LOOKING FOR A FIRM LEVEL MODEL TO EVALUATE SECTORIAL PUBLIC PROGRAMS IN LATE INDUSTRIALIZED COUNTRIES: A THEORETICAL REVIEW

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ABSTRACT

Late industrializing countries, like Brazil, design public programs for developing specific industrial sectors. The evaluation of impacts provided by these programs is very necessary in order to evaluate the use of public funds. Preferably, such evaluation should take into account the impacts at the firm level. In such context, the main objective of this paper is to analyze the most relevant academic approaches for evaluating public programs. Thus, this paper made a review that included the most relevant methods that have been utilized throughout the world. Economic analysis, non-economic analysis, hybrid and data driven analysis, and evolutionary approaches have been presented there, including the matrices proposed by early previous authors, and the BETA approach, which focused on indirect impacts.

Most of economic approaches of research and development (R&D) evaluation focus on the discrete products of research. If one is interested in the capability created by R&D or in its transformational impacts, then cost-benefit or rate of return approaches provide only limited insights. They rarely take into consideration the mutability of the products evaluated, much less the changes in people and institutions. Product-oriented and output-focused evaluations tend to give a short shrift to the generation of capability in science and technology, and to the ability to produce sustained knowledge and innovations. These frameworks usually utilize aggregated data at macroeconomic level. In fact, these approaches are really important for the understanding of issues involved in policies decisions. However, they are not useful enough. In some cases, they are not even appropriate for late industrializing countries, because most of the data used are not available, such as patent analysis and the data before and after the public program intervention in econometric evaluations.

In the context of evaluating the impacts of the Brazilian sectorial programs on specific firms, there is a scarcity of aggregated and non-aggregated public data. It seems necessary to use a descriptive model that could capture these impacts in terms of the development of technological capabilities in basic, intermediary and advanced levels. So, the descriptive model of accumulation of technological capabilities developed in Brazil by Paulo. N. Figueiredo was reviewed, who was inspired by the whole evolutionary literature. After analyses of literature review, it was argued that Figueiredo's model provides a framework which is useful for analyzing and evaluating impacts of Brazilian Programs designed for developing industrial sectors.

Keywords: Evaluation Methods, Brazilian Sectorial Public Programs, Technological Capabilities.

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1. Introduction

Late industrializing countries, such as Brazil, design public programs for developing specific industrial sectors (instruments on the demand side: Edquist *et al*, 2000; Edler and Georghiou, 2007; Aschhoff and Sofka, 2008). In Brazil, from 2011 to 2014, Plano Brasil Maior (PBM, 2011) was developed, under the slogan: "Innovating to compete. Compete to grow”, with the following priorities: creation and strengthening of critical competences for the national economy; strengthening the production and technologies of the value chains; expansion of domestic and foreign markets for Brazilian firms; guarantee of socially inclusive and environmentally sustainable growth. In this context, programs have been developed to strengthen strategic sectors such as space, aeronautics, defense, oil, information technology, among others.

The evaluation of impacts provided by those programs is very necessary in order to evaluate the use of public funds. Preferably, such evaluation should take into account the impacts at the firm level. In the Brazilian aerospace case, Rocha (2014) applied BETA´s methodology to analyze the impacts of the Brazilian Space Program. In the Brazilian aircraft industry, Oliveira (2005) and Marques (2011) applied the Accumulation Theory of Technological Capabilities to the Brazilian aeronautical supply chain, even though they had not analyzed the contribution of public programs for their results. In the Brazilian oil case, Ribeiro (2009), also from the Theory of Technological Capabilities, analyzed the impacts of Petrobras procurement policies on the development of its local suppliers. However, it is argued herein that there is space for improving the methodology utilized for evaluating those types of development sectorial programs.

There are many difficulties in building an analytical construct to analyze sociotechnical impacts of public funded technological programs. According to Figueiredo (2009), most of frameworks generally use aggregated data at macroeconomics level. In fact, these approaches are really important for the understanding of questions involved in policies decisions, however they are not enough. In some cases, they are not even appropriate for late industrializing countries, because most of the data used is not available, such as patent analysis and the data before and after the public program intervention in econometric evaluations.

In the last thirty years (1982-2012), the investments in public goods, research and development (R&D) investments in particular, have risen around the world. Both government and general public are asking about efficiency, effectiveness and accountability of these investments in science, technology and innovation. It also includes demands for transparency, accountability and performance. This is the context of public policies and the assessment of public R&D funds. The evaluation aims to measure the performance, based on management and on budgeting, to enhance the accountability and transparency, to improve the communication of program activities and outcomes to policy decision-makers and sponsors. There are a wide variety of methodologies and methods to evaluate the objectives, pathways, outputs and outcomes. (LINK and VONORTAS, 2013)

Most of economic approaches of research evaluation focus on the discrete products of research. If one is interested in the capability created by research or in the transformational impacts of research, then cost-benefit or rate of return approaches provides only limited insights. They rarely take into consideration the mutability of the products evaluated, much less the changes in the people and institutions. Product-oriented and output-focused evaluations tend to give a short shrift to the generation of capability in science and technology, and to the ability to produce sustained knowledge and innovations. (BOZEMAN and KINGSLEY, 2013)

Therefore, the main objective of this paper is to present the most relevant academic approaches for evaluating public programs. This review includes the most relevant methods that have been utilized throughout the world. Economic analysis, non-economic analysis, hybrid and data driven analysis, evolutionary approaches are presented, including the matrices proposed by early authors, and the BETA approach, which focused on indirect impacts. Finally, it presents a descriptive model that could capture the impacts in terms of the developing of technological capabilities in basic, intermediary and advanced levels. So, the descriptive model of accumulation of technological capabilities developed in Brazil by Paulo. N. Figueiredo was reviewed, who was inspired by the whole evolutionary literature. Figueiredo’s model provides a framework, which is useful for analyzing and evaluating impacts of Brazilian Programs designed for developing industrial sectors. It enables to identify technological key sectors in the economy and makes possible to distinguish the most dynamic sectors of the slowest and thus implement measures and different incentives for different sectors in order to develop technological capabilities.

