovation capacity - Strength of collaboration
H2	There is a correlation between the technological segment of a firm and its innovative capacity	- Innovation capacity - Technological segment
H3	Companies tend to perform outside-in activities more often than inside-out	- Outside-in innovation - Inside-out innovation
H4	Companies tend to be more collaborative in the development of pre-competitive technologies (i.e., those within basic and applied research). In other words, the higher the TRL, the lower the relevance of collaboration.	- Project TRL - Strength of collaboration
H5	In more traditional sectors – i.e., outside “open-dominated segments” (CHESBROUGH et APPLEYARD, 2007) – collaboration tends to be more concentrated within the boundaries of the industry.	- Strength of collaboration - Value chain position
H6	Well-structured IP management enhances a firm’s capacity for collaboration	- IP management capacity - Strength of collaboration
H7	Support from government and industry associations enhance local companies’ collaboration links.	- Government and industry association support - Strength of collaboration
H8	Brazilian aerospace firms are more open in relation to Canadian firms, because these firms and their local innovation systems lack enough structure to perform all innovation in-house.	- Outside-in innovation - Inside-out innovation - Coupled innovation

5.4 Questionnaire organization and data collection

The first thing one must have in mind when building an innovation survey questionnaire for the aerospace is that this industrial segment is quite heterogeneous, comprising companies of very distinct natures and technologies. Therefore, the questionnaire should not only be limited to specific questions regarding OI practices, but it ought to include questions that allow the correct characterization of the firm within the industry. Thus, it should also contain general questions about the company and its placement within the aerospace value chain, as well as general questions about its innovation processes.

To that effect, the initial part of the questionnaire (qq.1-33) encompasses questions that are similar to general-purpose innovation surveys, which follows the standards of the Oslo manual (OECD et EUROSTAT, 2005). As a matter of fact, these questions were inspired in nationwide innovation survey questionnaires run by government agencies. Particularly, this research used as models the Brazilian national survey on technological innovation PINTEC⁸⁷ (IBGE, 2008) and the Canadian survey of innovation (STATISTICS CANADA, 2005).

The rest of the questionnaire (qq. 34-71) is divided into three sections: the first addresses OI in the operational level (R,D&I management), the second aims at strategic issues and the third section regards cultural aspects. For elaborating such questions, additional sources were consulted. Due to the broad view of OI tools and processes that this survey is intended to provide, all topics tagged in OI literature as OI practices were covered in the questionnaire, however bizarre they may be for an aerospace survey. The list of topics covered and the respective sources used for elaborating the questions is found in Table 22.

⁸⁷ Pesquisa de Inovação Tecnológica

Table 22 OI topics covered in the survey questionnaire

Topic	Sources ⁸⁸
Collaboration with universities and STI	FABRIZIO, 2006 NIETO et SANTAMARÍA, 2010
Collaborative alliances	VANHAVERBEKE, 2006 NIETO et SANTAMARÍA, 2007
Core processes	CHESBROUGH, 2003a ENKEL et GASSMANN, 2004
Crowdsourcing	HOWE, 2006
Government support	CGEE et ANPEI, 2009 FIESP, 2009
Innovations intermediaries	CHESBROUGH, 2006 HOWELLS, 2006
IP protection	USDC, 2003 WIPO, 2004
Lead user method	VON HIPPEL, 1986
Open design	VALLANCE et al., 2001
Open source development	WEST et GALLAGHER, 2006
Peer production	BENKLER, 2005 TAPSCOTT et WILLIAMS, 2006
R&D services and outsourcing	GRIMPE et KAISER, 2010
Sources of knowledge	VEYBEL et PRIEUR, 2003
Spin-ins and M&A	HBS, 2000b CCRLC, 2005
Spin-offs and divestments	HENNESSY, 2000 ITURRIAGA et CRUZ, 2008
Technology intelligence	VEUGELERS et al., 2010
Technology scouting	ROHRBECK, 2007 HUSTON et SAKKAB, 2006
Technology Transfer Office (TTO)	USDC, 2003 WIPO, 2004
Technology transfer mechanisms	USDC, 2003 WIPO, 2004 LOS ALAMOS, 2006
Venture Capital (VC), funding and financing	CHESBROUGH, 2006 HELLMANN et PURI, 2002

⁸⁸ This list of sources is not intended to be an up-to-date literature review on OI, but just shows the references used when the first version of the survey questionnaire was made. Notice that all references are prior to 2010.

From these sources, and considering the hypotheses and perspectives under analysis, in 2010 a first version of the survey questionnaire was built. This first version was then used to perform an exploratory study with two goals, as follows.

- 1) Validation of the questionnaire itself, that is, to verify whether it would be able to provide reliable data for analysis;
- 2) Check the consistency of the hypotheses and to verify whether they make sense and/or there are other relevant issues that should also be added to the analysis.

This exploratory study was performed between October 2010 and April 2011. During this trial period, 15 companies were interviewed in Canada and 5 in Brazil. During these interviews, the interviewer was careful to inquire the respondents about relevance of the questions and to collect suggestions and impressions for future improvement.

This exploratory study resulted in a research paper (ARMELLINI et al., 2012), whose main findings are summarized as follows.

- The questionnaire was able to provide reliable data for analysis;
- IP protection in Brazil is much weaker in relation to Canada, and the impact of that in the innovative and collaborative performance should be added to the analysis (hypothesis H6 added in Table 21);
- Innovation public policies in Brazil are much newer than Canadian's, and, consequently, Brazilian government support programs are not as mature. Therefore, another hypothesis (H7 in Table 21) should be added to the analysis in order to verify its impact to local firms collaborative performance;
- Brazilian firms seem to be more prone to openness than Canadian ones. In order to explain this finding, we drew an hypothesis (H8 in Table 21) analogous to the findings from Van de Vrande et al. (2009) in relation to SMEs, i.e., that Brazilian aerospace firms (of any size) tend to be more prone to manage their innovation with greater openness, because these firms and the local systems within which they work lack enough

structure to perform all innovation in-house. Therefore open innovation would not be a choice, but a necessity for their survival in the innovation economy.

For this paper, in order to establish a reasonable comparison, only 5 Canadian companies were used, all of them within the electronics and ICT technological fields, narrowing the differentiation in order to compensate the small number of samples in the analysis.

Afterwards, using all information collected from the 20 first interviews, a second and final version of the questionnaire was built, where some relevant changes were performed. All 20 companies interviewed in the exploratory phase were contacted again in order to adjust the data accordingly. Table 23 shows the structure of the final version of the questionnaire, used for the complete survey run in 2012.

Table 23 Questionnaire structure

Section	Subsection	Questions
General information	General information about the interviewee	1
	General information about the firm and the plant	2-12
	Product innovation	13-18
	Process innovation	19-24
Innovation	Innovation activities	25-26
	IP protection	27-29
	Funding and support	30-33
	Sources of knowledge for R&D	34-38
R,D&I management	Integration of clients and users in the innovation process	39-40
	Integration of the supplier in the innovation process	41-43
	Licensing in	44
	Licensing out	45
	Peer production	46
	R&D services	47-48
	Collaborative alliances for R&D	49-53

Besides the English version, the questionnaire was also translated to Portuguese and French, so that all languages spoken in both loci of analysis were covered.

The results, analysis and discussion over the data raised through this survey are subjects for the next chapter.

6 RESULTS AND ANALYSES

“Do not be surprised with the flight altitude. The higher, the farther from danger. The more one rises, the more time there is to recognize a failure. It is when it is close to the ground that one should be wary.”
Alberto Santos Dumont (1873-1932)

The survey subset comprises a total of 53 aerospace companies, being 22 in Brazil and 31 in Canada, which provided detailed information between the years 2007 and 2011.

The sample is representative of the population under study. In Brazil, after studying the official aerospace catalogue CESAER (DCTA, 2011), we noticed that from the 270 companies listed in the catalogue, 150 are indeed aerospace companies⁸⁹, and only 59 of those perform research and development (R&D), according to the very description of activities of the companies in the catalogue. In Canada, from the 240 aerospace companies listed in the official MDEIE⁹⁰ (2012) directory, only 77 were considered a target for the study, once again though an analysis of the description of firms' activities in the directory. Therefore, the sample obtained represents about 37% (22/59) of the population in São Paulo and about 40% (31/77) of the population in Quebec.

In the following subsections, the primary data is compiled, first to characterize the sample (section 6.1), then to show their innovative performance (section 6.2). After that, open innovation is analyzed under three aspects: management (section 6.3), strategy (section 6.4) and culture (section 6.5). This distribution follows the survey questionnaire structure presented in Table 23 (p.186).

⁸⁹ The others are companies from other industrial segments (e.g. tires, carpets suppliers) that are occasionally suppliers for aerospace firms.

⁹⁰ By the time this text is being written we learnt that MDEIE (Ministry of Economic Development, Innovation and Export in the French acronym) has been merged in September 2012 with other two ministries to create the MFE (Ministry of Finances and Economy). Nevertheless, MDEIE aerospace directory is still the official and most trustworthy list of aerospace companies in Quebec, in our opinion.

Next, a general analysis and discussion of the results is performed in section 6.6, and the main findings and recommendations from the analysis are summarized in section 6.7.

6.1 Sample characterization

In this section one finds the compilation and analysis of the data from questions 1 to 12. Not all questions are covered here, only those whose result interest to the present analysis. Here, the goal is just to characterize the sample of analysis from which comes all results. There are two subsets of analysis, one for each country.

6.1.1 *Technology fields*

First of all, since the aerospace industry comprises a number of different technology fields, it is important to know from which fields are the companies that comprise the sample. This is shown in Figure 43. The fields follow the pattern defined in Table 12⁹¹ (p.153).

The only remark worth of note on this distribution is the high number of aircraft companies in Brazil. As a matter of fact, besides the prime contractors Embraer and Helibras, it is very common to find in the Brazilian cluster aircraft manufacturers that design and produce small aircrafts⁹², such as ULA and UAV. In the MDEIE (2012) directory there is not a single company of that kind, which may denote either that this niche is not focused in the cluster in Quebec or that this kind of company is considered part of another industry.

⁹¹ There are no samples for 2 categories defined in Table 12 and, therefore, they are not present in Figure 43. These categories are: 'Speciality chemicals and lubricants' and 'Other services and products'.

⁹² There are nine (9) in the CESAER catalogue (DCTA, 2011)

Figure 43 Distribution of companies in the sample by technology field

6.1.2 Industry sectors

Another dimension to characterize our subsets is the distribution of companies within the three aerospace sectors, that is, aeronautics, defense and space, which is shown in Figure 44. Since they can act in more than one segment at the same time, the distribution takes into account all possible permutations.

Figure 44 Industrial sectors distribution in the samples

One interesting remark on that is that 100% of the sample in Canada acts in the aeronautic segment, which denotes the prominence of this sector over the other two in the cluster. In Brazil, while the majority acts in aeronautics, there are some (~19%) that only act in defense and/or space segments. In both clusters, the most common

combination is to act in aeronautics and defense (and not in space), coincidentally accounting for about 55% in both clusters.

6.1.3 Value chain position

Next, companies are clustered according to their value chain position. As presented in Table 11 (p.151), there are four possible alternatives: prime contractors, equipment manufacturers, subcontractors or end users. Since this survey purposely does not include end users, only three clusters are present, as one realizes in Figure 45.

Figure 45 Value chain position distribution

These distributions are quite different from those of their respective local industries. In Brazil, from the 150 companies in CESAER catalogue (DCTA, 2011) there are 2 (~1%) prime contractors, 23 (~15%) equipment manufacturers and 125 (~84%) subcontractors; in Canada, from the 240 companies in the MDEIE (2012) directory, 4 (~2%) are prime contractors, 16 (~7%) are equipment manufacturers and 220 (~91%) are subcontractors.

The reason for such difference is that we prioritized companies that perform R&D, and not all subcontractors (which are in massive majority SMEs). If one takes into account only companies that perform R&D activities, in CESAER catalogue (DCTA, 2011) one finds 59 companies with the following distribution: 2 (~3%) prime contractors, 20 (~34%) equipment manufacturers and 37 (~63%) subcontractors; in MDEIE (2012) directory, from the 77 companies that perform R&D, 4 (~5%) are prime contractors, 16 (~21%) are equipment manufacturers and 57 (~74%) are subcontractors.

Contrasting the survey sample with the list of companies with R&D, in Brazil the survey covers all prime contractors (2/2), 55% (11/20) of all equipment manufacturers and only 24% (9/37) of subcontractors; in Canada, the survey also covers 100% prime contractors (4/4), 69% (11/16) of equipment manufacturers and only 16% (9/57) of all subcontractors.

As one can realize, the survey strategically focuses on the main players of the industry. Not neglecting the importance of smaller companies, neither that they have different challenges and motivations to innovate (VOSSEN, 1998; VAN DE VRANDE, 2011), this strategy is to guarantee that the main players of the segment are analyzed. Nevertheless, subcontractors are not neglected in the survey and account for about 41% and 61% in the Brazilian and Canadian clusters, respectively.

