ABSTRACT: This paper explores the semiconductor industry and its supply chain characteristics in order to aid understanding of its overall trajectory. How can a country like Brazil produce such an insignificant amount of semiconductor components? What has led the country to this situation? The objectives of this paper are twofold: first, to describe the semiconductor supply chain in order to understand its major elements; and second, to delineate the trajectory of this industry. More specifically, we draw on evolutionary theory to analyze three macro trajectories: economic, governmental and technological. We collected archival data about these macro drivers and conducted interviews with professors and professionals in the semiconductor field. The results show four major events in the trajectory of the Brazilian semiconductor industry: (i) investment in microelectronic laboratories; (ii) a policy of market protection; (iii) a policy of market openness to product imports; and (iv) public policies to help the development of semiconductor companies through incentives.

Keywords: Semiconductor, trajectory, Brazil, supply chain
1. INTRODUCTION

The trajectory followed by an industry and its supply chain is directly linked to several factors, which include governmental actions, technological changes, innovations and the economic scenario in which it operates. Recently, studies have been specially focused on knowledge-intensive industries, such as the semiconductor industry. Mastering knowledge in all the productive stages of this industry has been a constant concern of industrialized countries, and understanding the development of the semiconductor industry and its supply chain has also been a constant task for researchers.

Since the starting point of this industry, which came with the creation of the first transistor (by Bell Laboratories) in 1947, besides the development of the first integrated circuit (by Texas Instruments) in 1961, the semiconductor industry has been the object of seminal studies, such as the work of Nelson (1962), Freeman, Harlow and Fuller (1965), Freeman (1982), Dosi (1984), Hippel (1977), Mowery (1978), Freeman and Soete (1987). These studies have unveiled the political, legal, economic, social and technological scenarios that have made countries, like the U.S. and Japan, become the world leaders in this industry. In addition, Brown and Linden (2005) identified some variables that may explain the migration of the development of semiconductors to Asia.

However, there are few studies analyzing the development trajectory of high technology products, such as semiconductors, especially in emerging countries like Brazil. The literature on supply chain management has placed great emphasis on the manufacturing supply chain of traditional products (e.g. Choi & Hartley, 1996; Flynn et al., 2010; Schoenherr et al., 2012), but little attention has been paid to high technology products. These tend to be more knowledge-intensive than traditional products, which have an impact on the entire supply chain because buyers and suppliers must possess knowledge-related capabilities that are not easily acquired. Beckman and Sinha (2005) drew attention to this gap in the literature on operations and supply chain management, even though few studies about this topic have been developed since then.

For more than three decades, Brazil, as an emerging country, has been trying to develop a semiconductor supply chain, since this country shows favorable market conditions for such an industry to flourish, as well as for an electronics industry to thrive. Revenue in the electrical and electronic industry in 2010 reached US$ 53.90 billion, which represented a growth of 11% compared to 2009. However, imports of electronic products grew 40% in dollar terms, from US$ 24.953 billion in 2009 to US$ 34.882 billion in 2010 (MCTI, 2011). The Brazilian institutional environment, composed of universities, research centers and governmental agencies, is another factor related to the evolution of the semiconductor industry. Despite the national effort, the current domestic production is still rather insignificant, showing a series of difficulties for both start-ups and for international groups to produce in Brazil.

In the Brazilian context, some studies have attempted to contribute to the knowledge about this industry. Silva (1985) highlighted the pattern of international competition and the possibility of including Brazil in this scenario, as, for Kimura (2005), it was aimed at identifying opportunities for the Brazilian semiconductor industry. Recently, Freitas (2012) assessed the innovation policies and their influence on the competitive advantage through the case of the Brazilian semiconductor industry. However, many questions still remain unanswered, especially those that contribute to a better understanding of the trajectory of this industry in Brazil: What macroeconomic events have impacted the current trajectory of the semiconductor industry? What government actions have influenced the development cycle of this industry? What were the main actions in the scientific-technological development of Brazil and their impacts on the national semiconductor industry?