The second section will present the theoretical framework that underpins this work. The third section will present the model applied. The fourth section discusses the importance of this approach to evaluate defense Brazilian programs. Finally, the paper is concluded.

2. Theoretical Review

2.1 Evaluation methods of technological impacts: the state of the art

The utility of each technique will vary according to the object of the study and the set of the program under evaluation. They may be used singly or in combination; they entail collection of primary data or secondary data, simple linear or complex, non-linear relationships, directed at one or more outputs and outcomes. The choice of the mix instruments is central to the success of evaluation. (LINK and VONORTAS, 2013)

There are four problems inherent to the evaluation of programs: 1) Time: the effects of the program or research often manifest themselves long after the completion of the program or research, when the connections have already obscured; 2) Assignment: innovation can result from multiple projects and a research project can generate several innovations; 3) Appropriability: the beneficiaries of the program or research may not be the same people or organizations that performed; 4) Asymmetry results: the distribution of the impacts of portfolio projects is highly biased, so that only a small number of projects can explain most of the results. (LINK and VONORTAS, 2013 *appud* GEORGHIOU and LAREDO, 2006, p. 3 and 5)[d]

According to Link and Vonortas (2013), the methods of evaluation of programs and policies can be categorized as economic (economic analysis of the impact, econometric methods and selection of the portfolio of R&D projects), non-economic (peer review and expert panels, logic modeling, research value mapping), hybrid (social networking, estimating emissions avoided environmental and health benefits, evaluating cooperative research centers) and data-driven (Bibliometrics, patents analysis and innovation surveys).

2.1.1 Economic methods

In the non-economic category, there are the economic analysis of the impact, econometric methods and selection of the portfolio of R&D projects. The economic analysis of the impacts is a way for public institutions to quantify the social contribution of the activities; it also provides important lessons about the management of resources and important guidelines for future strategic planning. The evaluation of R&D programs is often focused on the criteria of efficiency and the relation between benefits and costs of the program. The central questions are: "How efficient are all program´s attributes including program management strategy, planning strategy and investment strategy?" "How can social benefits associated to the program be compared to the society´s costs to undertake the program?" (Link and Scott, 2013, p. 15). In other words, this type of evaluation works with the executive power of a country, in the sense that it explains how taxes can be used effectively and efficiently. The theoretical bases for this type of evaluation are Griliches (1958), Mansfield *et al* (1977) and Tassey (1997).[e] (LINK and SCOTT, 2013)

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[d] GEORGHIOU, Luke and LAREDO, Laredo (2006) “Evaluation technology of publicly-funded research: recent trends and perspectives”, Report DSTI/STP (2006)7, Paris: OCDE.

[e] GRILICHES, Zvi (1958) “Research costs and social returns: hybrid corn and related innovation”, journal of Political Economy, 66, 419-31. MANSFIELD, Edwin; RAPOPORT, John; ROMEO, Anthony; Wagner, Samuel; and BEARDSLEY, George (1977) “Social and private rates of return from industrial innovations”, Quarterly Journal of Economics, 91, 221-40. TASSEY, Gregory (1997), The Economics of R&D Policy, Westport, CT: Quorum Books.

The econometric models quantify the firms' level of performance before and after the government's program intervention. Time series of the affected firms are used, and at some point in the data series, the government finances a project and the remainder of the series reflects the technical and economic impact of the intervention (Link and Scott, 2013, p. 38, *appud* Tassey, 2003, p. 15).[f] There is still a need for estimating the performance of not affected firms. However, the required information is only available for the affected firms. The counter factual situation is given by other firms in the absence of intervention, the control group (Link and Scott, 2013). Arvanitis (2013) briefly shows the main econometric approaches of impact evaluation based on Link and Rossner (2000), Klett *et al* (2000), Hall and Van Reenen (2000) and David *et al* (2000).[g] He stresses that the impact of evaluation should consider the comparison between the variable analyzed of the firm after program participation with the same variable of the firm in case of non-program participation. It cannot be seen, so the counter factual situation is not found in reality. The construction of a valid control group is a challenging task to be performed by the evaluator.

Thus, a large number of econometric methods demand to estimate this state, which includes the need to address an important issue: selection-bias problems, because firms subsidized by the government were not chosen randomly, they were selected due to the high quality of their projects, they are the best candidates to receive public funding. According to Arvanitis (2013), there are several empirical strategies for mitigating selection bias in the ex post evaluations, for example, regression with controls for unobserved effects; regression with fixed effects or "difference-in-differences", selection models and matching methods based on direct comparisons of participating and non-participating agents, that is on matched samples treat and untreated entities.[h]

Casault *et al* (2013) presents the selection of a portfolio of R&D projects (three or more projects). This method aims to integrate the managing of a portfolio of R&D projects by the use of finance tools (Modern Portfolio Theory) to reduce the risks of failure of a specific program at firm level. Finance can offer insights from managing project interactions. Usually, the projects are defined in an isolated way; the relationships between projects are rarely considered formally from a centralized coordinated perspective. The main principle is that the portfolio should not be selected based on their individual merits (expectation of returns). The portfolio projects could be measured by a set of techniques: financial characteristic of the project´s monetary resource utilization, potential future market returns, probability of success, contribution, expert opinions and others. Financial tool of the project: The Return on Investment – ROI, Discounted Cash Flow – DCF, Net Present Value – NPV, Real

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[f] TASSEY, Gregory (2003) "Methods for assessing the economic impacts of government R&D", NIST Planning Report 03-1, Gaithersburg, MD.