6.1.4 Firm size

Firm size is also an important dimension to analyze. In this survey a firm is considered an SME if it has 500 employees or less globally (that is, accounting all plants around the world). The distribution obtained applying this criterion is illustrated in Figure 46.

Figure 46 Firm size

A prominence of SMEs is observed in both loci, although with a higher intensity in the Brazilian subset. These distributions do not reflect the overall distribution of any local industries: investigating both the CESAER catalogue (DCTA, 2011) and MDEIE's (2012) directory, in both clusters the proportion between large companies

and SMEs is of about $1/9^{93}$. The subset in Brazil is closer to the national average, but then again, not too close. The reason for this distortion is that the survey primarily focused the main players (prime contractors and equipment manufacturers) which perform R&D. This profile is often more suitable for larger firms rather than SMEs. Therefore, this distortion from the national distribution is somehow expected.

Some countries define firm size in terms of total revenues, or a mix between number of employees and revenues. Although aware of the fact, this survey does not adopt such a criterion, since the survey questionnaire only inquires the total annual revenue of the plant where the interview took place⁹⁴, and therefore is not able to measure the size of the firm from this datum. There could be a plant that, although with small local operations, is part of a large multinational firm.

Nevertheless, the classification according to revenues would not be too different. Figure 47 shows a rank (in percentiles) of the companies in both subsets according to their revenues, keeping the label 'SME' or 'large company' from the criterion previously adopted. As one realizes, in Brazil the classification remains unchanged: there is a clear division line in terms of annual revenues between SMEs and large companies: all companies labeled as 'SME' had revenues lower or equal to US\$ 30 million, while all large companies had revenues in 2011 larger than this value. In Canada, however, four (4) firms that are considered large according to the number of employees criterion had smaller revenues in 2011 than some SMEs, causing the "spread" noticed in the Canadian bar of Figure 47. These four companies fall under the case previously mentioned: they are indeed part of large multinational companies; however, their local operations in Canada (at least in terms of revenues) seem like a SME.

⁹³ The exact proportion found is 92% of SMEs in Brazil and 88% in Quebec.

⁹⁴ The reason for not asking the firm annual revenue was to avoid different interpretations from companies that, although small, are part of large holdings. We believed that this could distort the analysis.

Figure 47 Distribution of SME and large firms according to the revenue percentile

Just for information, the US\$30 million division line that in Brazil clearly distinguished SMEs from large companies, in Canada would embrace four (04) companies labeled as SME among the large ones, while three 'large' firms would again be found among SME in terms of revenues. One notices, in the Canadian bar, a second division line at US\$50 million, above which no SME is found.

In spite of these differences, the criterion of number of firm employees (<500) to classify SMEs is kept throughout the survey.

6.1.5 Firm ownership

The last dimension analyzed to characterize the subsets regards the ownership of participating firms, shown in Figure 48.

Figure 48 Firm ownership

One notices a higher incidence of foreign companies in Quebec (45%), in relation to the sample in São Paulo (14%). Although we were not able to raise from our sources the exact proportion within the whole industry, this distribution

reasonably reflects the evident fact that there is a larger presence of foreign companies in the aerospace cluster in Quebec in comparison to the Brazilian cluster.

Another highlight from Figure 48, related to the previous note, is that the effect of the neighbor economies in Brazil is practically negligible within the aerospace industry, since there is virtually no presence of companies from other Latin American countries (members of the Mercosur trade agreement or not) in Brazil. On the other hand, U.S.-owned companies are very relevant for the aerospace cluster in Quebec, which includes large and important companies such as the prime contractors Bell Helicopter Textron and Pratt&Whitney and large equipment manufacturers with local R&D and/or manufacturing activities, such as Lockheed Martin and L-3 Communications. U.S.-owned companies account for 16% of the samples in Quebec.

6.2 Innovative performance

In this section one finds the presentation and analysis of the results of the issues addressed in questions 13 to 33. The questions in this section follow the standards of general purpose innovation surveys, such as PINTEC (IBGE, 2008) in Brazil and the Canadian survey of innovation (STATISTICS CANADA, 2005).

6.2.1 *Product innovation*

This subsection is to show the general results for the questions that inquire how many product innovations the plant developed during the five years of analysis within the survey (2007-2011).

First, regarding the distribution innovation for goods and services, Figure 49 shows a relatively similar distribution between the Brazilian and the Canadian subsets. Most companies performed at least one product (goods and services) in both clusters. As expected, innovation in goods are more usual (87% in Brazil and 80% in Canada), but an interesting remark is that service innovation rates are not too low: about 60% of Brazilian firms and 58% of Canadian firms claimed to have performed at least one service innovation in the five years.

Figure 49 Goods and services innovations

The main locus of innovation development is quite similar in both countries: when inquired who developed these product innovations, 75% of the companies in Brazil claimed that they were mainly developed by the firm, while the rest (25%) asserted that it was the firm in collaboration with other firms or organizations; in Canada, the rates were 71% and 29% respectively. There was not a single company, either in Brazil or in Canada, which claimed that internal innovations were mainly developed externally. It indicates that product innovation is considered a core competence for these companies and is strategically kept internal even though sometimes the responsibility is shared with other players. This corresponds exactly to what Pavitt (1984) defines as a science-based industry, which is exactly the taxonomy in which the aerospace industry sits⁹⁵.

Regarding the impact of such innovations, though, Figure 50 shows a relevant difference between the Brazilian and the Canadian samples: while in Canada there is a prominence of world-level innovations (that is, innovations that are novelties for the global market), in Brazil the most common level of impact of product innovation is at the continental level (including the Mercosur).

⁹⁵ Pavitt (1984) proposed a division of innovative firms within four categories or taxonomies: (i) **supplier-dominated firms**, normally associated with very traditional industries (e.g. textiles), in which innovation is in general performed by their suppliers; (ii) **specialized suppliers**, in which innovation arises from their interaction with customers; (iii) **production intensive firms**, associated with mass-production scale-intensive industries such as automotive and consumer's goods and; (iv) **science-based firms**, in which products exploit new scientific discoveries. Archibugi (2001: p.418), in a review paper about this taxonomy, explicitly cite aerospace as a science-based industry.

Although this information alone is not sufficient to prove it, it indicates that Brazilian firms innovation strategies are often aimed at “replacing imports”, that is, to level up national products in order to be able to compete with international products that are more advanced in technological terms. In contrast, Canadian firms seem to be more engaged in R&D at the cutting edge of aerospace technologies.

Figure 50 Highest product innovation impact

As for the number of product innovations performed, they are highly variable. Actually, it depends on the very business of the company: a company that supplies small components may incur a high rate of product innovations, since their product is simpler; on the other hand, a aircraft producer takes several years to take to the market a innovative product. But that does not mean that the small-component supplier is more innovative than the aircraft manufacturer. This information should be clustered by business type in order to produce meaningful information. But then again, the subsets are too small to allow this kind of clustering, which would pulverize the data.

6.2.2 Process innovation

Regarding process innovation, Figure 51 shows the distribution of companies according to the three types of process innovation inquired in the survey questionnaire.

Figure 51 Process innovations

In order to produce a comprehensive illustration, in this figure innovation in logistics and in support activities were clustered, since they are less frequent and more similar with each other in comparison with the third type: manufacturing processes.

Comparing the results in Brazil and Canada, one realizes that Canadian firms seem to be more active in process innovation in comparison to Brazilian firms: roughly 32% of the participating companies in Brazil claimed not to have performed any process innovation in the five years (2007-2011); in Canada, this is only true for 16% of the samples. This difference is even more evident when regarding only innovation in logistics and/or support activities: about one third of the Brazilian subset have engaged innovations in these areas, while in Canada roughly 71% of the companies have performed such innovations.

Analyzing now the impact of such innovations, an interesting finding: contrasting the results obtained for product innovation (Figure 50), in process innovation, both in Brazil and Canada, a large proportion of firms (60% in Brazil and 48% in Canada) are engaged at performing innovation at the firm level and very few (20% in Brazil and 11% in Canada) claimed to perform at least one world-level process innovation.

This finding indicates an industry trend in aerospace: manufacturing processes within the industry are not in general in the state-of-the-art, with respect to the manufacturing technologies employed. As a matter of fact, it is known for every aerospace professional that, in general, manufacturing processes that have been

employed for some time in other industries, such as the automotive industry, are just now reaching aerospace companies. This is true for automation assembly, welding and painting, for instance (FALCÃO et KOBAYASHI, 2011).

Figure 52 Highest process innovation impact

Another evidence that indicates that process innovation is not as important for aerospace companies as product innovation is regarding the main player in the development of such innovations. Contrasting the information presented in the previous item, that there was not a single company that claimed that product innovation are carried out by external players rather than internally, for process innovation this scenario is quite different: in Brazil 20% of the firms claimed that process innovation is mainly developed outside the firm, 40% claimed that it is performed by the firm, in collaboration with other players and 40% that it is mainly internal; in Canada the results are similar: 15% of the firms relegate process innovation for third parties, 41% develop such innovations in collaboration and 44% develop process innovations internally. Nevertheless, one cannot assert that process innovation is not considered a core competence in the industry, given that a considerable proportion within both subsets claimed to carry out such innovations internally.

A final remark that is evident for both product and process innovation, in relation to the Brazilian cluster, is how the Brazilian industry perceives to be far more developed in relation to its neighbors in Latin America. The fact that there are no innovations at national level in both cases indicates that all innovations that are

novelty for the Brazilian market are automatically assumed to be innovation for the whole Latin America as well.

6.2.3 IP protection

Next, the survey questionnaire inquires which IP protection methods the firms use. Table 24 shows the percentage of firms that use each method, in both clusters.

Table 24 Adhesion to IP protection methods

Type of protection	IP protection method	Brazil	Canada
Formal methods	Patents and utility models	18%	48%
	Trademarks	23%	48%
	Registration of industrial designs	5%	23%
Strategic methods	Secrecy	55%	61%
	Complexity of design	45%	68%
	Lead-time advantage	18%	58%

As one realizes, the patterns of adoption of these methods is similar, although in terms of intensity, IP protection is more heavily adopted in Canadian firms than in Brazil. Comparing the adoption of formal methods of protection (patents, utility models, trademarks and industrial design registration) to strategic methods (secrecy, complexity of design and lead-time advantage), in both clusters a higher incidence of the strategic ones is observed. Notice as well a significant difference for the ‘lead-time advantage’ method, which indicates once again that Canadian firms seem to work close to the state-of-the-art, while Brazilian firms seem to be lagging behind in technological terms.

Regarding how IP is internally managed, the survey inquired about the internal organization to address these issues. The results are presented in Figure 53.

An expressive majority (about 73%) of the firms in Brazil claimed not to have a formal structure to manage IP, and only 14% claimed to have an established Technology Transfer Office (TTO) at the plant’s disposal. In Quebec, about one third (33%) of the firms asserted not to deal with IP formally, and 22% claimed to have a

TTO. In consonance with previous results, this information ratify that IP management is less intensive in Brazil in relation to Quebec.

Figure 53 IP management organization

6.2.4 R,D&I funding

The next issue in the survey is about funding sources for R,D&I activities. First of all, regarding only whether the company received any external funding in the five years (2007-2011), Figure 54 shows the distribution in Brazil and Canada.

Figure 54 External funding for R,D&I

Regarding the sources of external funding, Figure 55 shows the distributions found in both countries. It is worth highlights three pieces of information from this data:

- In Brazil, those companies which do use external funding sources prefer to use conventional sources (banks), while in Canada the most used source is the government;

- Canadian firms diversify more than Brazilian firms: as a matter of fact, Brazilian firms with external funding uses in average about 1.4 sources; in Canada, this average is 2.3;
- The use of venture capital, that is claimed by initial studies on open innovation as one of the “erosion factors” of the closed model, does not seem to be yet a trend in aerospace: no Brazilian interviewed plants use the source, and in Canada the frequency is low (13%).

Figure 55 Use of sources for external funding⁹⁶

6.2.5 Use of government programs

The last issue within this section regards the use of government innovation support programs. Figure 56 shows the distribution of companies according to the use of federal and/or state (in Brazil) and provincial (in Canada) programs.

The first information that stands out from this data is the massive use of such programs on the behalf of Canadian companies (about 97%) in comparison to Brazilian firms (73%). Another interesting information is about the high relevance of

⁹⁶ Values can add to more than 100% given that a firm can use more than one source at the same time.

provincial programs in Quebec (about 93% of the firms in the subset), in comparison to the state programs in São Paulo (around 27% of the firms).

Figure 56 Use of government support programs

Regarding the number of different programs, Canadian firms make use of 5.0 different programs in average (2.3 provincial / 2.7 federal); in Brazil, the average is 1.9 (0.4 state / 1.5 federal).