In order to contribute to the knowledge about the current scenario of the semiconductor industry in Brazil, this study aims at understanding its development trajectory from the evolutionary trajectory (Nelson & Winter, 1982). To this end, three dimensions will be analyzed: governmental, macroeconomic and technological. To meet the objective of this article, we have chosen the following structure: Besides this introduction, an assessment of evolutionary theory is presented, as well as an assessment of the main ideas presented by researchers in this macroeconomic context, plus the technological trajectory and governmental approach. In the second part, the method is described. The third section covers discussion of the results. Finally, in the fourth section, the concluding remarks and suggestions for future research are presented.

2. LITERATURE REVIEW

2.1. Supply chain management

The supply chain has gained considerable attention from companies. So too have grown researchers’
attempts to create an adequate definition that describes the field. Many of these definitions are broad (Harland, Lamming, & Cousins, 1999) or biased towards a particular theory and the work of the corresponding author (Tan, 2001). In fact, each definition varies depending upon the theoretical perspective used to address the subject (Teixeira & Lacerda, 2010). There is no general consensus on what exactly supply chain management really is or what it entails. Variation in the most recent and advanced definitions of supply chain management is a symptom of the infancy of the field. For example, the definition of supply chain management proposed by Chen and Paulraj (2004) highlights factors and activities that lead companies to create and maintain relationships with their suppliers, but it does not include the results and consequences of these practices. Moreover, Li et al. (2005) restrict the concept to the activities essential to management, and fail to include antecedents and results. In an attempt to synthesize a broad, comprehensive definition of the subject, Mentzer et al. (2001) analyzed several studies on supply chain management. According to the authors, supply chain management is defined as “the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole” (Mentzer et al., 2001, p.18). This definition is similar to that provided by other authors in the supply chain literature, such as Croom, Romano, and Giannakis (2001), Wong, Boon-itt, Wong (2011), and Gunawardane (2012).

A general supply chain model is shown in Figure 1. Typically, a supply chain encompasses a supplier, manufacturer, distributor, retailer, and the final customer (Chopra & Meindl, 2007; Fawcett, Ellram, & Ogden, 2007). In this illustrative chain, the flow of material moves downstream, from the suppliers to the customers, and the flow of information is upstream, from the customers to the suppliers. It is important to note this general model varies depending on the industry as well as the company characteristics. For instance, the Dell Computer supply chain model tends to be shorter than that of Figure 1, since Dell does not have distributors and retailers, selling its computers directly to the final consumer. In the case of services, the supply chain tends to be composed of suppliers, service providers, and final consumers. On the other hand, food companies sell their products through grocery stores, which indeed implies a supply chain like that presented in Figure 1.

![Figure 1 – A general supply chain model](source: Adapted from Chopra and Meindl (2007))

2.2. Evolutionary theory

The evolutionary theory, also known as the neo-Schumpeterian approach, contemplates the main Schumpeter (1934) ideas. Nelson and Winter (1982) are the main articulators of this theory based on the work of Simon (1945) and Schumpeter (1934), which represents the origin of the insights on bounded rationality, innovation and ideas transposed from the evolutionary biology to explain company behavior. Other important authors are Freeman (1995), Dosi (1982, 2006), Lundvall (1992), Mowery and Rosenberg (2000), Griliches (1957) and Utterback (1996).

The term “evolutionary”, according to Dosi and Nelson (1994), was used to highlight one of the main ideas presented by this theoretical mainstream, that is, the theory gains identity by allowing “explanation of why the existence of something must be closely connected to how this has become what it is” (Dosi, 1997, p.1531), emphasizing the path, the trajectory. As long as the technical shift and the industrial transformation are dependent on the trajectory, the future contains historical elements. This trajectory helps to explain the existence of different economic performances of countries, regions and sectors, as well as differences in their ability to innovate. Therefore, to assess the evolution of an industry, region or nation, it means that the study of
history, which comprises the technological macro-economic and governmental trajectory, helps in understanding the current issues that stimulate the innovation process.