[g] LINK, A. N.; ROSSNER, J. D. (2009) The economics of technology policy, The Special Issue of Research Policy, vol. 29. KLETTE, T. J.; MOEN, J.; and GRILICHES, Z. (2000) "Do subsidies to commercial R&D reduce market failures? Micro-econometric evaluation studies", Research Policy, 29, p. 471-95. HALL, B. H. and VAN REENEN, J. (2000) "How effective are fiscal incentives for R&D? A review of the evidence, Research Policy, 29, p. 449-69. David, P.; HALL, B.; and TOOLE, A. (2000) "Is public R&D a complement for private R&D? Research Policy, 29, p. 497-529.

[h] For more details, see: Cameron, A.C., Trivedi, P.K. `Treatment Evaluation', Chapter 25 in Microeconometrics, Methods and Applications, Cambridge University Press 2005. Dupas, P. and J. Robinson (2013). Savings Constraints and Microenterprise Development: Evidence from a Field Experiment in Kenya. AEJ: Applied Economics 5(1), pp. 163-92. Dupas, P. and J. Cohen (2010). Free Distribution or Cost-Sharing? Evidence from a Randomized Malaria Prevention Experiment. Quarterly Journal of Economics 125 (1), pp.1-45. Horiuchi, Y., Imai, K., Taniguchi, N. (2007). Designing and analyzing randomized experiments: Application to a Japanese election survey experiment. American Journal of Political Science 51, pp. 669–687. Miguel, E., Kremer, M. (2004). Worms: Identifying Impacts on Education and Health in the Presence of Treatment Externalities. Econometrica, Vol. 72, No. 1. pp. 159-217. Ravallion, M. (2008). Evaluating anti-poverty programs. Handbook of Development Economics, Chap. 59, Vol.4. Papers by James Heckman, Guido Imbens, Angus Deaton. in Journal of Economic Literature (2010), vol. 48. Background Econometrics: Cameron, A.C., Trivedi, P.K. Microeconometrics, Methods and Applications. Cambridge University Press 2005. William H. Greene (2011). Econometric Analysis, 7th Edition. Prentice Hall. Jeffrey M. Wooldridge (2010). Econometric Analysis of Cross Section and Panel Data, 2nd Edition. The MIT Press. This set of reading is a module of discipline at UNU-MERIT (Maastricht, Netherlands, http://www.merit.unu.edu/) called Evaluation of Programs and Policies taught by Prof. dr. Théophile T. Azomahou (http://www.merit.unu.edu/about-us/profile/?staff_id=898).

Options (Black-Scholes equation). Qualitative and visual information of the project: Peer Review Score (a group of experts affixing a score on individual projects against a series of technical merit criteria) and Growth Share Matrix (a tool to help visualize the attractiveness of various products based on their market share and growth rate).

Analytic Hierarchy Process (AHP) is another technique for organizing and analyzing complex decisions that require several inputs from a group of people. This framework helps the decision maker to structure a problem in logical hierarchical structure against overall goals and alternative solutions. It helps to transform a series of qualitative project attributes into a quantitative one. Data Envelopment Analysis (DEA) technique has a great capacity to quantify the relative attractiveness among projects based on a series of inputs and outputs. There are other techniques that could be used to select a portfolio of R&D projects: Portfolio View, Advanced Multi-Dimensional Visualization Analysis, Balance Scorecard, etc. (CASAULT *et al*, 2003)

2.1.2 Non-economic methods

In the non-economic category, there are peer review panels and experts, logic modeling and research value mapping. The peer review and panels experts are widely used to evaluate the scientific quality of government programs or specific projects to support the technological development, academic production for the progress of science, specifically related to the submission of papers to the journals internationally recognized by the academic community. They are also used to improve the content of projects and programs by putting such programs and projects on the frontier of knowledge. (FELLER, 2013)

Logic modeling is a process, a management, and an evaluation tool utilized to develop the big picture of a program´s goals and strategies, so that they could be achieved within a broader context. It builds a model of how the program, projects, portfolios or process will be worked in a specific condition to solve selected problems; it makes explicit what is often implicit. Logic modeling provides a shared understanding of the program, performance expectations and performance story for senior managers and Congress. This tool is used to identify measures and indicators, and researchable issues or questions that need to be evaluated. (JORDAN, 2013)

Research value mapping (RVM) and evaluation is an amalgamation of techniques rooted in common assumptions. It uses multiple and interrelated cases of studies and combines qualitative approaches (the case studies) with quantitative approaches (the data developed from the case studies). The focus is on "network uses survey". It provides insights into the reason why the benefits are achieved, and then it is useful for policy management strategies seeking to replicate success. RMV focuses intensely on particular projects and the events surrounding them, much common in case studies. (BOZEMAN AND KINGSLEY, 2013)

2.1.3 Hybrid methods

In the hybrid methods´ category, there are social network methodologies, estimating avoided environmental emissions, environmental health benefits, and evaluating cooperative research centers. According to Vonortas (2013), social network methodology is a tool for evaluating important aspects of research and development programs such as the nature of the knowledge and partnership networks in a specific period in different sectors; if networks establish effective channels of knowledge and communication across sectors; the identification of hub[i] organizations and their effectiveness in creating and diffusing knowledge; the position of the hub in relation to other global networks; the role of specific funding instruments in facilitating the effectiveness in creating leading knowledge hubs, and other important issues about the establishment of networks of knowledge and the diffusion of knowledge.