All these pieces of information show that innovation public policies in Canada are more disseminated and established, when compared to Brazilian policies.

Regarding the specific policies, Figure 57 shows the distribution in both loci of analysis.

Some considerations can be derived from these results:

- In Brazil, the most used program is that of grants for R&D projects, which is mostly due to the FINEP “subvenção econômica” program, presented in section 4.4.2;
- This same policy (grants for internal R&D projects) is only policy in which the Brazilian subset surpasses the Canadian, once again thanks to FINEP “subvenção econômica”;
- The resulting lower rates for the other policies reflect a concern that several SMEs respondents reported to the interviewer: that public policy makers in Brazil do not seem to take SMEs into consideration when designing support programs, given the constraints and eligibility criteria required to access such programs;

- In Canada, R&D tax credits is the most common policy used (about 90%), which is on consonance to the information given in section 4.5.2 that the SR&ED program is the most relevant in the Canadian system of innovation;
- In contrast, the R&D tax credit program in Brazil has very few adhesions (about 23%), mostly because SMEs have difficulties to fit the eligibility criteria for the program, lack of knowledge about the program and lack of confidence in federal revenue agency (RFB);
- Venture capital is once again very poorly adopted either in Brazil or in Canada, which corroborates a previous impression that venture capital is not a trend in the segment.

Figure 57 Adhesion to innovation public policies⁹⁷

6.3 Open innovation management

At this point, all characterization and all general innovation questions have already been addressed. Open innovation is now the issue at stake. The questions of this last part of the survey are split into three categories: management, strategy and culture.

⁹⁷ Idem to the previous note.

In this section, the focus is on open innovation management issues discussed in questions 34 to 53.

6.3.1 R&D activities

In the introductory part of this final section of the survey questionnaire, the reference model built and discussed in Chapter 3 is briefly presented. During an interview, the interviewer takes some time to explain the three-folded division of the product development process to the interviewee. An interesting perception, that has not been computed in the survey database, is that most managers interviewed quickly associated the model with the TRL classification, which denotes how the latter is a top-of-mind concept among aerospace managers in Brazil and Canada. Besides, many considered interesting the reference model approach, which considered knowledge and technologies as intermediate assets of the PDP. For some, it seemed to be something they have never thought about.

After defining basic research, applied research and development, the survey inquires which of these activities are performed by the plant (Figure 58) and by the larger firm (Figure 59).

As expected, the higher the TRL, that is, the closer the activity is to the final product, the larger the adherence of companies to the activity. Another finding that is expected is that few companies are engaged in basic research, which is a reality not only for the aerospace industry, but to industry in general. The higher rates for firms in relation to plants are also expected, since the plant is part of the firm.

One information that is not too trivial is that the proportion of plants in Quebec engaged in basic research is impressive (about 35%), even though it is lower than the percentage for applied research and development. Inquiring further on the nature of basic research projects, we found that the majority is due to the commitment of the plant to CRIAQ, the research consortium presented in section 2.1.8.3 (p.90).

Figure 58 R&D activities performed in the plant

Figure 59 R&D activities performed in the firm

Besides, all plants engaged in basic research (which includes Brazilian plants as well) are from dynamic technology segments in terms of innovation, namely: electronics, ICT, simulation equipment and technical consulting companies.

Data that might seem odd and deserves further explanation is that not all Canadian plants are engaged in development (the result found is about 97%). As a matter of fact, this is due to one single technical consulting company that claimed not to perform development activities in Quebec, but that is just engaged in research of in some technologies of interest for the cluster. Far from being a negative finding for the Canadian cluster, the fact that it is possible for a private-for-profit company to survive in the cluster based only on the provision of research services is an indication that this activity is a very dynamic one in the Province of Quebec.

Finally, regarding the number of different activities that firms are engaged in both clusters, the results from the survey are found in Figure 60 (for the plant) and Figure 61 (for the firm).

Excepting that consulting plant in Quebec that claimed not to perform development in the cluster, for all the others 1 activity means “development”, 2 activities means “applied research” and “development” and three means the previous two and “basic research” as well. Therefore, from the number of activities one perceives “how deep” R&D goes for the company. It is expected that a given plant that perform all three activities is highly engaged in R&D. And even though the numbers cannot state this for themselves, we assert so for knowledge of the facts and the plants involved⁹⁸: the higher the number of activities, the more intense is R&D.

Figure 60 Number of R&D activities in the plant

Figure 61 Number of R&D activities in the firm

From these results one observes a higher intensity of R&D in the plants (and firms) of the Canadian subset in relation to the Brazilian one.

⁹⁸ All interviews were performed inside the plant, which were therefore visited.

6.3.2 *R&D internationalization for multinational subsidiaries*

Although it is not within the goals of this research, there is an interesting finding from this survey, under an exploratory basis, that may interest scholars engaged in researching internationalization trends observed in multinational companies.

Gupta and Govindarajan (1994) propose a four-fold division of multinational companies' (MNC) subsidiaries, according to their R&D strategies. According to these authors, depending on the knowledge flows from and to the subsidiary, it can be classified as (i) global innovator, (ii) local innovator, (iii) integrated player or (iv) implementor.

This present survey does not inquire about knowledge flows between subsidiaries and the matrix of a given firm. However, from the measurement of R&D intensity in the local plant and in the larger firm, something can be inferred, at least in an exploratory basis. Considering only local subsidiaries of international firms in both subsets, through the comparison of the number of R&D activities in the plant and in the larger firm, one can verify whether the level of R&D in the local subsidiary is equal or greater than the rest of the firm (if the number of R&D activities is the same in both cases) or if it is lower than the rest of the firm (if the number in the plant is lower than in the firm). Performing this comparison to all local subsidiaries and grouping the results by cluster, we found that two thirds (about 67%) of MNC subsidiaries in Brazil have lower intensity of R&D in comparison to the larger firm, which allows us to raise the hypothesis that they are simple implementors, using Gupta's and Govindarajan's (1994) classification. In Canada, about only 14% of the local subsidiaries claimed to perform less R&D activities than the global firm. These results are shown in Figure 62.

Through the data raised in this survey we are not able to perform the inverse analysis, that is, how MNC owned by the local clusters (Brazil and Canada) strategically use their subsidiaries around the world. For that, the questionnaire

should cover questions regarding knowledge flows among the matrix and its subsidiaries, but this is not part of the scope within this research.

Figure 62 Level of R&D of subsidiaries in relation to larger firm

6.3.3 Sources of knowledge

After inquiring about the types of R&D activities performed by the plant, for each type the survey presents a list of internal and external players, from which the respondent ought to provide the degree of importance of each given player for each type of R&D activity. To avoid misinterpretation or bad data, the interviewer's role during this part of the interview is to continuously recall the respondent to which activity the importance is being given, and also to stress that this importance is about the player's contribution to the activity as a source of knowledge, no matter whether through direct contact (e.g. partnership arrangements) or by distance. There is a similar question ahead in the survey questionnaire to inquire exclusively about partnerships.

This exercise provided a rich dataset that is presented and analyzed here. The importance degree is given by a 7-point Likert scale with no central point. All results presented here are obtained through the calculation of the simple average of all answers provided to the same object (i.e. the importance of a given player at a precise activity). One must recall that this average in most cases is not performed over the whole subset, but only within those companies in which the question is applicable. If, for instance, the company claimed not to perform the given activity (basic research, applied research or development), a whole set of question is skipped. For firms if one only plant, the player "firm R&D" does not make sense and is also skipped. Finally,

CRIAQ is only applicable for Canadian firms, and is not inquired in the Brazilian survey.

Regarding initially internal players, Figure 63 show the results for internal plant R&D staff. As expected, respondents in both countries attributed a very high level of importance to this player, and this importance grows with the TRL. This result is consonant to what is discussed in the product innovation item (section 6.2): since this aerospace falls under the “science-based” industry, according to Pavitt’s (1984) taxonomy, internal R&D staff is one of the most important within the innovation process.

Figure 63 Plant R&D as source of knowledge

Figure 64 shows the degree of importance of R&D staff from other plants. This is only applicable to firms which have R&D in other plants besides the one interviewed. The players’ importance is from mid to high, lower than in relation to plant R&D, which is expected since they are geographically farther from the problem. It is important to note that the absolute values may vary, since there is some subjectivity in scoring system. However, one easily recognizes that Brazil and Canada present a similar pattern of change throughout the PDP: importance increases from basic to applied research, and decreases again at development.

Figure 64 Firm R&D as source of knowledge

Next, Figure 65 shows the importance of other internal sources besides R&D staff. The player is of mid-importance in average (from 3 to 5). As for the evolution throughout the PDP, once again it is noticed a similar trend of evolution: its importance grows as the TRL increases. This is natural, since non-scientific personal as sales, marketing and manufacturing staff becomes increasingly important as the product approaches its launch in the market.

Figure 65 Other internal sources as source of knowledge

Going now for external players, the first kind of player are STIs. Figure 66 shows the importance of universities and higher education institutes.

Figure 66 Universities as source of knowledge

One observes in Figure 66 a similar tendency of decrease from applied research to development between the two curves, but the behavior is different when comparing the evolution from basic to applied research (one is high and decreases while the other is low and increases). However, the latter is not significant information, since the number of samples that perform basic research within both subsets is very small (especially in Brazil).

After universities, the next STI players under analysis are governmental and private non-for-profit laboratories and research institutes (Figure 67).

Figure 67 Public research labs sources as source of knowledge

As it happened in the previous case, Figure 67 also shows a tendency of decrease of importance from applied research to development. Once again, within basic research a different pattern is observed between Brazil and Canada, which can once again be attributed to the small number of samples under analysis.

The last STI type of player analyzed in Figure 68 are commercial private-for-profit institutes, which includes commercial labs, R&D firms and technical consultants. The same behavior observed in the last two graphs is observed in this case: there is a decrease in the level of importance from applied research to development, and a different pattern within basic research.

Figure 68 Commercial labs, R&D firms and technical consultants as source of knowledge

Analyzing all three types of STI players together, one realizes that, as expected, this kind of player is more important for lower TRL, the farther from the market the better. These results can only be stated between applied research and development. No conclusion can be drawn from basic research data, since the subset is too small to allow any deductive general conclusion: basic research data show the particular situation of the companies in the subset rather than general trends of the industry.

Moving now to industry players, Figure 69 shows the measurement of the importance of suppliers as sources of knowledge throughout the PDP. Similar to the pattern observed for clients in Figure 70, there is an increase of importance

throughout the PDP, which is directly proportional to TRL. Comparing, though, the absolute values for suppliers and clients, one realizes that the latter is considered of importance by aerospace firms interviewed: suppliers' importance average scores vary from 2.5 to 4.5 while this variation is from 3.9 to 6.0 for clients' importance.

Figure 69 Suppliers as source of knowledge

Figure 70 Clients as source of knowledge

After suppliers and clients, the survey inquires about the other aerospace companies that are neither of them, which includes competitors, which may be, for instance, object of a benchmarking or technology intelligence study. Figure 71 shows the general pattern for this category: one observes an increase of importance from

applied research to development; from basic to applied research there is once again an odd behavior: it was found the same average result in both cases (3.0), which does not follow the pattern of the rest of the curve. The overall importance of this player varies from low to medium.

Figure 71 Other aerospace firms as source of knowledge

Figure 72 shows the results for firms from other industrial segments.

Figure 72 Firms from other industries as source of knowledge

What can be stated from that is that the overall importance of this kind of player is low in both clusters, which denotes a tendency within aerospace companies

not to interact with other industries and/or markets (a closed innovation characteristic). As for the pattern of change throughout the PDP, there are no similarities between the curves that resulted from each subset.

The last group of industry players are industry associations, whose curves are found in Figure 73.

Figure 73 Industry associations as source of knowledge

What one can assert from Figure 73 is that industry associations are of mid to high importance as sources of knowledge for aerospace firms in both locations. The patterns of change are not too similar, although there seems to be a slight decrease in the level of importance from applied research to development, although the difference is too low to be sure whether it is significant or not.

The last player under analysis is a government player: CRIAQ. This analysis is only applicable to Canada, though, since there is no similar player in the Brazilian cluster to be compared to this consortium. Its curve is shown in Figure 74.

Over the whole subset, overall results are low, because they mix members and non-members. In general, CRIAQ members, with some exceptions, rank the consortium highly, while non-members see little or no importance of CRIAQ to their own businesses, which is expected. In order to separate the perception of importance of CRIAQ members from non-members, Figure 74 also shows a curve, whose

averages are calculated taking only members' answers into consideration. The curve pattern suggest that CRIAQ members perceive a mid to high importance of the consortium for basic and applied research (in which pre-competitive technologies are studied), but this importance drops for development, as expected.

Figure 74 CRIAQ as source of knowledge

An alternative approach to analyze sources of knowledge is found in the next three figures, which group sources' importance by R&D activity, that is, they compare the importance of all players within basic research (Figure 75), applied research (Figure 76) and development (Figure 77) by means of radar-like illustrations.