2.2.1. Technological trajectory

The technology comprises a set of parcels of knowledge, both practical and theoretical know-how, methods, procedures, experience of success and failure, as well as physical devices and equipment (Dosi, 2006). Thus, in analogy to scientific paradigms discussed in Thomas Kuhn’s (1970) work, Dosi (2006) highlights the existence of technological paradigms, or technology research programs. Thus, the paradigm is treated as a model or a standard solution for problems related to technology (Dosi, 2006). In this way, the evolution of different technologies, incorporated in goods and/or processes for solving problems in the production system, providing progress, is what Dosi (1982; 2006) and Nelson and Winter (1982) call a technological trajectory. As time goes by, the technological directions change in order to face the new opportunities, for reasons related to the technology itself, or even issues related to economics (Dosi, 1982). And this dynamic change explains the technological leaps of an industry (Perez, 1999), or a technological paradigm shift.

In a survey conducted in the 1980s, which took into consideration the institutions that support the technical advancement of industry, Nelson (1986) points out that universities are public repository of knowledge. There are some cases that have been the objects of study of entrepreneurship linked to human capital formation and the creation of knowledge and technology for the private productive sector, such as Silicon Valley, which represents a region of high technology in the United States resulting from the interaction among universities, the government and industry (Goldstein & Drucker, 2006). Allied to this comes Dosi’s argument (2006) regarding the first 10 years in the history of the semiconductor industry. For him, this period was characterized by the critical interrelationship between “science” and “technology.” This interaction was able to open the way to fast generation of new technical knowledge and very successful commercial exploitation. Thus, a technological trajectory depends basically on new knowledge and its applications to solving problems, or to generating new knowledge to meet new needs; it is composed of elements and events stemming from changes and developments in technology, and it can be influenced by an economic trajectory.

2.2.2. Economic trajectory

The characteristics of the situation of an industry, or a particular sector, region or nation, economy or society are borne into the future (Nelson & Winter, 1982). In this regard, it is noteworthy that all modifications within an industry make firms adapt to their environment. In other words, any change in the structural conditions of an industry interacts with the changing patterns of corporate behavior (Dosi, 2006). These characteristics of the economic environment can also become selectors in the technological trajectory to be followed (Dosi, 1982; Perez, 1999). Thus, the institutional context can motivate or decrease the expenditure of funds for innovative activities in accordance with their expected economic returns, or when they are threatened by loss of something, some current economic benefit, or even for both reasons (Dosi, 2006).

Transitions of paradigms and technological opportunities may come from situations in which social and economic conditions are not the best (Perez, 1999). Perez (1999, p.17) emphasizes in his paper on technological change and development opportunities that it is necessary to “dance with the wolves.” The author uses this analogy to explore the idea that, in a dynamic context in evolution, it is necessary for organizations to understand the conditions of access to technology according to the economic context, and that they use successive development strategies along with successive phases of paradigms. Ruttan (1997) emphasizes that the prevailing economic conditions may affect the future dimensions of knowledge and technology. Thus, successive historical events that affect the economic context of a country and ultimately influence the technological trajectories of various sectors are the macroeconomic trajectory.

2.2.3. Governmental trajectory

The laws, policies and public organizations represent an important part of the environment that shapes the private sector activities. Accordingly, the government has a central role in promoting and developing policies to support the start-up of new economic basis, as well as to generate the necessary institutions to support technological development and stimulate search for solutions to local problems that are not well solved by the market (Lundvall, 1992). So, for Nelson and Winter (1982), policies evolve partly in response to the changing demands and opportunities perceived, and such
changes may result from the evolution of technologies and private market structures. So, the government role can be fruitful or unfruitful in productive innovation. Public policies are essential to ensure increased capacity for learning and dissemination of knowledge (Cooke, 2001).

Seeking to exemplify how government interventions can be crucial to the technological paradigm shift, Freeman (1989) highlights the Japanese case. The focus of the strategy was, according to Freeman (1989), the government’s ability to provide integration among universities, the government and public and private industry. For Freeman (1989), the recognition of the new Japanese technological trajectory, focused on robotics, information technology, and computers, was made possible by the central coordination of the government along with the keiretsu (conglomerates of Japanese industries).