Estimating avoided environmental emissions and environmental health benefits is an evaluation approach that connects the awareness of the impacts of fossil fuels (poor air quality) to the increased value of the sustainability, avoided fuel consumption results in avoided emissions of common air pollutants. Changes in air

[i] "… a hub may be defined as a node with a very large number of links or, alternatively, as a node that is highly influential by playing the role of network connector, that is, one connecting node that would otherwise remain unconnected. (…) Hubs are expected to play an important role in producing and diffusing knowledge." (VONORTAS, 2013, p. 219 and p. 222)

quality are associated to changes in adverse health events. It´s possible to measure and monetize impacts on environmental emissions and related health benefits using the Co-benefits Risk Assessment Model (COBRA). The benefits are conceptually important and in practice not insignificant in monetized value. There are five environmental performance metrics of interest for program evaluators: energy consumption, environmental (criteria) pollutant emissions (O_3, CO, NO_x, SO_2) greenhouse gas emissions (GHG: CO_2, CH_4, NO_2, SF_6), environmental health and adverse health events (asthma, heart attacks, respiratory illness, mortality) and equivalency numbers of passenger vehicles, barrel of oil consumption, carbon sequestered annually by a number of pine forests). (O´CONNOR *et al*, 2013)

Rivers and Gray (2013) describe the methodology used for capturing economic impact data from private sector firms involved in cooperative research with universities. The focus is a specific science, technology and innovation programmatic initiative. These authors used the program evaluation protocols and/or annual reports to identify estimations of economics outcomes (funding amount by source, personnel counts (center staff), invention disclosures, patent applications, publications, start-ups, license agreements, R&D outcomes translated into cost savings and cost avoidances) and interviewed-based approach for gathering more distal economic impact data with key informants inside the firm (questionnaire data collected from participants on a regular basis).

2.1.4 Data-driven applications

Data-driven applications present Bibliometrics as a tool for research evaluation, patent analysis and the measurement of innovation with official statistics (innovation official surveys). According to Hicks and Melkers (2013), Bibliometrics is a method for the analysis of the output of basic research, it´s also useful as a partial indicator of R&D output and of the productivity and impact of funded research teams and centers. Bibliometrics involve other types of analysis such as publication counts, citation counts, co-citation analysis, scientific mapping and, in the best evaluation, qualitative methods are also used. Publication counts are based in the amount of times that some earlier paper´s reference appears, so that the most important work will have the highest number of citations. Co-citation is a method for identifying groups of papers that are often found in the same reference lists; these groups of authors can be the most productive, and influential scientists.

Patent analysis is used to evaluate applied research programs and innovation because they are knowledge outputs and indicators of invention. It allows the tracing of knowledge dissemination through patent citation analysis. Patent citation analysis is also used (an earlier patent can influence downstream innovation and commercial development). Patents can be used to provide simple output metrics (program output measure or as a short-term performance metrics), to provide program description (to identify areas of downstream program influence), to provide compelling evidence that a program has had long-term impact (additionality), such as knowledge benefits and spillover effects. Patents analyses are very useful tool for certain types of evaluation, especially when patents are the most important outcome of the program evaluated, but it also has some limitations. It only captures a part of the program´s output (not all knowledge output) and the patent citation does not reveal the value of patent use. (RUEGG and THOMAS, 2013)

Innovation surveys are a data-gathering technique that can be used both for economic evaluation, and for the economic impact analysis. This is the collection of data on various aspects of the innovation process from a national perspective (Link and Scott, 2013, p. 42, *appud* Polt and Rojo, 2002)[j]. According to Figueiredo (2009), it refers to the measurement based on statistical studies of large samples of firms of various industries; it is essentially a macro-level approach.

[j] POLT, Wolfgang and ROJO, Jaime (2002) "Evaluation methodologies", in FAHRENKROG, Gustav; POLT Wolfgang; ROJO, Jaime; TUBKE, Alexander; and ZINOCKER, Klaus (EDs) RTD Evaluation Toolbox, Seville: European Commission, p. 65-70.

2.1.5 Other techniques

Other techniques can be used to evaluate the programs, such as productivity models and benchmarking. Productivity models are special cases of performance models, and are also estimated based on econometric techniques. They are supported by the production function, which is a mathematical representation of the relationship between the outputs and the inputs to generate these outputs, such as labor, capital and technical knowledge: Q = F (L , K, T). Given some assumptions, the model can be derived into a function of T and R&D that meets the rate of return of these investments. It can be useful for analyzing impacts if the model can be estimated before and after the intervention. However, they are not widely used for these purposes. The benchmarking analysis involves comparing the firm's performance affected by public R&D to a particular purpose, to the best practices of other firms or other chosen standard. (LINK and SCOTT, 2013)

2.2 BETA´s methodology

In general, the evolutionary literature about the evaluation of public technological programs in aerospace sector and technological specific projects shows that such programs can be evaluated by their direct and indirect outcomes or impacts (Bach, 1992; Furtado *et al*, 1999 e 2008; Furtado e Costa Filho, 2009; Hasegawa, 2005; Miranda, 2008; and Rocha de Oliveira, 2014).[k] The direct outcomes refer to program objectives defined in the contracts and the indirect ones, refers to the spinoffs. Spinoffs are new combinations of existing knowledge in the program that overflow into other areas and activities generating positive impacts for the organization as a whole, such as unpredicted products, new technologies, organizational changes, new methods, new techniques, new technological capabilities, etc. The spinoffs are a broader phenomenon than the process of technological transfer and can generate an economic impact as, or more important than the expected innovation (BACH, 1992). According to Furtado *et al* (2008), spinoffs are the result of the learning process, which is derived from the sedimentation of organizations' technological capabilities.

The spinoffs generated during the program create new technological capabilities that are relevant for the technological progress of the country. The evaluation of these indirect results can be performed using the methods of assessment of impacts of large programs developed by the Bureau *d'Economie et Théorique Apliquée* (BETA), which divide the indirect results of a program into four types of impacts: technological impacts, commercial (and competitive) impacts, organizational impacts, and impacts on human resources (BACH, 1992). The BETA methodology was initially developed to capture the indirect impacts resulting from major investments that were made in the aerospace sector in Europe (BACH, 1992). In Brazil, it was also shown as very suitable for capturing the effects of investments in projects to develop specific technologies in the oil industry (FURTADO *et al*, 1999), aeronautical sector (FURTADO e COSTA FILHO, 2009), and aerospace sector (ROCHA, 2014). It was also used in very specific Research and Development projects, the PROCANA genetic improvement program (HASEGAWA, 2005) and the PROSAB research and basic sanitation program (FURTADO *et al*, 2008).