The random patterns drawn in Figure 75 corroborate the assumption that results within this activity are not significant due to the small number of samples under analysis. On the other hand, the patterns drawn in Figure 76 are quite similar for Brazilian and Canadian plants, and show a prominence of internal R&D and STI sources as the most important sources of knowledge for applied research. Patterns in Figure 77 are also quite similar in both subsets, and show a prominence of internal and industry players as the most relevant sources.

Basic Research

Figure 75 Sources of knowledge radar within basic research

Applied research

Figure 76 Sources of knowledge radar within applied research

Development

Figure 77 Sources of knowledge radar within development

To end this discussion about sources of knowledge, the survey also inquires about the geographical location of such sources. Table 25 shows the distribution within the Brazilian subset, whereas Table 26 shows the results in Canada.

Table 25 Location of sources of knowledge in Brazil

Type of source	Local	São Paulo (not local)	Brazil (not SP)	Mercosur	International	Do not use source
Universities	77%	14%	32%	0%	14%	18%
Government labs	68%	0%	0%	0%	5%	32%
Commercial labs	77%	14%	14%	0%	9%	23%
Suppliers	82%	59%	55%	9%	73%	5%
Clients	95%	55%	68%	32%	27%	0%
Aerospace firms	68%	41%	41%	18%	68%	9%
Other companies	32%	32%	32%	5%	18%	55%
Do not use any	0%	18%	18%	55%	9%	0%

Table 26 Location of sources of knowledge in Canada

Type of source	Local	Quebec (not local)	Canada (not QC)	USA	International	Do not use source
Universities	84%	48%	32%	23%	29%	13%
Government labs	48%	23%	48%	16%	23%	29%
Commercial labs	45%	32%	42%	39%	32%	29%
Suppliers	55%	52%	52%	58%	42%	23%
Clients	48%	42%	52%	65%	68%	23%
Aerospace firms	32%	29%	32%	55%	45%	39%
Other companies	29%	26%	29%	39%	26%	48%
Do not use any	10%	16%	13%	16%	19%	0%

Comparing the two tables, one verifies that, in Brazil:

- There is a strong concentration around local players, especially in relation to STL, with highlight for clients (95%);
- Mercosur countries as well as the whole Latin America are not relevant for aerospace firms in the subset as sources of knowledge except as potential (or actual) clients;
- The only two international players with high adoption as sources of knowledge are suppliers and other aerospace firms, which is explained by the fact that the Brazilian cluster is highly-dependent on foreign technologies and ought to rely on such international players to learn about and use technologies in the state-of-the-art of the industry;

In Canada, the rates are fairly more distributed. A highlight is due for local universities (84% of the respondents claimed to use them). Canadian firms present high rates of international clients that are regarded as sources of knowledge, which indicates that plants in the Canadian cluster have a stronger interaction with international players.

Notice the high rate of companies that do not use firms from other industry segments as sources of knowledge. In Brazil, it corresponds to 55% of the respondents, in Canada, 48%. This data corroborates with a previous impression,

from the analysis of Figure 72 (p.216), that aerospace firms do not to interact with other industries and/or markets.

6.3.4 *Early involvement of clients*

After generally inquiring about sources of knowledge, the survey begins to further analyze specific points within open innovation scope. The first point is about the early integration of clients and customers.

Figure 78 shows how often aerospace firms in both clusters claim to early integrate their clients in the PDP.

Figure 78 Early integration of clients

As one realizes, firms in the Brazilian cluster are more engaged in this open innovation practice in relation to Canadian ones. Given that many firms interviewed provide R&D services for the Air Forces and/or INPE, from the Brazilian space agency, this result reflects the fact that their direct contract development projects are regularly inspected by military authorities.

As for tools for involvement of clients, regardless the intensity their use, similar results are found in both locations, as Figure 79 shows.

Two relevant differences among results are the following.

- Firms in Quebec perform more codevelopment with clients (about 90%, in relation to 68% in Brazil). This collaboration may be at later phases of development, such as for customization of existing products, not during their development, because this rate is much higher than that of Figure 78, about early integration of customers;

- Firms in Brazil perform more R&D services for clients (about 77%, against 55% in Quebec). This information corroborates what has just been put above about the reason why Brazilian firms claimed to make broader use of early integration of clients in their PDP.

Figure 79 Customer involvement tools

After customer involvement, the survey performs a similar analysis of the early involvement of suppliers in the PDP, which is analyzed next.

6.3.5 Early involvement of suppliers

Figure 80 shows how often aerospace firms in both clusters claim to early integrate their suppliers in the PDP

Figure 80 Early integration of suppliers

The results are quite close in Brazil and in Canada. In both clusters most of the companies (50% in Brazil; 61% in Quebec) falls under the “rarely/sometimes”

category, which indicates that the practice is not usual, but it does happen. Few companies in both clusters (18% in Brazil; 10% in Quebec), claimed not to ever early integrate suppliers in the PDP.

Regarding now tools for involvement of suppliers, Figure 81 shows the results from the survey in Brazil and Canada. Once again highlight to codevelopment in Canada, which has a higher rate (55%) in comparison to Brazil (41%). Another difference worth of note is within “adoption of supplier’s new technology”: the higher incidence in Brazil (77% against 55% in Quebec) is one more indication of Brazilian dependency on external technologies.

Figure 81 Supplier involvement tools

6.3.6 *Licensing in*

The following issue is about licensing trends. Regarding the purchase of licenses, a higher incidence of licensing in is found in Canada, as Figure 82 shows.

Analyzing the source of these licences, Figure 83 shows quite similar distributions in Brazil and Canada. A significant difference, though, is about the purchase of licenses from STI sources in Canada, which is almost negligible in Brazil.

Figure 82 Licensing in rates

Figure 83 Sources of licenses purchased⁹⁹

The survey also inquires whether these licenses are part of a collaborative arrangement: in Brazil, around 18% of the companies use licensing in as a tool for collaboration, against around 26% in Quebec. In both countries, these companies are all from dynamic technology segments in terms of innovations (electronics, ICT, simulation equipment and technical consulting companies).

Even though the rate is a little higher in Quebec, the incidence is low in both clusters, and confined to some technology segments, which denotes that licensing is not a general trend within the industry.

⁹⁹ Percentages in Figure 83 are in relation to the firms that do purchase licenses at each cluster, and not in relation to the whole sample.

6.3.7 Licensing out

The survey inquires about licensing out in an analogous structure as done in the previous item. The results are found in Figure 84, which shows the licensing rates found in Brazil and Canada, and in Figure 85, which illustrates the destinations of the licenses sold by aerospace companies in the subset.

Figure 84 Licensing out rates

Figure 85 Destination of licenses¹⁰⁰

No Brazilian firms interviewed performed any licensing of own IP in the five years (2007-2011). In Canada, around 26% of the companies performed at least one licensing out in the same period. In relation to the destination of licenses in Canada, one notices a diversified spectrum of destinations for Canadian licenses, with

¹⁰⁰ The percentage is in relation to the total number of companies that did sell at least one license in the five years.

highlight to firms from other industries (around 50%) and STI. When analyzing from which technology segments the licensors belong, once again they are found among the same dynamic segments: electronics, ICT, simulation equipments and technical consulting firms.

From the results here, in consonance to the conclusion of the previous analysis, one realizes that licensing (in and out) is not a general trend within the aerospace industry, since there is a low incidence of licensing (in/out) in both clusters, and whenever it is found it is confined to the same specific technology segments.

6.3.8 *Peer production*

After licensing, the survey investigates whether peer production¹⁰¹ practices are adopted by aerospace companies. It may sound odd that peer production could be a trend in an industry segment such as the aerospace, often involved with military technologies, and therefore surrounded with secrecy and other IP related-issues. However, since the goal behind this research project is to perform an extensive study of open innovation in the industry, peer production could not be put aside.

Nevertheless, as expected, this kind of mass-collaboration tools does not seem to be a tendency among aerospace companies. The survey inquires about three specific practices: open-source software (OSS) development, open design and crowdsourcing. The results are shown in Figure 86.

All questions are within a 7-point Likert scale with no central point, as usual. Since the scoring for these practices is low, the cutoff for determining whether a plant adopts a given practice is '1', that is, the percentages obtained for Figure 86 reflect those companies did not answer '1' (never) to the practice.

As one realizes, as expected, peer production practices are poorly adopted by aerospace companies. The only type of peer production whose results are not negligible are in relation to OSS. But, then again, further inquiring about the

¹⁰¹ Peer production is described in section 2.2.5.1.

engagement on this practice, aerospace firms in both subsets qualify better as OSS users rather than as developers, that is, they integrate OSS solutions to their products, and are not part of the communities of open source developers.

Figure 86 Peer production practices

6.3.9 R&D services

Previously, in the item about early integration of clients, we have verified that aerospace companies in Brazil are engaged in the provision of R&D services through direct contract, mainly to the Air Forces and INPE. The survey questionnaire dedicates a whole section to the subject, which is here analyzed.

The results previously found are confirmed in Figure 87: once again Brazilian plants indicate a higher engagement in the provision of R&D services in comparison to what is observed in the Canadian cluster.

Figure 87 R&D services

Regarding the location of R&D services clients, Figure 88 shows the distributions found in Brazil and Canada. If on the one hand, Brazilian companies

perform such services more often, on the other hand, it is confined within local players and it is not part of collaborative arrangements, that is, it is mostly (around 67% of the times) through a direct service contract. The relatively high value found for the location “within the country (not in the State)” is because there are military facilities in Rio de Janeiro/RJ and the country capital Brasília/DF, as well as the rocket launch facilities located near to the equatorial line (Natal/RN and Alcântara/MA) that often contract R&D services from companies in the cluster in São José dos Campos and surroundings.

In contrast, there is a much more balanced distribution in Canada, with all locations with proportions ranging from 44% and 61%). Besides, one realizes that the most common reason (67% of the times) for the provision of R&D services is a collaborative arrangement, and not a direct service contracts.

Figure 88 Location of R&D service clients

6.3.10 Partnerships

The following topic under analysis is partnerships. This work considers a partnership any collaborative arrangement whose goals include the joint development of knowledge, technologies, products (goods/services) and/or processes.

Firstly, the survey inquires about some types of collaborative arrangements in which the plant may be engaged. Figure 89 shows the results for both clusters. The results are quite similar, except for two points: (i) the high rate of companies in Brazil which do not have any established partnership (41%, against 17% in Quebec) and, (ii) the high adhesion of our samples in Canada to research consortia, that is, to CRIAQ.

Figure 89 Types of collaborative arrangements

Next, from the same list of players previously used to inquire about sources of knowledge, the respondent shall indicate to whom his or her company has established partnerships, and where these partners are located. Table 27 shows the results in Brazilian subset, and Table 28 in the Canadian subset.

Table 27 Geographical distribution of partners in Brazil

Type of source	Local	SP (non-local)	Brazil (not SP)	Mercosur (not BR)	International	Do not use source
Internal (other plants)	5%	0%	27%	0%	9%	68%
Universities	55%	18%	27%	0%	9%	41%
Government labs	27%	5%	9%	0%	5%	73%
Commercial labs	36%	18%	18%	0%	5%	64%
Suppliers	32%	14%	9%	0%	32%	41%
Clients	45%	23%	45%	0%	9%	32%
Aerospace companies	45%	9%	18%	0%	27%	50%
Other companies	9%	5%	5%	0%	9%	86%
No partner at location	18%	59%	45%	100%	59%	14%

Table 28 Geographical location of partners in Canada

Type of source	Local	QC (non-local)	Canada (not QC)	USA	International	Do not use source
Internal (other plants)	13%	10%	26%	29%	39%	39%
Universities	65%	42%	32%	16%	23%	32%
Government labs	29%	16%	42%	16%	19%	42%
Commercial labs	35%	29%	26%	35%	26%	52%
Suppliers	39%	26%	39%	52%	42%	29%
Clients	45%	35%	39%	55%	45%	23%
Aerospace companies	29%	16%	19%	19%	19%	55%
Other companies	3%	3%	3%	6%	6%	94%
CRIAQ	71%					29%
No partner at location	10%	32%	32%	32%	32%	6%

Analyzing these two tables, some highlights are due:

- The distribution of partnerships follow a similar distribution as that observed for sources of knowledge (Table 25 for the Brazilian cluster and Table 26 for the Canadian one), with lower percentages, though;
- The Brazilian subset is less intensive in partnerships in comparison to Canada and is more concentrated locally;
- The Brazilian cluster is very poorly connected to international players: the only two worth of note are international suppliers, which reinforce that Brazilian companies rely on foreign technologies in their innovation process;
- Brazilian companies in the subset have not a single collaborative arrangements with players in other Mercosur countries, neither in Latin America as a whole;
- In contrast, Canadian companies have strong ties with players located in the USA;
- Local universities in both clusters have a high rate of partnerships, which denotes their importance to the local cluster;

- The interaction with clients in Brazil sits at national level, while in Canada there is a high rate of collaboration with foreign clients (USA and elsewhere);
- Likewise in the case of sources of knowledge, the samples in both countries indicate a lack of interest of aerospace companies in relation to firms from other industrial segments;
- CRIAQ is considered a partner for most Canadian plants interviewed (71%).