The importance of public policy for sectoral development was also highlighted in the work of Dosi (2006). He points out that the American supremacy in production and innovation in the semiconductor industry in the 50s and 60s was stimulated by public policies (mainly regarding the military and space). It is understood, therefore, that the use of policy instruments to extend and modify the private incentives to create new technologies, the importance of support, sectoral diversity of the situations and the complexity of the technical issues, are all combined to suggest policy interventions relating to R&D (Nelson & Winter, 1982; Dosi, 2006) and, in this way, it builds a path of governmental actions in the development of a nation, region or sector.

2.3. Theoretical model

The trajectories used in the analysis of the trajectory refer to different data sets and can be classified within the same group with similar characteristics. Anyway, the goal is to use these trajectories to guide data analysis and description of the results, allowing a more detailed understanding of the events, in particular, the historical ones that may have affected the trajectory of the industry analyzed. In order to develop this work, three trajectories were considered:

i. Macroeconomic trajectory – elements and events related to Brazilian macroeconomics and its indicators;

ii. Governmental trajectory – elements and events in the political and regulatory framework;

iii. Technological trajectory – elements and events resulting from changes and developments in technology, especially in the area of electronics and computing.

The perspectives used in the analysis of the trajectory of the Brazilian semiconductor industry involved a certain concern regarding long-term processes and progressive changes that are the result of a dynamic process. Thus, according to this dynamic view, it is necessary to know and to conjecture about the past to understand the present, as well as to see the present features that can lead to a different future, through the same dynamic process (Nelson & Winter, 1982). Figure 2 illustrates the theoretical model that guides the empirical methodology and analysis used in this study to provide understanding of the trajectory of the semiconductor industry in Brazil. Briefly, the evolutionary theory provides the theoretical foundation for understanding the phenomenon analyzed, while the semiconductor industry per se provides the case for review.
3. METHODS

The research design employed in this work is case study, indicated for the initial, exploratory stages of a given phenomenon (Meredith, 1998; Yin, 1989), in which the experiences of professionals are essential to the practical relevance of the results (Fisher 2007). Furthermore, a case study can provide a rich description of the phenomenon under investigation (Siggelkow, 2007), which is the Brazilian semiconductor industry. Thus, case study is the most appropriate research design because it offers the opportunity for in-depth understanding of the semiconductor industry from a historical viewpoint, outlined by three trajectories. Another justification for using this research design is based on the lack of studies that depict the development of this industry in Brazil, which ultimately hampers the use and combination of other methods.

It is worth noting that this paper aims to make the first exploration of the semiconductor industry in Brazil. Our study had the following general guidelines: i) main links in this supply chain; ii) main actors; iii) key policies governing the semiconductor industry; iv) main government assistance programs; and v) how the semiconductor industry is organized. This first study allows us to understand the current scenario of this industry.

From this scenario it is possible to trace the history of the industry and identify the events that have contributed to its development. To achieve this objective, three trajectories were defined: a) technological, b) governmental, and c) macroeconomic. The choice of these trajectories was to provide a mapping of the trajectory of the advancement of this industry in Brazil over the years, the central focus of this paper. Economic, technological, and governmental trajectories were analyzed according to the features commonly used in each. For example, the macroeconomic trajectory analyzes characteristics, such as the inflation rate, interest rate, and the exchange rate. From a technological standpoint, the study analyzes changes in usage of technology, such as the introduction of new research laboratories or the introduction of new material used in the production process. Finally, from a governmental trajectory, our study analyzes federal government decisions that directly or indirectly affect this industry in Brazil.