BETA provides a wide range of variables that can be analyzed through evaluation models designed to assess the impacts of large programs. The technological impacts refer to the transfer of knowledge that was not originally expected (new products, new processes, technological services, patents). Commercial impacts analyze network impacts from the relationships between participants (collaboration links after the project, reputational

[k] Furtado and Costa Filho (2009) apply the BETAS´s methodology to the Program ERJ 145 and EMBRAER 170/190. Rocha (2014) characterized the public purchases of the Brazilian Space Program and from the BETA´s methodology, presented the economic impacts of the program. Miranda (2008) introduced the systematics and the effects of Brazilian Aeronautical Command nationalization policy implemented by the Logistics Center of Aeronautics (CELOG) on the training level of national aeronautic suppliers. Hasegawa (2005) analyzed the process of creating spinoffs of a specific program. She has built a typology of capabilities and also created a list of possible spinoffs for the program (PROCANA: an agricultural program that aimed to get rich productive varieties in sucrose, resistant to pests and diseases and also presented the additionality of economic benefits).

impacts, from the largest project recognition and external visibility, quality certificate); and competitive impacts resulting from new partnerships and opportunities because of project learning. The organizational and method impacts refer to marks that the project has left on the culture of the organization and organizational structure (skill in managing projects, changes in organizational structure, implementing quality and research and development departments, new methods that are transferred to other activities). The impacts on human resources relate to new contracting that were made during the projects and the specific training, beyond the learning processes during the execution of the project. (BACH, 1992)

Furtado *et a*l (2008) and Lima and Urbina (2009)[l] help us to understand that it is possible to evaluate the programs through their impacts that are manifested such as the creation and strengthening of technical, organizational and technological capabilities. In the case of programs of a technological nature, technological capabilities created and developed by the program are a key aspect to evaluate the investment realized. Hasegawa (2005) goes further and analyzes the process of spinoffs creation and shifts attention to the intermediate results that are created by the program. These interim results are precisely those generated capabilities that make spinoffs possible.

Hasegawa (2005) provides a typology of capability. 1) Organizational capability: capability of the institution to organize internally in a way to optimize the learning process, the internal knowledge base and still be able to make changes. 2) Relational capability: ability to establish and maintain contacts with external actors, learn collectively and exchange tangible and intangible assets. It includes the ability to disseminate knowledge, to choose partners know-who, to encode know-who and to gain visibility and reputation. 3) Scientific and technological capability: ability to use scientific and technological knowledge to assimilate, use, adapt, and change existing technologies; and to develop new technologies, products and processes. It also includes the absorption capability (ability to absorb external knowledge and use it for the benefit of the company).[m]

2.3 "Accumulation Theory of Technological Capabilities"

2.3.1 Theoretical background

A theoretical framework that allows us to understand what happens and what can be leveraged within the firm, in the context of late industrialized countries, to overcome the technological underdevelopment is the "accumulation theory of technological capabilities" of the evolutionary economic literature that began with Penrose (1959).[n] Edith Penrose realized the firm as a repository of resources, involving the specific capabilities of the firm, which were responsible for distinguishing the firm to the others in the same industry and a key factor for competitive performance. This way[o] of perceiving the firm boosted a lot of research about the nature of technological change process throughout the 1980s and 1990s, as well as a large number of empirical studies. (FIGUEIREDO, 2009)

In Latin America and later in Asia during the 1970s and 1980s, based on Penrose (1959) and on the emergent evolutionary theory (NELSON and WINTER, 1982), the first studies derived from pioneering research efforts of Jorge Katz (Katz, 1987), Martin Bell (Bell, 1982; BELL and Pavitt, 1993), Keith Pavitt, Carl Dahlman (DAHLMAN, Ross-Larson and WESTPHAL, 1987), Lall (Lall, 1982, 1987, 1992, 1994), among others.[p]

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[l] Lima and Urbina (2009) developed an evaluation method of the capability management of innovation projects.

[m] This categorization approaches the functions of the Lall´s Technological Capability Matrix (Lall, 1992) and differs because it includes an organizational function. For our purposes, it is important to emphasize that the Beta´s analysis measures the indirect impacts, not the capabilities. Hasegawa (2005) identified the capabilities that could create these impacts.

[n] PENROSE, Edith (1959) The Theory of the Growth of the Firm. Oxford: Basil Blackwell.

[o] Based on Joseph Schumpeter, Edith Penrose e Hebert Simon (FIGUEIREDO, 2009).

[p] KATZ, J. "Domestic technology generation in LDCs: A review of research findings" in KATZ. J. (ORG) **Technology Generation in Latin America Manufacturing Industries**, New York: St Martin´s Press, 1987. BELL, M. **Technical change in infant industries: a review of the empirical evidence**. Brighton, SPRU/University of Sussex, Mimeo, 1982. DAHLMAN, C.; ROSS-LARSON, B.;

These studies were facing the scarcity of research about the late industrialized countries. Studies that prevailed in developed countries took care of dynamic capabilities and emphasized the constant need for renewal: rapid change, uncertainty, global competition and interdependence, and the fact that companies act on the border of technological knowledge. The innovative capabilities have already existed and the concerns are the sustainable management of innovation and the competitive leadership. Thus, studies about technological path were not usual. (FIGUEIREDO, 2001, 2009 and 2014)

According to Figueiredo (2009), during the 1990s and 2000s, a new generation of researchers (Hobday, 1995; Kim, 1997; Lee, 2000; Dutrénit, 2000; Ariffin, 2000; Figueiredo, 2001, 2002, 2004, 2005, 2008, 2009, 2010, 2014)[q] refined and expanded analytical models of the accumulation of technological capabilities, and applied them in various industries.

2.3.2 Technological capabilities and innovation

2.3.2.1 Technological capabilities

The technological capabilities are originally broadly defined by Bell and Pavitt (1993) as the resources needed to create and manage technological change, including skills, knowledge, experience and institutional structures, connections inside the organizations, inter firms and external environment. These capabilities have diffuse, complex and comprehensive nature. They are incorporated and accumulated in individuals (through the skills, knowledge and experience), and in organizational systems (through the routines and procedures). The technological capability has been still intrinsic to the firm context, to its institutional structure and geographical location.