Next, from that list of players respondents are required to point the two most important to their innovation process. Figure 90 shows the result from this exercise: in both countries, the client is the “top-of-mind” within the respondents of our survey. In Brazil, universities come in second place, with 50% of nominations. Suppliers also have significant rates of nominations. It is also worth of note that CRIAQ was recalled by 10% of respondents in Quebec.

Figure 90 Top-of-mind partners

In other words, with the exception of the 50% nominations for universities in Brazil, the two “top-of-mind” players are clients and suppliers, which the innovation literature traditionally indicate as the most common collaborative arrangements (e.g. LIYANAGE et al., 1999).

Next, the survey investigates the reasons why companies engage in collaborative arrangements. The analysis is split in two: firstly it inquires about the motivations for collaboration with STIs (Figure 91), and afterwards to partnerships with other companies (Figure 92).

Figure 91 Reasons for establishing partnerships with STI

Figure 92 Reasons for establishing partnerships with other companies

Analyzing Figure 91, it seems that there are two prominent reasons for establishing partnerships with STI in Brazil: access to critical expertises and to renowned researchers; Brazilian firms in the subset give a smaller importance to reasons like cost reduction, access to public research and conduction of long-term research.

In Canada, in contrast, it was found a quite balance distribution among all reasons from the list with no particular reason(s) standing out from the others. Access to R&D structure is not an important issue for companies in both subsets.

Looking up now Figure 92, once again the search for critical expertises is at the top of the list in both countries. This is an important result, for it shows that, above all, knowledge is sought within collaborative arrangements, and not pecuniary or organizational benefits. Cost reduction comes in second place in Quebec in both cases; Brazilian firms, however, give a lower importance to this motivation, maybe because collaboration in Brazil is not performed as an option, but as a necessity (as we have risen as a hypothesis in this work). Since Brazilian plants do not have enough structure to perform innovation in-house, they go external not because they see cost benefits, but because they need to collaborate. As a matter of fact, since they do not perform innovations internally, they do not have the internal cost parameter to compare.

Another data that is worth of highlight is the high importance given in the Brazilian cluster for the access to new markets, which is a motivation very connected to open innovation.

6.3.11 Outbound practices

Finally, the last issue under R&D management is about some practices used by companies to get information from the market. Figure 93 shows the results for these so-called outbound activities.

The analysis here is very straight-forward: in both clusters, from the list of activities provided by the questionnaire, the only two that seems to be significant to a reasonable share of our samples in both clusters are technology intelligence and the participation at scientific events and/or trade fairs. Although more dynamic tools, such as innovation competitions or web portals to collect ideas do not seem to be a tendency in the sector, these results indicate that aerospace firms are at least externally aware.

Figure 93 Outbound activities

6.4 Open innovation strategy

In this short section one finds the analysis and discussion of the subject of questions 54 to 58. It embraces only two issues, analyzed next.

6.4.1 Spin-ins¹⁰² and acquisitions

The first one is about spin-in and acquisitions. Firstly the survey inquires how important this issue is for the firm's strategy. The results are shown in Figure 94.

Figure 94 Strategic importance of spin-in and acquisitions

¹⁰² Spin-in is the incorporation (merger) of a start-up or small business with its own.

In this figure, the 7-point Likert scale is split as follows: ‘1’ is taken as of “no importance”; ‘2’ and ‘3’ are grouped as “low importance” and higher answers (‘5’, ‘6’ or ‘7’) are grouped as “high importance”.

Although one finds no significant difference between the two distributions found from the adoption of the criterion just explained, the difference is evident when one analyzes the average of acquisitions and spin-ins within these three groups, as one sees in Table 29: in Canada the higher strategic importance of acquisitions and spin-ins is translated into more acquisitions, while for the firms in the Brazilian subset, regardless of the importance attributed to the activity, there is not a significant number of acquisitions.

Table 29 Average of acquisitions and spin-ins

Group of importance	Average in Brazil	Average in Canada
No importance	0	0
Low importance	1	2.67
High importance	1.14	4

That does not mean that a significant higher proportion of firms in Quebec are performing acquisitions and spin-ins, as Figure 95 shows. Those which performed such did it with a higher intensity, though.

Figure 95 Firms that performed spin-ins and/or acquisitions

6.4.2 Spin-offs¹⁰³ and divestments¹⁰⁴

Analyzing now spin-offs and divestments, as resulted in the previous case, this activity is not very broadly adopted by aerospace firms in both subsets, as one can infer from Figure 96 (spin-offs) and Figure 97 (divestments): a small proportion of the samples performed such activities during the five years on focus (2007-2011).

Figure 96 Firms that performed spin-offs

Figure 97 Firms that performed divestments

Looking now at the main reason for companies to create a spin-off, in Brazil, three companies (60%) claimed that the spin-off was the result of a successful joint venture, one (20%) that it resulted from a successful internal endeavor and the other (20%) that it is the result of the search for new markets. In Canada, two (50%) spin-offs created are the result of a search for new markets, one (25%) is due to strategic changes in the firm's business core and one (25%) was created within a strategy to increase firm's total revenues.

¹⁰³ A spin-off is an enterprise originated from another organization, which remains owned and managed by its founders.

¹⁰⁴ A divestment is characterized whenever the controlling enterprise loses possession of a business unit. It may happen due to a spin-out (creation of a new enterprise, as a spin-off, but in which the control is passed on to third parties) or due to selling or dismantling a business.

In relation to divestments, both (100%) divestments found in the Brazilian subset were due to changes in the firm's core business; in Canada, the reason for all divestments found in the cluster are related to the firm's core: in five cases (around 71%), the reason claimed is that the divested unit always diverted from the firm's core, the other two (around 29%) were due to changes in the firm's core.

As one can realize from all that, the creation of spin-offs found in the samples are in general bonded to an open innovation strategy, but there are very few cases found to allow any conclusion towards an industrial tendency in relation to open innovation. As for divestments, the motivations just presented show that it is connected to core business matters, therefore not related to open innovation.

Finally, within this section, and just for information, the survey inquired whether the companies under investigation are themselves the result of spin-offs or divestments. As Figure 98 show, this proportion is relatively low, but not that low in the Brazilian case: more than one quarter of the sample is constituted of firms originated from a spin-off (18%) or a divestment (9%).

Figure 98 Firms that resulted from a spin-off or divestment

The conclusion for this section is clear: although such strategic issues exist within our subset, their incidence is very low, which denotes a low intensity of acquisitions, spin-offs and alike.

6.5 Open innovation culture

In this final expositive section, one finds the analysis and discussion of the data from questions 59 to 71, which are focused on cultural aspects of open innovation. To analyze data, open innovation practices are labeled according to the three core-

processes defined by Gassmann and Enkel (2004), namely: outside-in, inside-out and coupled.

In this final part of the questionnaire, the respondent is required to answer how much these processes are part of the firm's day-by-day. Questions in previous sections of the survey questionnaire inquire about the facts (outcomes) and their importance of these processes; here, though, about their implication to the firm's daily routine.

In order to standardize the results in this section, a scoring strategy is established. For each activity inquired, a factor scale was performed in order to transform the scores from a 1 to 7 scale to a 0 to 10.

Later on, a score of the whole process is calculated, in order to perform comparisons among the three core processes. When the text reaches this topic, the scoring strategy is presented in details.

6.5.1 *Outside-in activities*

The first core process analyzed is the outside-in. Figure 99 shows the average scoring (from a 0 to 10 scale) of the practices labeled as outside-in activities. From the five activities listed as outside-in activities, both in Brazil and Canada, two obtained a high score (external sourcing and early integration of customers), one obtained an intermediary score (early integration of suppliers) and the other two had low scores (spin-in & acquisitions and licensing in¹⁰⁵). For these two low scores, even though they are low in both clusters, one observes that in Canada these scores are a little bit higher in relation to the Brazilian scores.

¹⁰⁵ Licensing may be part of all three core processes, depending on the direction (in or out) and whether it is part of a collaborative arrangement (for coupled) or not.

Figure 99 Outside-in scores

These results agree with other data previously presented:

- Aerospace firms are externally aware;
- The customer is the primary source of information for innovation; suppliers comes in second place;
- Licensing is not a tendency in the segment, except for electronics, ICT and simulation equipment companies in Canada; in Brazil, the whole subset is in general not intensive in the adoption of formal IP protection methods;
- Pecuniary and strategic methods as spin-in and acquisitions are not tendencies in both subsets, although their intensity is a little higher in the Canadian cluster.

Recalling that outside-in activities are more intense than inside-out (GASSMANN et al., 2010), and that normally companies begin their open innovation journey by initially adopting outside-in activities and, later on, inside-out practices, these results shall be compared to next analysis'.

6.5.2 Inside-out activities

Three activities are labeled as inside-out in the survey, namely: R&D services, spin-out and divestments and licensing out (not within collaborative arrangements).

Figure 100 shows the perception of the respondents about how they are part of the firm's daily routine.

Figure 100 Inside-out scores

Based in this information, some highlights follows:

- In both countries, inside-out scores are much lower in comparison to outside-in scores, as expected (GASSMANN et al., 2010);
- Patterns are also similar, excepting those activities that involve IP protection;
- The only high inside-out score in the whole subset is for R&D services in Brazil. This result corroborates with the fact that many samples are engaged in providing R&D services to the Air Forces and INPE through direct development contracts;
- Pecuniary activities of spinning-out and divestments are not a trend also outwardly;
- Although low in absolute terms, one notices a much higher score for licensing out in Canada, relative to the Brazilian score. This is due to electronics, ICT, simulation equipment and technical consulting firms in Canada, which are more intense in licensing than the other technology segments within aerospace.

The last core process is the coupled one, which is analyzed next.

6.5.3 Coupled activities

Figure 101 shows the scoring for all five activities labeled as coupled activities, namely: collaboration with other firms, collaboration with STI and three activities previously mentioned, but now in the context of collaborative arrangements: R&D services, licensing in and licensing out.

Figure 101 Coupled scores

Notice that, in this third case, scores are intermediary in relation to outside-in and inside-out. The analysis of these scores allows some comments:

- In both countries, the collaboration with industry players (suppliers and clients, for instance) is more frequent than with STI (university and research institutes);
- The scores for R&D services within collaboration are quite similar in Brazil and Canada, contrasting the results found in the inside-out analysis. That is to say that Canadian firms may not be much engaged in providing R&D services through direct contract, outsourcing its own R&D expertise to the development of other organizations' products, but they do provide R&D services within the context of collaborative arrangements, i.e., for developing a joint product;

- Once again IP tools are almost negligible, while in Canada they exist, although the intensity of use of such tools is low in absolute terms.

After analyzing each core process individually, in the next item all three processes are compared.

6.5.4 *Integrated analysis of the three core processes*

An interesting insight when one regards all three core processes together, as presented in Figure 102. In this figure, one calculates the average among all activities within a given core process. Through this operation, one gets the overall index for this core process.

Figure 102 Three core process indexes

Once again, similar results are found in Brazilian and Canadian subsets, which indicate that the intensity of openness is relatively similar. However, as discussed in the previous three sections, there are differences in the activities performed in the clusters, but those differences are compensated in the averages presented in Figure 102.

Another difference, discussed in sections 6.3.3 and 6.3.10, which Figure 102 does not show is that the motivation for opening and the geographical location of sources of knowledge and partners are quite different. As for the motivation, the type of players with whom Brazilian clusters collaborate and outsource indicate that they may be collaborating not for realizing a benefit in opening in relation to doing internally, but for necessity, for lack of internal choices; the same cannot be asserted

from Canadian results. Regarding the location, collaboration within the Brazilian cluster seems to be preformed mostly locally, while in Canada it was found a much more balance distribution with respect to geography.

Finally, we used the survey data to infer whether the findings from Chiaroni's et al. (2011) are observed in the subset. In order to do that, we have established for every company a cut-off score of '3' (in a scale from 1 to 7) in the core process index (outside-in, inside-out and coupled) in order to determine whether a given company can be considered to perform this core process.

Next, we have clustered companies in each subset according to the core processes they are engaged in, according to the cut-off criterion just explained. The result of this clustering among Brazilian samples is found in Figure 103; in Canada, it is shown in Figure 104.

What one notices in each countries' subset is that, discarding close innovators, that do not perform any of the three core processes, outside-in seems to be the first in which open innovators are engaged. There is not a single case of a company that is considered inside-out and/or coupled but NOT outside-in. This result is totally in consonance with Chiaroni's et al. (2011) findings.