Three sources were used for data collection. First, bibliographic references were used to provide initial data and information about the characteristics of the industry under analysis. This first step is essential to provide the authors of this paper with uniformity in the terminology used in the area and also information about the main features inherent in this industry. Second, documents, such as government reports and those of other institutions related to the semiconductor industry, were used. Analysis of these documents provides data and information about the characteristics of the industry over the past 30 years. This, to some extent, allows reconstruction and understanding of certain events that may be related to changes in this sector in Brazil over these years. Finally, in-depth interviews were conducted with experts, practitioners and researchers of this industry in Brazil. These were held between August and November 2012, based on a script containing semi-structured questions that served as a guide for the authors to conduct them in accordance with the research objectives. This script was pre-tested with the help of three experts in the semiconductor industry. Table 1 contains the major questions in the questionnaire.
Table 1 - Questions for in-depth interviews

<table>
<thead>
<tr>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What is the structure of the Brazilian semiconductor industry?</td>
</tr>
<tr>
<td>2. What are the main economic events that have contributed to its development?</td>
</tr>
<tr>
<td>3. What are the main technological events that have contributed to its development?</td>
</tr>
<tr>
<td>4. What are the main governmental decisions that have contributed to its development?</td>
</tr>
<tr>
<td>5. What are the main barriers to development of this industry?</td>
</tr>
<tr>
<td>6. What are the possible alternatives to overcome these barriers?</td>
</tr>
</tbody>
</table>

The selection of participants for the in-depth interviews was based on two criteria:

i. Experience in the semiconductor industry; and

ii. Potential contribution to achieving the objectives of our study. The interviews took place in the participants’ workplaces in order to make them feel comfortable enough to answer the questions. Table 2 presents some information about these participants.

Table 2 – Interviewees’ characteristics

<table>
<thead>
<tr>
<th>Interviewee</th>
<th>Institution</th>
<th>Highest Degree</th>
<th>Years in semiconductor industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewee A</td>
<td>Governmental agency</td>
<td>Doctorate</td>
<td>20</td>
</tr>
<tr>
<td>Interviewee B</td>
<td>Private company</td>
<td>Masters</td>
<td>5</td>
</tr>
<tr>
<td>Interviewee C</td>
<td>Private company</td>
<td>Bachelor</td>
<td>10</td>
</tr>
<tr>
<td>Interviewee D</td>
<td>Professor</td>
<td>Doctorate</td>
<td>25</td>
</tr>
</tbody>
</table>

Data from the interviews were transcribed and analyzed according to guidelines of content analysis. The content analysis was conducted based on major categories determined a priori according to our research objectives, which involve economic, technological and governmental perspectives. After transcribing the interviews, we counted and categorized the terms cited by interviewees, searching for patterns of response and classifying them in one of our three major categories: economic, technological, and governmental. In addition, as the main objective of this research was to understand the trajectory of the Brazilian semiconductor industry, a temporal logical analysis was used, in which the changes in the industry that have occurred over time were analyzed. Thus, the dates of data available were taken into account. By analyzing historical data, it was possible to identify the year to which they referred. Thus, adequate data were obtained to recreate the history of the semiconductor industry with the economic, governmental, and technological trajectories.

For the purpose of this study, a historical event is viewed as any event that has caused a significant impact on various actors, such as organizations and institutions within the industry in Brazil. These historical events are used in this study to identify possible disruptions in the structures, laws, rules, policies and existing processes in this industry. These disruptions help to highlight significant changes occurring in the industry, thereby indicating actions or decisions that have influenced its history.

4. RESULTS

All results presented in this section are based on data gathered through the interviews and documents analyzed.

4.1 The semiconductor industry and its supply chain

With a market whose figures reach US$ 248.2 billion annually worldwide (SIA, 2010), the semiconductor
industry becomes a single empirical case relevant to
the present study. According to Gutierrez and Leal
(2004), among the leading countries in the produc-
tion of integrated circuits in 2002 were China, which
exports US$ 3 billion, Ireland US$ 6 billion, Malaysia
US$ 13 billion and Taiwan US$ 15 billion. One reason
for the rapid development of this industry in these
countries may be associated with the adoption of
partnerships with universities, companies, research
institutes, industry federations and funding agencies.

It is worth mentioning the countries with a high
level of development that also invest in attracting
companies in the semiconductor industry, such as:
Japan, Germany, USA and France. These coun-
tries have made huge investments in this activity,
because they have identified the integrated circuit
industry as strategic for maintaining the country’s
development, along with growth of research insti-
tutes and innovation. According to Fernandes (2010,
p. 21), “The national competitiveness and economic
development are closely linked with the concepts
of information and knowledge economies”.