According to Figueiredo (2004, p. 329-330), technological capability is stored (accumulated) into four components:

i. Physical technical systems (physical capital): machinery, equipment, information technology-based systems, software, manufacturing plants;
ii. Knowledge and skills of people (human capital): tacit knowledge, experience; skills are acquired over time and by formal qualification;
iii. Organizational system (organizational capital): accumulated knowledge in organizational and managerial routines of the firm, procedures, instructions, documentation, management techniques, production flows, ways of doing them;
iv. Products and services: it is the most visible part of the technological capability. It reflects the tacit knowledge of people and the organization and its physical and organizational systems, such as design, development, prototyping, testing, production and marketing.

The firms´ ability to create, adapt, manage and generate these four components and the interaction between them is what, in fact, most visibly, is called technological capabilities at the firm level. There is also a degree of importance and priority between these four components: human capital and organizational overlap with physical systems and products and services.

WESTPHAL, L. E. "Managing technological development: Lessons from Newly Industrializing Countries." **World Development**, v. 15, no. 6, p. 759-775, 1987. LALL, S. Technological learning in the Third World: some implications of technology exports. In: STEWART, F. e JAMES, J (eds). **The Economics of New Technology in Developing Countries**. London, Frances Pinter, 1982. LALL, S. **Learning to Industrialize: the Acquisition of Technological Capability by India**. London: Macmillan, 1987. LALL, S. "Technological Capabilities", *in* SALOMON, J. J. et al. (ORGS.), **The Uncertain Quest: Science Technology and Development**, Tokyo: UN University Press, 1994.

[q] HOBDAY, M. **Innovation in East Asia: The Challenge to Japan**. Aldershot, Edward Elgar, 1995. DUTRÉNIT, G. **Learning and Knowledge Networks in the Firm**. **From Knowledge Accumulation to Strategic Capabilities.** Cheltenham, UK and Northampthon, USA, Edward Elgar, 2000. ARIFFIN, N. **The Internalization of Innovative Capabilities: The Malaysian Electronic Industry**. D. Phil. Thesis, SPRU/University of Sussex, 2000.

> *"It is a cognitive asset or knowledge base owned to each firm and it reflects the tacit knowledge of their engineers, managers, technicians and operators, codified knowledge and impregnated tacit in their organizational routines, procedures, manuals education, management techniques, organizational and management structures, technical-physical systems, facilities, process design, develop and improve their products and services, but also the values and standards of the firm (the way that things are done)." (FIGUEIREDO, 2009, p. 23).*

Afterwards, they determine the operations of the technology and production system, the ability to modify technologies and production system and to create new technologies and production system.

2.3.2.2 Innovation

The concept of innovation used in this paper is broader than the concept of technological change proposed by Bell and Pavitt (1993). Technological change is any process in which the technology is incorporated into the production capacity of firms and countries. It can be differentiated into two types: the first involves the incorporation of new technology supported by a new investment, and the other type comprises incremental changes in existing production. However, to define innovation, we followed the broader concept propagated by Figueiredo (2009) from important references in the literature that focus on technological change: Schumpeter (1911 and 1942), Rosenberg (1982), Nelson and Winter (1982), Freeman and Soete (1987), Dosi (1988), Lundval (1992), Nelson (1993), Cooke (2001), Malerba (2002) and OECD (2005).[r] Thus, the innovative concept adopted here includes:

> *"... (i) the implementation of changes in products/services, processes, organizational and managerial systems – of the initiation to adapting to the less to more advanced – that are new on the local context, and not necessarily new to the world (ii) as well as the design and development of new global systems. So, innovation is a continuous process and not mere episodes. This process involves the resolution of problems from different types of activities as well as a stock of specific skills and firms´ learning processes. These, in turn, are affected by the nature of the institutional context in which they are born and grow."(FIGUEIREDO, 2009, p. 32 and 34)*

It is a broad spectrum of activities that include varying degrees of innovation.

3. Accumulation Matrix of Technological Capabilities

The Descriptive Model of Technological Capabilities Accumulation (Figueiredo, 2009) or Model Staged (Vértesy, 2011) was widely disseminated from Lall's article (1992). Lall (1992) was based on Katz (1984 and 1987), Dahlman, Ross-Larson and Westphal (1987) and Lall (1987) and the model was early called Matrix of Technological Capabilities. This matrix is a way to categorize and assess the technological capabilities of firms according to specific functions and an indicative of the level of complexity. In the columns of the matrix, the main functions are arranged to be internalized by the firm in order to obtain commercial success in a particular operation. The lines are arranged in degrees of complexity (basic, intermediate and advanced). These degrees are only indicative, considering the difficulty of judging *a priori* whether a function is simple or complex. The matrix

[r] SCHUMPETER, Joseph A. (1911 original, updated by the author in 1934). The Theory of Economic Development. Sao Paulo: Abril Cultural, 1982. SCHUMPETER, Joseph A. (1942, 1st Edition.). Capitalism, Socialism and Democracy. Rio de Janeiro: Zahar Editores, 1984. ROSENBERG, N. Inside the Black Box. Cambridge, Cambridge University Press, 1982. DOSI *et al*. Technical Change and Economic Theory. Printer Publishers, London and New York, 1988. LUNDVALL, B. National System of Innovation. Towards a Theory of Innovation and Interactive Learning. Ed. Printer, London, 1992. NELSON, R. R. (1993) National Innovation System: A Comparative Analysis. Oxford: Oxford University Press. COOKE, P. (2001) "Regional Innovation System, cluster and knowledge economy", Industrial and Corporate Change, v. 10, n. 4. MALERBA, F. (2002) Sectorial system of innovation and production", Research Policy, v. 31, p. 247-264. ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD) (1995) Governance in transition. Public management in OCDE countries. Paris.

does not have an exact sequence of technological learning, and functions also presented do not exhaust all possibilities of functions. (LALL, 1992)

The functions of Lall´s Matrix (1992) were built according to three broad categories of capabilities: investment capabilities, production capabilities and linkage capabilities. They explain what the company needs to master to achieve certain technological level. The matrix allows to identify and categorize the technological capability from the activities that firms are able to perform throughout their existence. According to Lall (1992), investment capabilities refer to the skills required to identify, prepare and get technology from. Production capabilities are related to the basic skills of quality control operations, operation and maintenance and more advanced skills of adaptation, improvement or innovation. Linkage capabilities refer to the qualifications of transferring information, skills and technologies.