Figure 103 The three core processes in Brazil

Figure 104 The three core processes in Canada

Comparing Brazilian and Canadian results, one realizes a smaller proportion of close innovators in Canada (19%) with respect to the result in Brazil (32%). In contrast, Canadian firms are mostly within the “outside-in only” cluster (37%), while in Brazil there is a small proportion of firms in this category (9%): open innovators in general perform outside-in and one other process. But then again, when one regards the proportion of companies that are fully open innovators, that is, which perform all three core processes once again the Canadian subset produced better results (17%) with respect to the Brazilian one (9%).

Therefore, one cannot state that Canada is ahead in the “open innovation journey” proposed by Charoni et al. (2011), but only that Brazilian and Canadian firms do undertake the open innovation journey, through different paths, though.

6.6 Critical analysis of the results

6.6.1 Statistical correlation tests

In comparison to all statistical correlation analyses that could be performed with the survey data raised in this survey, not much was performed in this direction. This point is stressed in the suggestions for future research projects (section 7.1). However, some critical variables and relations were tested in order to verify whether

the apparent conclusions from the descriptive data make sense in terms of statistical significance.

The statistical software used not only to this analysis, but also for creating all research variables from the survey primary data was Stata 11.1 SE (Student Edition) for Windows 64-bits. All correlation analyses performed are nonparametric, since sampling is in general too small (<30) to allow parametric testing. In order to verify whether a given correlation is statistically significant, a probability cut-off of $p \leq 0.05$ is used to determine significance; within $0.05 < p \leq 0.10$ the testing is considered marginally significant.

Table 30 summarizes the correlation analyses performed that presented relevant conclusions, with the variables involved, the correlation test applied and the resulting conclusion from the test. Each test is analyzed in the following paragraphs.

Table 30 Correlation testing summary

Test	Variables involved	Hypotheses associated	Correlation test	Results
1	IP intensity index Inside-out index	H6	Spearman	Only one marginally significant positive correlation (in Canada)
2	IP intensity index Coupled index	H6	Spearman	Two positive correlations were found between IP intensity and the engagement in coupled activities (one in Brazil and one in Canada).
3	“Scientific level” Core processes indexes	H4	Spearman	There is a positive correlation between the engagement in research (basic and or applied) and inside-out and coupled processes (in Canada).
4	Importance of sources within R&D	H4 / H5	Signed rank	Statistical signification was found for some (but not all) trends discussed in section 6.3.3 (in Brazil and in Canada).
5	Organizational indexes Core processes	H1	Spearman	Positive correlation between the core process and the corresponding organizational structures (in Canada).

As one can see, the tests indexed in Table 30 do not cover all hypotheses of the research listed in Table 21 (p.182). It does not mean that there were not any

correlation tests performed. The previous table just lists the correlation tests that achieved significant results that contributed to the findings and conclusions of this work.

The first analysis performed was to verify whether there is a correlation between the intensity of IP protection and the inside-out intensity. For such, we have defined an index to measure IP intensity, in order to be correlated to the inside-out index previously presented and analyzed (see section 6.5.4). This IP intensity index is defined as the total number of formal IP protections divided by the total number of innovations performed in the period of analysis. The correlation calculated for this test in this case is the Spearman's rank correlation coefficient (MONTGOMERY et RUNGER, 2007). The testing was performed over the whole subset, and also within some clusters, according to technology segment, nature¹⁰⁶, value chain position, revenues¹⁰⁷ and size¹⁰⁸. In any case, not significant results were found, only a marginally significant ($p=0.0819$) positive correlation is found when performing the test with the complete Canadian subset.

The second analysis is similar to the first one: now the IP intensity index is compared to the coupled index. In this analysis, two significant correlations were found: in Brazil, a significant ($p=0.0320$) positive correlation among companies in the electronics, ICT and simulation equipment technology segments. In Canada, the only significant correlation found was also a positive one, but among product-oriented plants. Although it is not much to find only two significant tests among so many (38), the interesting point is that they both (as well as the only marginally significant result from the previous analysis) showed a positive correlation, that is, a higher IP intensity implies in a higher capacity to couple and to share internal knowledge.

¹⁰⁶ The clustering by nature split companies in three groups: product-oriented, process-oriented and service-oriented.

¹⁰⁷ The criteria for clustering companies according to revenues are the following: (1) Less than US\$5 million; (2) Between US\$5 million and US\$50 million; (3) Between US\$50 million and US\$200 million and; (4) More than US\$200 million.

¹⁰⁸ SME or large firm, as previously adopted (see section 6.1.4)

The third analysis presented in Table 30 was to verify whether the engagement in lower TRL activities (e.g. basic and or applied research) would make a company more prone to collaborate. In order to test this correlation, we have created a variable to measure the “scientific level” of the plant or firm. This variable adds up the number of different R&D activities (basic research, applied research and/or development) performed by the plant and the firm (two variables were created) are engaged was correlated with the three core processes’ indexes. Once again the Spearman correlation was found the most adequate to this testing (MONTGOMERY et RUNGER, 2007). In Brazil, no significant results were found in this test. In Canada, however, a very strong positive correlation was found between inside-out index and the number of activities both the plant ($p=0.0034$) and the firm ($p=0.0047$). The same happened with respect to the coupled index (plant: $p=0.0072$ / firm: $p=0.0018$). In contrast, the correlation is not significant for outside-in activities (plant: $p=0.1509$ / firm: $p=0.1924$). That is to say, firms with inside-out and coupled are associated with companies engaged in research, not only development: the more engaged in research, the higher those two indexes. For outside-in that is not necessarily true: development-only companies may also have high outside-in levels.

The fourth group of tests performed, presented in Table 30, is with respect to those tendency curves presented in section 6.3.3. Although a descriptive analysis of the averages may result in a curve that shows an increasing or decreasing importance of a given player as one goes from basic research to applied research and finally to development, a correlation test may show whether this tendency is verified within each company or that it is just a mathematical coincidence with the average. A convenient test to verify it is the Wilcoxon signed-rank test (MONTGOMERY et RUNGER, 2007). For this nonparametric analysis, test must be performed in pairs, covering all possible permutations two-by-two, that is, (i) from basic research to applied research, (ii) from basic research to development and (iii) from applied research to development. Since the number of samples in both subsets engaged in basic research is small, no significant correlations were found for permutations (i) and (ii), except for some marginally significant results in Canada. On the other hand, for the third pair (applied research to development), some significant correlations

were found, namely: in Brazil, for internal plant R&D ($p=0.0263$), for other internal sources ($p=0.0434$), for clients ($p=0.0035$), for suppliers ($p=0.0056$) and a marginally significant result was found for the grouping of all internal sources together ($p=0.0509$); in Canada the significant correlations found are for universities ($p=0.003$), for public labs ($p=0.019$), for clients ($p=0.0357$) and for the grouping of all STI sources ($p=0.0044$). That is to say that, for these cases, the slope of the curve shown in the respective figure in section 6.3.3 have statistical significance; for the others, the slope may be just a mathematical coincidence with the average, and does not mean that the increase or decrease of importance noticed in the figure correspond to an actual correlation: a larger subset would be required to confirm that. However, the comparison between Brazilian and Canadian results gives in some cases another parameter of comparison, even though no statistical correlation was found.

The fifth analysis and last analysis summarized in Table 30 is to investigate whether the existence of organizational structures for outside-in, inside-out and coupled activities are followed with higher scores for the corresponding core process. In order to do that, it was required to create three other indexes that could measure how organized the plant is for each core process. This measurement is performed by adding some dummy variables (yes=1/no=0). For outside-in organization, the score is computed summing up the answers for questions 60 (department for outside-in), 61 (business processes for outside-in), 5500 (technology intelligence¹⁰⁹), 5502 (technology scouting) and 5505 (external web portals); for inside-out organization, the score is obtained adding questions 64 (department for inside-out), 65 (business processes for inside-out), 2900 (formal structure to manage IP), 2901 (TTO to manage IP) and 5400 (policies for generating IP); finally, coupled organization is measured adding up questions 69 (department for coupled), 70 (business processes for coupled), 5401 (IP protection in collaboration) and 5402 (IP protection in contracts). Once the variables are created, the Spearman's correlation test is applied

¹⁰⁹ This question is a Likert-scale and not a dummy. In this case, and for all similar cases in these organizational scores, the procedure to transform a Likert-scale into a dummy is to compare the value attributed by the company with the average of the whole subset: if the value is greater than the average, the dummy is '1', otherwise it is '0'.

(MONTGOMERY et RUNGER, 2007). In Brazil, no significant correlation is found; in Canada, on the other hand, all three tests resulted in a positive correlation between a core process and the corresponding organizational structure. A strong correlation is found in the case of outside-in ($p=0.00193$) and coupled ($p=0.0054$) and a marginally significant correlation is found for inside-out ($p=0.0524$).

To close this section, it is important to stress that these are not the only interesting correlation tests that could be performed. As a matter of fact, this is a suggestion for future work in the short term, as exposed in section 7.1.

Analysing the subsets themselves, our impression is that in Canada, due to the larger number of samples ($n=31$) more significant correlations were found in comparison to what is found in the Brazilian subset ($n=22$). However, these subsets complete one another, because sometimes an analysis that was found not to be significant in one subset is significant for the other, and that allows this research to presume on the other, under an exploratory basis.

One possibility that was not explored in this work is to combine all 53 companies into one only subset, and investigate more general industry trends one could find.

6.6.2 *Test of hypotheses*

Enlightened by the description and analysis of all data from the survey, this work is now able to discuss the eight hypotheses raised in section 5.3 (more precisely in Table 21 on p.182).

- **H1 - Collaborative companies are more innovative.**

Comparing the Brazilian and Canadian industries it is relatively easy to show through the descriptive data presented throughout this chapter that the Canadian cluster is more dynamic in the innovative performed, for a number of reasons: international presence, higher impact of innovations, wider engagement in research activities. It was also shown through data description that Canadian firms are more engaged in partnerships with more players in more different locations.

Analysing individual firms, though, it is harder to state the same. However, some correlations can be found in this direction that although are not strong enough to validate the hypothesis, at least point towards it. In Brazil, there is a significant correlation ($p=0.0456$) between the number of product innovations and the intensity of coupled activities. There is also a marginally significant result ($p=0.0681$) in the correlation analysis between the same coupled activities and the highest impact of innovation. In Canada, only one marginally significant ($p=0.0658$) positive correlation between product innovation highest impact and the outside-in index. All other correlation tests performed did not show any significant or marginally significant results.

- **H2 - There is a correlation between the technological segment of a firm and its innovative capacity.**

This hypothesis was found true in this survey. Through survey data analysis, one notices some technology segments that present higher innovative and collaborative dynamics, namely: electronics, ICT and simulation equipment. One may recall that previously we have also mentioned technical consulting companies, but this is true depending technological specialization of the consulting. Then again, among the innovative consulting firms interviewed, electronics and ICT are their technology fields of expertise.

- **H3 - Companies tend to perform outside-in activities more often than inside-out.**

This hypothesis, based on Gassmann et al. (2010) findings, was also found true in this work. This is evident, for instance, from the analysis of Figure 102 (p.243), where the scores for outside-in in Brazil and Canada were the highest from all three core processes.

This survey's data also verifies Chiaroni's et al. (2011) findings: a similar pattern of gradual adoption of open innovation can be inferred in Brazilian (Figure 103) and Canadian (Figure 104) subsets, starting with outside-in and only afterwards going for inside-out.

- **H4 – Companies tend to be more collaborative in the development of pre-competitive technologies (i.e., those within basic and applied research). In other words, the higher the TRL, the lower the relevance of collaboration.**

What this research is able to assert is that companies engaged in research (basic and/or applied) tend to be more engaged at inside-out and coupled activities. It was even found statistical correlation for this assertion (see test #3 in Table 30).

Outside-in is not inhibited by the proximity to the final product (higher TRL), because what companies are afraid of during development is to disclose their own technologies. Adopting Dahlander's and Gann's (2010) terminology¹¹⁰, since outside-in does not involve selling and revealing, but only sourcing and acquiring, this core process is also performed during this phase. The same is not true for the other two core processes.

Therefore, if one takes open innovation and collaboration in strict sense, this hypothesis is true: companies are in general more comfortable in being fully "open innovators" during the development of pre-competitive technologies.

- **H5 – In more traditional sectors collaboration tends to be more concentrated within the boundaries of the industry.**

The survey is also able to provide reliable information to verify this hypothesis. As discussed in sections 6.3.3 and 6.3.10, aerospace firms do not often source and/or collaborate with companies from other industry sectors. Collaboration and sourcing with industrial players tend to be more concentrated within aerospace domain.

One may inquire how different it may be at other industrial segments. As a matter of fact, such information would be of great interest to this work, however, it is not of our knowledge any paper in the literature that provides something like that.

¹¹⁰ Presented in Table 7 (p. 118)

- **H6 - Well-structured IP management enhances a firm's capacity for collaboration.**

Correlation tests #1 and #2 in Table 30 show some correlation between IP intensity and inside-out and coupled indexes. Although this evidence is not strong enough to allow a verification of this hypothesis, these results show some signs that it might be true.