It can be affirmed that the attention given to the
semiconductor industry in recent years is associated
with the great techno-economic revolution of society.
Currently, people are immersed in a dynamic soci-
ety, without borders and permeated by technology.
More and more people are depending on technol-
ogy to run their daily activities. As technology tools
used extensively by society, one can cite, for example,
computers, iPods, iPads and iPhones, which constit-
tute facilitators of everyday activities. What might go
unnoticed in the use of these new technology tools is
that they all need semiconductors to work, the semi-
ciconductor also being known as a chip.

Semiconductor products, such as microchips, con-
stitute the foundation for the development of in-
formation and communication technologies (TICs).
According to Freeman and Soete (1987), these tech-
nologies can be considered a new techno-economic
paradigm, as they are ubiquitous in various produc-
tive activities. In other words, they are able to “[...]
revolutionize the processes of production and im-

impact all other industries and services” (Freeman &
Soete, 1987, p.105).

Furthermore, the semiconductor industry has: a
greatly accelerated dynamic of innovation, resulting
from the combination of high rates of technological
innovation (not only in product design, but also in
their processes); density and complexity in its tech-
nologies (Dahmen, 1993); and also a capital intensive
character and Research and Development (R&D) ac-
tivities, which generate high investments and risks
for manufacturers in this segment. The semi-
cductor chain is composed of macro-steps. They are:
conception, design, front-end, back-end, test and,
ultimately, customer service. The conception is the
first step in the semiconductor chain and consists of
idealization and activity planning. The second stage,
called design, is responsible for executing the inte-
grated circuit project. The third stage is processing/
manufacturing, which processes the physical and
chemical elements of semiconductors. The packag-
ing and testing of semiconductors refer to back-end
and chip functionality testing. The customer service
is the last step in the chain and corresponds to the
sale and delivery of the product to the consumer.

The various steps/processes comprising the semi-
corder chain can be performed by various com-
panies located in different regions, thus allowing
segment unbundling, since it makes possible the estab-
ishment of collaborative strategies in almost all
parts of the chain, as can be seen in Figure 3.

Manufacturers of integrated circuits are classified
according to their type of business or the way they
operate in the value chain. Thus, they can be clas-
sified as integrated manufacturers, fabless com-
panies, specialized foundries, packagers, design
firms and independent intellectual property firms.
Companies classified as integrated manufacturers
perform the entire process of semiconductor manu-
facturing, from the design of the component to con-
sumer delivery. The companies called fabless are
responsible for product design and are the brand
and market holders.
Companies known as specialized foundries only perform the physical-chemical processing of the products. The packager is dedicated to the back-end step. Companies known as design firms (design houses) perform the integrated circuit design. And, finally, intellectual property companies design specific parts of the projects and license them to third parties, generating royalties. Although the semiconductor supply chain seems lean and organized, it is important to emphasize the need for an ecosystem to provide the enabling environment for development of the semiconductor area.

The semiconductor industry has strict infrastructure requirements regarding quality and quantity. It is important to mention the necessary availability of water, electricity and transportation, including ports and airports. Moreover, the main requirement for an integrated circuit company, whatever its form or type of business activity, is the availability of skilled labor with a range of capabilities. This allows complete integration essential to the “ecosystem” structure and specific training in microelectronics.

In this regard, long-term R&D that articulates the various government agencies must be developed, providing them with stable resources and appropriate management mechanisms. Likewise, a model truly integrated with the business environment should take into account the comparative advantages of Brazil and the joint initiatives of R&D and human resource training in the field of microelectronics.

The path taken by the semiconductor industry is only relevant and can only be understood when viewing its trajectory. Thus, the event that initiated the semiconductor industry was the discovery of the transistor in 1947, in the United States, by the company Bell Labs. The transistor constitutes the main element of the semiconductor. The intensification of studies on the transistor was driven by historical events experienced in previous years, such as the two World Wars. According to Freeman and Soete (2008), the two Wars stimulated the growth of government support for scientific research and technological development in many countries.