The technological development of firms can be evaluated by Lall´s Technological Capability Matrix; it can capture the technological development of late industrialized countries or firms. In this context, firms first need to acquire technological knowledge at the operational level, afterwards they can master the technology and begin the process of accumulation skills. According to Figueiredo (2004), the Accumulation Matrix of Technological Capabilities allows to identify the technological level of key sectors of the Brazilian economy, and the speed at which certain sectors have accumulated technological capabilities over time. It also allows to distinguish the most dynamic sectors of the slowest, and thus implement measures and special incentives for different sectors.

Bell (1995) has categorized basic production capabilities for the use of production techniques that are already established; and technological capabilities for creating and managing technical change, according to the basic, intermediate and advanced levels. In the columns of the matrix proposed by Bell (1995) we can find: Investment Activities (Facilities to User for Decision Making and Control, and Project Preparation and Implementation); Capital Goods Offer; Production Activities (Processes and Organization of Production and Production-Centred) and Linkage Activities. The matrix shows what can be done at different levels of technological development. The emphasis of the model is directed to the different types of engineering skills needed to invest on building the machinery, developing products and strengthening the relationship with external technology sources.

Figueiredo (2001, 2002, 2004, 2005, 2008, 2009, 2010 and 2014) has applied empirically the Accumulation Matrix of Technological Capabilities for several firms from different industries. He has done an important contribution, as he formally connected the evolution of the level of the matrix to the learning mechanisms that support the accumulation of technological capabilities. The initial descriptive model proposed by Figueiredo (2001 and 2002) was applied to the steel industry in Brazil through a comparison of the capabilities accumulation trajectories between Companhia Siderúrgica Nacional (data from 1956 to 2000) and Usiminas (data from 1956 to 2000). The goal was to explain how learning processes could influence the technological capabilities accumulation rate (trajectory of the firm) and their implications on the technical and financial performance, which set a breakthrough for this type of approach.

Figueiredo´s Accumulation Matrix of Technological Capabilities (2001, 2002, 2004 and 2009) was inspired by Katz (1987), Dahlman *et al* (1987) and Lall (1987, 1992 and 1994). The functions were categorized as follows: 1) Investments (Facility User´s Decision-Making and Project Preparation and Implementation); 2) Processes and Production Organization; 3) Product-Centred; and 4) Equipment. The level of technological capabilities were: 1) Basic; 2) Renewed; 3) Extra Basic; 4) Pre-intermediate; 5) Intermediate; 6) High Intermediate and 7) Advanced. The model also distinguished routine technological capabilities of the production from innovative technological capabilities. Routine technological capabilities refer to the ability to produce goods at a given level of efficiency and inputs. The innovative capabilities refer to the ability to create, modify or improve products, processes or equipment. This model provides the accumulation rate to achieve a certain level of capabilities for specific functions, the trajectory of the mechanisms of learning and its interconnection with the development of technological capabilities, and the impact in terms of technical and financial performance.

Professor Paulo N. Figueiredo - PhD[s] has been supervising specific sectorial studies at FGV – Rio de Janeiro. Tacla and Figueiredo (2003) and Figueiredo (2009) examined the implications of learning processes to the mode and rate of technological capabilities accumulation in the sector of capital goods, for the period between 1980-2000. The objective was to contribute with empirical evidence and explanations about the management of technological development in firms of this industry, in Brazil. The proposed model had the following levels of technological capability: Level 1 Basic, Level 2 Renovated, Level 3 Extra-Basic, Level 4 Pre-Intermediate, Level 5 Intermediate, Level 6 High Intermediate, Level 7 Advanced. And the following functions: System Engineering, Project Management, Process and Operational Systems, Process Equipment. The model also has a detailed analysis of the adjacent learning mechanisms in a complementary external model to the matrix.

Figueiredo (2005) applied the descriptive model of technological capabilities accumulation to the information technology industry: 18 research institutes located in the South, Southeast, Northeast and North. The work considered metrics of the Capability Maturity Model - Software Engineering Institute (CMM-SEI) and the Project Management Body of Knowledge (PMBOK). The functions listed in the matrix were: Engineering activities and Project Management (Software Engineering and Project Management); Products and Solutions; and Tools and Processes. The levels of capabilities were divided into Level 1 Basic, Level 2 Extra Basic, Level 3 Innovation Basic, Level 4 Intermediate, Level 5 High Intermediate and Level 6 Advanced. Those levels were subcategorized into routine capabilities and innovative capabilities.

Castro and Figueiredo (2005) and Figueiredo (2009) presented a descriptive model of accumulation of technological capabilities for steelmaking, the learning mechanism that supported this accumulation, and the impacts in terms of technical and financial performance, for the period between 1997-2001. The levels of technological capabilities were categorized as Basic, Renewed, Extra Basic, Pre-Intermediate, Intermediate, High Intermediate, and Advanced. Also, the functions were classified as Production Process, Product and Equipment.

Figueiredo (2008 and 2009) presented an alternative view of the impact of economic policies of the 1990s on industrial performance, based on longitudinal data from 46 local and foreign firms in North sectors (Pole of Manaus): Electro-electronics, motorcycles and bicycles, and suppliers. A regression of selected factors on the capability growth rate for specific technological functions was estimated. The descriptive model was composed of 6 levels of technological capabilities: Operational Basic Level 1, Operational Basic Level 2, Innovative Basic Level 3, Innovative Intermediate Level 4, Innovative Advanced Level 5, Based Innovative Research Level 6. And the matrix had the following functions: Processes and Organization of Production, Activities centered on the Product and related Equipment activities.