Besides, when analyzing firms by clusters, survey results do show that the Canadian cluster, which is in general more structured in terms of IP management, is also more widely engaged in partnerships.

- **H7 - Support from government and industry associations enhance local companies' collaboration links.**

Once again, this hypothesis is easy to verify at the industry segment level, but hard to be verified at the firm level. The Canadian cluster presents a more effective set of public policies and technology support programs, including direct actions for enhancing firms' collaboration, such as CRIAQ, and IRAP. Besides, firms in the Canadian subset also performed better in terms of collaboration with regard to the Brazilian cluster. However, once again the findings from this work are not sufficient to verify this hypothesis at the firm level.

- **H8 - Brazilian aerospace firms are more open in relation to Canadian firms, because these firms and their local innovation systems lack enough structure to perform all innovation in-house.**

This final hypothesis was built as an analogy to Van de Vrande's et al. (2009) finding about SME and open innovation. According to these authors, SMEs are engaged in open innovation in a basis of necessity, since they do not have enough economies of scale and scope that would allow them to perform all innovation in-house. A similar hypothesis was drawn with respect to firms in emerging economies.

An interesting finding in this direction was obtained: through the survey we have observed that Brazilian firms rely on international suppliers and other

aerospace firms as sources of knowledge in their innovative process. We also verified that the impact of innovation in the Brazilian cluster is more often at national (and Latin American) level than at world level. These two points indicate a technological gap of Brazilian firms, which is compensated with an open innovation strategy.

However, it is not correct to assert that, because of that, Brazilian firms would be “more” open than Canadian firms. As a matter of fact, section 6.5 shows different patterns of openness between Brazilian and Canadian plants, but the final average openness rate is quite similar in both countries (see Figure 102). Therefore, this hypothesis is in part true, but should be reformulated. An alternative formulation is:

“H8 (alternative) - Aerospace firms in Brazil (emerging economy) and Canada (developed economy) have different motivations to engage open innovation practices. While in developed economies open innovation is regarded as an alternative to internal development, in emerging economies, because these firms and their local innovation systems lack enough structure to perform all innovation in-house, they regard openness as a necessity to carry out innovations.”

6.7 Findings and recommendations

Through this extensive survey, an interesting picture of the innovation dynamics of the aerospace industry in Brazil and Canada has been drawn. Through the various analyses performed in previous sections, some patterns can be identified, as well as some significant differences between Brazilian and Canadian plants towards innovation management.

In this section, which closes this chapter of results and analyses, some of these findings are recalled with the purpose of drawing recommendations to enterprises, STI and government in both countries, following the triple helix model (SÁBATO et BOTANA, 1968). These recommendations are organized in Table 31, which present the identified problem, the proposed solution and the triple helix player affected by the recommendation. Given the initial motivations of this work, most recommendations are applicable to the Brazilian case, however, some are directed to the Canadian aerospace innovation system. These recommendations are not

exclusively supported by the survey results, but also by personal impressions and shared confidences from the many visits to aerospace companies performed throughout the research project, as well as on the author's personal former experience in aerospace product development.

Table 31 Final recommendations from this work

Identified problem	Recommendation	Applicability
There is no central coordination of precompetitive technologies in Brazil	To create a research consortium in Brazil similar to CRIAQ in Quebec. Following the Canadian success model, the initiative of such a consortium could come from a STI, with institutional, managerial and financial support from the government. The author considers DCTA the most adequate player in the Brazilian aerospace cluster to head such a consortium ¹¹¹ .	Government / STI (Brazil)
In general, innovation in Brazil is of national impact, at most, with strategy focused on import substitution, which does not contribute to make Brazilian companies globally competitive	STIs in Brazil should stimulate product development of higher global market relevance in cooperation with private companies. The establishment of a consortium with periodical innovation forums to discuss relevant technology projects would also contribute to that.	STI (Brazil)
Companies in Brazil in general underuse innovation public policies	Brazilian companies should improve their organizational structures to be able to properly use public support programs. That is inclusive of having R&D accounting and managerial structures segregated from operational structures, following the ambidextrous organization concept (O'REILLY III et TUSHMAN, 2004), whenever applicable. Besides, Brazilian firms should be more active in getting to know about existing policies.	Enterprises (Brazil)
	The Brazilian government should strategically focus SMEs when designing innovation public policies, in order to grant their access to such resources, suiting eligibility criteria to their reality. Besides, the government should work toward a wider dissemination of existing policies with their potential users.	Government (Brazil)
	The Brazilian government should also create technology assistance programs, such as IRAP in Canada, to provide organizational, information and networking support to emergent business in the country.	Government (Brazil)

¹¹¹ In a previous paper (ARMELLINI et al., 2011a), we have analyzed the viability of the creation of such a consortium in Brazil. Although we have pointed some difficulties, we believe they are manageable.

Identified problem	Recommendation	Applicability
R&D in most Brazilian SMEs are in general directed for providing specialized services to governmental players and not for the development of products of their own	Brazilian companies should have greater concern in generate a portfolio of products of their own, from the R&D services provided to government customers (INPE and the Air Forces, for instance).	Enterprises (Brazil)
	In the same direction of previous recommendation, as well as companies should be worried about creating their own product portfolios, governmental players that outsource R&D services from them should make this creation easier. Some ways to do it includes the characterization of their needs as products that may be useful for a wider range of applications, rather than as mere parts of their own projects. Besides, direct contracts that demand R&D should be characterized as such, providing time and budget for development. Finally, these government customers should stimulate and be active in forming R&D joint ventures that are capable of producing products that meet not only Brazilian market needs, but that could also be globally competitive.	Government (Brazil)
The Brazilian cluster is too much centered in one big prime contractor (Embraer)	The government should create a favorable environment for large international aerospace firms (prime contractors and equipment suppliers) to establish facilities in Brazil that perform R&D activities. In the short term, one suggestion is to stimulate the coming of Embraer risk-sharing partners to the country, in order to bring to the Brazilian cluster their expertise. The cluster should learn from past failures, such as Kawasaki's and Liebherr's (GOMES, 2012), in order to understand what is missing in the cluster for these companies remain.	Government (Brazil)
	The government should bet on other aircraft manufacturers (e.g. ULA) in Brazil so that, following disruptive ¹¹² innovation model that has made Embraer grow in the past (CHRISTENSEN, 2003). One way to do this, is by providing specific policies to benefit them, in the same way Embraer was benefited in the 1970's.	Government / STI (Brazil)

¹¹² Clayton Christensen, one of the most renowned innovation experts in the world, formulated the disruptive innovation model to explain the rise of newcomers from unexpected markets, usually designed at a first moment to supply products to a less demanding market, but that gradually reaches the most demanding markets by continuous improvement of their product platforms. In his best-seller "The innovator's solution" Christensen (2003) claims that Embraer was one such case that followed the disruptive path.

Identified problem	Recommendation	Applicability
Companies in Brazil in general are not engaged in research	<p>Brazilian companies need to formalize their R&D structures as such. Without a clearly defined R&D, they shall have a hard time in capturing part of the value created from collaborative arrangements in which they are inserted, and therefore will not profit from open innovation, as advocated by Chesbrough (2003a).</p> <p>Besides, this formalization would make it easier to frame companies into the requirements of innovation public policies and support programs. Finally, as discussed elsewhere (ARMELLINI et al. 2011a), corporate R&D is also strongly recommended in order for companies to find interest in research consortia.</p>	Enterprises (Brazil)
Aerospace companies' collaborative links are too much centered within the boundaries of the industry	<p>Aerospace companies in Brazil and in Canada should look for partnerships beyond aerospace frontiers. Companies from industrial automation segment, for instance, could be interesting sources of process technologies; aerospace companies could also manage to find alternative application for advanced technologies in the segment, such as composite materials and flight simulation.</p>	Enterprises (Brazil and Canada)
VC is seldom used by aerospace companies as source of investments for creating new businesses	<p>According to Hellmann and Puri (2002) and Chesbrough (2003a), VC plays an important role in open innovation as an innovation intermediary, that goes beyond the contribution of traditional financing agents. Perhaps this low VC intensity in the industry is what prevents companies in both subsets to be more engaged on pecuniary open innovation activities (such as spin-ins, spin-outs and acquisitions).</p> <p>The recommendation here is two-folded: on the behalf of enterprises, there should be interest from enterprises to evaluate whether VC suits their business as a possibility to leverage internal technologies, or whether the dynamics of aerospace is not interesting and/or unsuitable for VC funds. On the behalf of the government, there should be an effort to evaluate the viability to create local viable VC funds aimed at aerospace technologies.</p>	Enterprises (Brazil and Canada)
Although economically relevant to Canada, aerospace is not a science and technology priority to the Canadian government	<p>There should be more public support programs for the aerospace industry. In addition, existing programs should be strengthened. Emerson (2012) provides several pertinent suggestions in this direction.</p> <p>Given the relative importance of the aerospace segment to national gross domestic product, Federal government should add aerospace as a science and technology priority, likewise does Quebec government.</p>	<p>Government (Canada)</p> <p>Government (Canada)</p>

7 CONCLUSIONS

"The only thing we know about the future is that it is going to be different."

Peter Drucker (1909-2005)

This research project is about the integration of open innovation within product development. Open innovation is an emergent mindset that is being observed in some technology segments, the so-called open-dominated segments (CHESBROUGH et APPLEYARD, 2007). Within this new mindset, firms become increasingly aware of external knowledge to be used in internal technologies and markets, as well as external opportunities for application of internal knowledge. The body of knowledge that is being constructed in the specialized literature is mostly based in the study of success cases within these open-dominated segments, mostly within the context of developed economies.

Based on that, this research project aimed at analyzing the applicability and relevance of open innovation within a context of product development that differs from what is normally observed in the exploratory literature on open innovation. Four research questions, attached to the research goals¹¹³, were raised in the introductory part of the text, which directed the whole research. In this final chapter, these questions are once more posed, for a closing discussion of the text.

1) "What exactly does open innovation stand for?"

By means of an extensive literature review, performed in Chapter 2, this work compared the findings and frameworks from several scholars and executives engaged on product development and innovation, as well as adjacent fields of knowledge, such as knowledge management, R&D management, industrial organization, to name a few.

This review allowed one to see that open innovation literature fits into the broader context of innovation management, and actually bring up a new insight for R,D&I managers to think when drawing and organizing product development

¹¹³ The research goals are presented in section 1.5 (p.52)

strategies for firms. Through this literature review one also realizes that although a body of knowledge is being formed, there are different understandings of the same concepts as well as the scope of open innovation, and that research projects such as this one need to be fully define the concept prior to engage in the specific goals of the research.

On the other hand, through the same literature reviews one realizes that in the last few years, papers in high-impact journals present a fairly uniform view of open innovation, with few or no contradictions among themselves, so that one can infer that now, responding to Dahlander's and Gann's claim in 2010, "*a coherent body of literature is being developed.*" (DAHLANDER et GANN, 2010: p.9)

This text presents this uniform and consistent view of open innovation, which is translated into a list of outbound practices that are split into three core processes that Gassmann and Enkel (2004) call outside-in, inside-out and coupled. Outside-in refers to all practices aimed at sourcing and incorporating external knowledge and technologies into the firm's internal technologies. Inside-out is a set of practices in the opposite direction, to look for external opportunities to profit from internal knowledge, technologies and expertise. Finally, the coupled process embraces those processes that are common in partnerships and other collaborative arrangements; in which outside-in and inside-out occurs simultaneously. This understanding of the concept fulfills research goal "a" (p.52).

Besides understanding these three core processes, another important issue discussed in this text to allow a consistent comprehension of the open innovation concept is to be aware that open innovation regards openness as an alternative to internal development, and must be attached to a business strategy that aims at capturing part of the value created through collaboration, sourcing and revealing. If there is no business model to capture part of the value it cannot be considered open innovation. Enlighten by this information, the text studies contiguous innovation and collaborative practices, such as open source software development and user innovation to understand what stands out open innovation from these practices, which fulfills the research goal "b" (p.52).

This extensive review on open innovation was particularly useful in this research to create the questionnaire used in the research survey, which performs a comprehensive investigation of open innovation practices within a plant.

2) “What are the implications of open innovation within the Product Development Process?”

In Chapter 3, this work closes the literature review with the proposal of a reference model that integrates open innovation to the product development process. This model is original in identifying intermediary assets the PDP that, in the open innovation mindset, shall be regarded as merchandise that may be bargained within collaborative agreements. However, in order to be offered as products, internal knowledge and technologies shall be structured and formalized as such, which constitutes a cultural shift in R&D management.

This reference model is also interesting for linking these intermediary products with the common outputs of basic research, applied research and development, the three R&D stages according to the Frascati manual (OECD, 2002), which makes easier for R&D managers to identify such assets. This model also fulfills research goal “c” (p.52).