Other evolutionary researchers applied the Matrix of Technology Capabilities (Lall, 1992), for example, Ribeiro (2009) and Iammarino *et al* (2008). Ribeiro (2009) analyzed the impact of Petrobras´ procurement policy on the technological development of the local supply chain for their offshore projects. Iammarino *et al* (2008) analyzed the technological capabilities at micro level (the firm is the center of the analysis) and meso level (there is no central actor, the system components are interconnected and interdependent), emphasizing local and global interactions.

For Brazilian aeronautics industry, there are three important studies that also use the concepts of the Matrix of Technological Capabilities: Cabral (1987), Oliveira (2005) and Marques (2011). Cabral (1987) identified technological relevant areas of the main Brazilian aircraft manufacturer, EMBRAER, and explained its history of technological learning through its development programs and the production of aircraft. Oliveira (2005) analyzed the EMBRAER´s supply chain, mainly focusing on the technical level of suppliers located in Brazil. He

[s] Professor Paulo N. Figueiredo – PhD is from Brazilian School of Public and Business Administration (EBAPE)/Fundação Getúlio Vargas (FGV) in Rio de Janeiro, Brazil. The concepts, metrics and analyses along his trajectory derived from two main sources: academic training in Science and Technology Policy Research (SPRU), the University of Sussex in the UK, where you can get direct influence of Christopher Freeman, Keith Pavitt, John Bessant, Sanjaya Lall (Oxford University), Richard Nelson (Columbia University) and Martin Bell, his advisor. The second source refers to several studies conducted over the last 10 years of the Research Program in Management of Technological Learning and Industrial Innovation in EBAPE, which was created and is coordinated by him. (FIGUEIREDO, 2009)

constructed a matrix without functions and different levels of complexity, which was utilized to identify the levels achieved by suppliers. Marques (2011) investigated how small and medium firms that provide less complex products for commercial aircraft are developing their innovation capabilities and set them in an adapted matrix for the aeronautical sector.

4. Discussion

As shown by the literature review in the previous sections, some of the modern evaluation programs approaches require strong databases, in order to obtain macro or meso view of the impacts. After analyses, it is argued herein that those evaluation models do require information usually not available in late industrialized countries, such as Brazil. Additionally, it is believed that evaluation models for Brazilian development Programs would demand another kind of approach, which differs from the commonly used in developed countries. In this sense, evolutionary approaches are more easily applied to the Brazilian reality, in fact, the evolutionary BETA's approach has influenced several researches in Brazil. Those models focus on identifying direct outcomes of programs, as well as the indirect ones, which are spinoffs that are generated during programs, as a result of the learning process that create new technological capabilities.

A very close related approach, the Accumulation Theory of Technological Capabilities set a theoretical framework for understanding what happens and what can be leveraged within the firm, in the context of late industrialized countries, in order to overcome technological underdevelopment. In Brazil, the Accumulation Matrix of Technological Capabilities was inspired by those evolutionary approaches, such model allowed new features considered vital to the development of the specific sectors and established more realistic levels of technological complexity. It starts from the recognition that the technological capabilities are accumulated in the organization and its members. They are divided between production and innovation capabilities and have different natures which mutually reinforce each other. It shifts the focus from developing the ability to learn and generate knowledge and innovation, in a specific area, to the ability to learn how to learn, in a sustainable training system for innovation. This approach also can be used with a particular objective: to investigate the accumulation trajectory of technological capabilities of specific sectors that have participated in a series of public, research and development programs in emerging countries. It is argued that the Accumulation Matrix of Technological Capabilities could be able to answer the following question: How such public programs might have influenced these trajectories? The main gaps of "traditional" (developed countries) evaluation methods are listed below:

i. Lack of indicators or metrics that reflect the reality of innovation processes of firms that need firstly to acquire outside technology;
ii. Lack of simplified approaches to model the reality of firms in terms of levels of complexity and maturity levels;
iii. Lack of studies that can analyze the technological trajectory of the firm and the impact of the participation of a series of public programs on this path.

In terms of contribution, after reviewing the relevant academic literature, it is argued that the Accumulation Matrix of Technological Capabilities could be used as a method for evaluating the impacts of public program, since it could offer:

i. Important insights about the trajectory of the firms that have participated in a series of public programs, so that this relationship can be enhanced in future programs;
ii. Important insights about the key functions that can orient the process of accumulating technological capabilities.

5. Conclusion

Brazilian public programs for developing specific industrial sectors need to be evaluated in terms of their impacts. Since this category of public programs look for developing technologically the suppliers of national networks, such evaluation should take into account the impacts at the firm level. In such context, the main objective of this article was to analyze the most relevant academic approaches for evaluating public programs. Thus, this paper made a review that included the most relevant methods that have been utilized throughout the world**.** Economic analysis, non-economic analysis, hybrid and data driven analysis, the evolutionary approaches, including the matrices proposed by previous authors, the BETA approach that focused on indirect impacts were presented. Finally, the descriptive model of accumulating technological capabilities developed in Brazil by Paulo. N. Figueiredo was reviewed, who was inspired by the whole evolutionary literature.

After analyses of literature review, it was argued that Figueiredo's model provides a framework that can be adapted for evaluating impacts of Brazilian Technological Programs on the firms of the national suppliers network. Most of the theoretical approaches were not recommended because of their level of analyses and their need for databases which were not available in Brazil. On the other hand, the Figueiredo's Model is appropriate for capturing the evolution of the firm through the technological capabilities that have been developing along the most important functions of firms. Finally, it was pointed out that the recommended model would need to be adapted in order to be transformed into an evaluation tool for capturing public technological programs focused on developing specific industrial sectors.

6. Acknowledgements

This work was supported by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP).

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