3) “Is open innovation applicable to emergent economies as well as to developed economies? What differences and similarities shall be observed in the approach of open innovation for both realities?”

With a full understanding of the context, scope and definition of open innovation, the research project returns to the initial motivation of this work: study the concept within a different context of what is most commonly seen in the literature. The proposal is then to study the applicability of open innovation within the Brazilian aerospace industry, as defined in research goal “d” (p. 53).

However, in order to allow a comparison parameter, this research should perform the same analysis in Brazil and in a developed economy context, which in this case is Canada.

Through an extensive survey that took place from October 2010 to December 2012, this project raised a total of 53 companies, 22 in Brazil and 31 in Canada for this comparative study. Among the findings, we realized that open innovation is also a reality within emergent economies, although with a different motivation: while in developed economies, such as Canadian's, open innovation is regarded as an alternative to reduce internal development costs, in emergent economies, such as Brazilian's, open innovation is the only alternative for carrying out innovations, since the firms within this economy do not possess economies of scale and scope to afford performing all innovation internally.

With this insight in mind, what one should have in mind is that the way to motivate companies to go open in both clusters differ. In developed economies, such as Canadian's, companies already adopt tools that could also be used to collaborate (such as IP protection mechanisms, for instance); in this case, the role of policy makers should be to stimulate professionals to use these tools for becoming more externally aware and accessible. In contrast, in emergent economies like Brazilian's, policy makers and entrepreneurs should work together to fill the structural gaps that prevent companies to perform what they already realize as important to their product development process.

4) "How open is (and should be) innovation in more traditional high-tech industries, particularly in Aerospace?"

Finally, in order to accomplish research goal "e" (p. 53), regarding the specific case of aerospace through the survey, it is possible to identify similarities and differences in the patterns of open innovation in the two clusters: among the similarities one highlights the focus on the product, the early involvement of customers in the PDP, the strategies adopted regarding intellectual property (IP) protection, the concentration of collaborative arrangements within the boundaries of the aerospace industry and the low intensity use of pecuniary tools, such as venture capital, spin-offs and/or acquisitions. Among the differences, Canada stands out with respect to its innovation public policies and assistance programs, which are found to be more effective in relation to Brazilian policies. Besides, Canadian plants

seem to have a better innovative performance, at the cutting edge of aerospace technologies and higher international relevance.

The survey also finds that the intensities of openness in Brazil and Canada are quite similar, although the patterns and motivations differ: Brazilian plants are more engaged in providing R&D services under direct contract (and not within collaborative arrangements) to local customers, while Canadian plants seem to be more engaged in a wider spam of collaborative fronts in a wider geographical range. Besides, Brazilian plants are much less intense in the adoption of formal IP protection methods in relation to Canadian ones, which hinders (but not prevents) the full adoption of open innovation in the Brazilian cluster.

What should be done to improve the innovative performance is to fix the gaps identified in both clusters.

Especially in Brazil, there should be an effort from firms and the government to provoke a cultural change towards IP protection mechanisms. Efforts shall also be done in improving public policies to better suit local firms' needs. There should also be a greater concern of government aerospace agencies, such as INPE and the Air Forces, that companies in the local cluster develop globally-competitive products of their own, rather than just serving as R&D service suppliers for these agencies internal projects.

Exclusively in Canada, an improvement to innovation performance in aerospace would certainly come with the sector is regarded as strategic also by the federal government (and not only by the provincial government).

Regarding, at last, improvements that are applicable to both clusters, one highlights that there should be a greater interest of aerospace firms in collaborating with companies from other industrial segments, both to find external opportunities to aerospace technologies and as to bring to the segment innovations from these segments that may be applicable to aerospace products and processes.

7.1 Suggestions for future research

Finally, from the research conducted in this project, some ideas for improving this research's results or to study contiguous topic are suggested next.

- 1) Firstly, one suggestion for the short-term is to make further analyses on the survey data raised through this research, in order to extract more information that may be latent within the data;
- 2) Also within the same scope of this work, what one should do to improve the results from this work is to try to increase the number of samples in the two clusters, especially in Brazil. It is desirable that parametric statistical analyses could also be performed with the sample;
- 3) Another suggestion for deepening the comprehension of open innovation for firms in the sector is to perform in-depth case studies with some companies that took part of the survey, in order to propose concrete action towards the adoption of open innovation techniques, and the integration of the reference model proposed in Chapter 3 to the firm's technology development strategy;
- 4) Another suggestion is to perform intersectoral analyses. One way to do so is to run this same survey within a different industry sector (e.g. automotive) and evaluated the similarities and differences between these two realities. That could be an interesting approach to extent this research beyond the aerospace boundaries, however, it would demand adaptations in the survey questionnaire to the reality of the other(s) sector(s) and to establish parameters of comparison. Nevertheless, it seems to be a very interesting research opportunity to advance in the general goal of this research;
- 5) Recent papers on innovation management point to service innovation as the future of the research in the topic. A final suggestion is to investigate, within aerospace product-oriented companies, how they incorporate service to their product platforms in order to provide competitive advantages.

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APPENDIX A – Open innovation processes and perspectives

Perspective	Outside-in processes					Inside-out processes				Coupled processes		
	External knowledge/ technology sourcing	Integration of the customer and/or user in the innovation process	Integration of the supplier in the innovation process	Licensing in	Spin-in and M&A	IP portfolio activity	Licensing out	Spin-offs and divestments	R&D outsourcing	Co-development (with other companies)	Collaboration with Universities and other STI	External funding
Spatial perspective	38	-	-	44	-	-	45	-	48	50	50	-
Structural perspective	25/35/36/37	-	-	25/44	-	-	45	-	47	49/51	49/51	30/33
User perspective	-	39	-	44	-	-	45	-	-	50	-	-
Supplier perspective	-	-	41/42	44	-	-	45	-	-	50	-	-
Leveraging perspective	-	-	-	-	-	28/54	4539	57	4701	5305/5306	-	30/5206/5307
Process perspective	59/60/61					27/29/63/64/65	63/64/65			68/69/70		
Tool perspective	55	41	43	27	62	27	27	-	-	62	-	30/33
Institutional perspective	-	-	-	46	07/56	-	46	57	-	50/53	52	30/31
Cultural perspective	35/36/37/55/59/62	40/41/59/62	41/42/43/59/62	54/62/59	07/56/59/62	27/28/54/66/67	54/45/66/67	57/58/66/67	47/66/67	49/53/62/71	49/52/71	32/71

APPENDIX B – Survey questionnaire: list of questions

In order to avoid occasional copyright problems, the survey questionnaire is not integrally reproduced in this appendix. However, in order to give the reader an idea of the comprehension of that, besides the excerpt presented in Figure 42 (p.187), this appendix shows the statement of the 71 questions that encompasses the survey questionnaire.

Number	Question
1	Information about the interviewee
2	Year of establishment of your firm
3	Placement in the value chain within the sectors of the Aerospace Industry
4	What was the total annual revenue OF YOUR PLANT in 2011?
5	Employees
6	Is your firm on the stock market?
7	Has your firm merged with another firm?
8	Firm Ownership and subsidiaries
9	Please estimate (as best as you can) the percentage of the full-time employees in your plant who had in 2011 the following levels of instruction:
10	Which of the following business activities are performed in your plant?
11	How many clients does your plant have?
12	How many suppliers does your plant have?
13	Product innovation: during the five years 2007 to 2011, did your plant introduce:
14	Who developed these product (good or service) innovations during the five years 2007 to 2011?
15	Did your plant introduce ANY new or significantly improved products (goods or services) onto your market before your competitors during the five years 2007 to 2011?
16	Did your plant introduce ANY new or significantly improved products (goods or services) onto your market that were already available from your competitors, during the five years 2007 to 2011?
17	On average, how long does it take for your plant to develop a new or significantly improved product (good or service)?

Number	Question
18	During the five years 2007 to 2011, were ANY of the new or significantly improved products (goods or services) introduced by your plant a first to:
19	Process innovation: during the five years 2007 to 2011, did your plant introduce:
20	Who developed these process innovations during the five years 2007 to 2011?
21	During the five years 2007 to 2011, were ANY of the new or significantly improved processes introduced by your plant:
22	Did your plant have ANY activities to develop product (good or service) or process innovations that were still ONGOING at the end of 2011?
23	Did your plant have ANY activities to develop product (good or service) or process innovations that were ABANDONED during the five years, 2007 to 2011?
24	Why did your plant NOT develop or introduce any new or significantly improved products (goods or services) or processes during the five years 2007 to 2011?
25	During the five years 2007 to 2011, did your plant undertake the following innovation activities?
26	Please estimate (as best as you can) the percentage of your plant's total revenues in 2011 that were reinvested in R&D.
27	Please indicate which of the following methods your plant applied to protect its intellectual property (IP) during the five years 2007 to 2011.
28	Please estimate (as best as you can) the percentage of your products (goods or services), in terms of their contribution to total revenue, that were protected in 2011 by:
29	How Intellectual Property (IP) issues are managed?
30	During the five years 2007 to 2011, did your plant receive external funding?
31	What kind of investor is the Venture Capitalist of your plant?
32	How important were the following reasons for your plant to decide to get Venture Capital?
33	What types of programs sponsored by the federal or provincial/territorial governments did your plant use during the five years 2007 to 2011?
34	Are the following activities performed by your plant and/or other plants of your firm?

Number	Question
35	How important is each one of the following sources for your plant for the generation of internal knowledge within basic research?
36	How important is each one of the following sources for your plant for the generation of technologies within applied research?
37	How important is each one of the following sources for your plant for the generation of products (goods or services) or processes within development?
38	Where geographically are located the external sources of knowledge and technology of your plant?
39	How often does innovation in your plant arise from a solution provided by clients and/or users?
40	How often does your plant use the following mechanisms for involving clients and/or users in its innovation process?
41	How often does innovation in your plant arise from a solution provided by suppliers?
42	How often are the following mechanisms used by your plant to integrate suppliers into its innovation process?
43	Does your plant have tools to help integrate suppliers to the product development process? (Examples: Service Oriented Platforms (SOA) or Enterprise Resources Planning (ERP) modules designed to share information with the supplier during development)
44	During the five years 2007 to 2011, did your plant acquire licenses from other firms or organizations? (Please exclude software licenses under \$1,000)
45	During the five years 2007 to 2011, did your plant license its own IP to other firms or organizations? (Please exclude software licenses under \$1,000)
46	How important are the following Peer Production practices for your plant?
47	How often does your plant provide R&D contracted services to other firms or organizations?
48	Where are located the firms and organizations to which your plant provide R&D contracted services?
49	During the five years 2007 to 2011, did your plant form the following types of collaborative alliances?

Number	Question
50	Fill up the following tables informing whether your plant has a particular type of partner at a specific geographical location (tick all applicable options).
51	In your opinion, which are the two most valuable partners (from the list of question 50 above) for your plant's innovation activities, regardless of its location?
52	Regarding ONLY collaborative agreements with University and other S&T institutions, how important are each one of the following reasons for establishing the partnership?
53	Regarding all OTHER collaborative agreements, excepting those with Universities and other S&T institutions, how important are each one of the following reasons for establishing the partnership?
54	Do you agree or disagree with the following statements regarding IP protection?
55	How often does your firm perform the following activities?
56	How important is acquiring or spinning-in companies for your firm's strategy?
57	During the five years 2007 to 2011, did your firm create a spin-off?
58	During the five years 2007 to 2011, did your firm sell or divested a business unit?
59	How much are the following OUTSIDE-IN activities part of the day-by-day of your firm?
60	Does your firm have a department formally responsible for implementing OUTSIDE-IN processes?
61	Are any of the OUTSIDE-IN activities listed in question 59 explicitly cited in formal business process maps (BPM) and flowcharts of your firm?
62	"Not-Invented-Here" (NIH) is the name given to a syndrome whose effect is a high confidence in the internal products of your firm and high repulsion to everything that comes from outside. How much is the NIH syndrome present in your plant's culture?
63	How much are the following INSIDE-OUT activities part of the day-by-day of your firm?
64	Does your firm have a department formally responsible for implementing INSIDE-OUT processes?
65	Are any of the INSIDE-OUT activities listed in question 63 explicitly cited in formal business process maps (BPM) and flowcharts of your firm?

Number	Question
66	"My firm's internal technologies are accessible and visible for people from outside." How much is this statement true to your firm?
67	"Not-Sold-Here" (NSH) is the name given to a syndrome whose effect is an overprotection of internal knowledge of the firm and difficulty to make internal technologies go outside in business models different from that of the firm. How much is this syndrome present in your plant's culture?
68	How much are the following COUPLED activities part of the day-by-day of your firm?
69	Does your firm have a department formally responsible for managing collaborative alliances and other COUPLED processes?
70	Are any of the COUPLED activities listed in question 68 explicitly cited in formal business process maps (BPM) and flowcharts of your firm?
71	"My firm is engaged on several collaborative fronts". How much that statement is true for your firm?