Due to the world conflicts, the need to improve communication among the military in combat has caused learning to advance in the telecommunications field and led to subsidized development of studies aimed at the creation of the semiconductor era postwar (Swart, 2010). The invention of the diode and triode vacuum tube, in the first two decades of the 20th century, provided the basis for the spectacular growth of the transistor, the main input of semiconductors (Adner & Kappor, 2010).

In the following years, the Bell Labs patent, licensed to other transistor manufacturers, started a cycle of intense research. In 1959, it created the first Planar process for integrated circuits. This raised the possibility of coupling various transistors to form an integrated semiconductor circuit. Shortly thereafter, in 1962, the first commercial integrated circuits reached the markets. Already in the late 60s, multiple firms were manufacturing integrated circuits in Silicon Valley.

By analyzing the process of creation and development of the semiconductor, one can see that the concept of technological development is critical. In-depth analysis of texts that highlight the emerging semiconductor demonstrates that this discovery only became feasible due to the formation of
research groups that shared knowledge and generated collective learning. It seems possible to show that, according to this industry’s history, technical change has been the major booster of its development worldwide.

In the 70s, there was the oil crisis, which marked the economics of global markets, forcing industrialized countries to promote adjustments in the productive sector, aiming to resume economic growth. The changes in the economic scenario forced a need to adopt coping strategies to deal with uncertainty. Because of inflation in oil prices, the oil crisis in 1973 had a significant impact on the competition and modified the trajectory of the global market. With the globalization of the world economy, there have been new patterns of international trade and competition. The main features of this process are: increased market competitiveness and uneven growth in different regions of the world. This process of globalization, access to new markets and technologies has helped other countries, such as Japan, to initiate semiconductor production. After starting production, Japan invested heavily in research and development and eventually overtook the United States, making it the largest manufacturer of these products in the world. Heavy demand for semiconductors in the late 70s and early 80s brought some ease of access to this market for incoming countries. This is the case of Germany, France and the UK, which started production in the 80s. Other countries involved in the semiconductor market started to invest in R&D, such as South Korea, Taiwan and Singapore. Until the 80s, the largest share of integrated circuit production was in the United States and Japan.

The following decades were characterized by great expansion in the countries called the “Asian Tigers”, which came to dominate the global manufacture of electronic products: Hong Kong, South Korea, Singapore and Taiwan. This rapid expansion was, among other factors, a result of the implementation of long-term government policies aimed at increasing the value of its industrial production. Brown and Linden (2005) present some factors to explain the migration of semiconductor development to the Asian continent: the existence of close contact with customers and ease of access to specialized human resources, plus relatively lower cost, implying a reduction of total production costs.

4.2. The semiconductor industry and its supply chain in Brazil

Results from analysis of interviews and documents reveal the semiconductor industry and its supply chain in Brazil, as illustrated in Figure 4. For Gutierrez and Leal (2004), Brazil is one of the few countries among the major world economies that do not have an electronics industry that includes the manufacture of integrated circuits. In the field survey, we found 22 companies operating in Brazil working in the conception and design of integrated circuits, which is the first stage in the production of semiconductors, as presented in Figure 3. At the front-end, we found 4 enterprises developing some manufacturing activities; while at the back-end, we found 7 companies performing packaging manufacturing activities. Finally, providing support for this supply chain, we found 23 training institutions promoting and generating labor and some type of knowledge to be used directly by companies in the chain. These companies and institutions are spread throughout Brazil, and receive support from the government, especially through tax incentives. It is noteworthy that there are 34 companies that supply raw materials, equipment and specialized services. We presented this model to participants of our research in order to validate the final model. Results from this validation process lead to a validated semiconductor supply chain model.
After a thorough analysis of the path taken by the semiconductor industry, it can be said that in Brazil it has undergone various processes, marked by several technological, macroeconomic and government events. In this sense, one can understand its history, and guidance can be given by analysis of the events that make up these technological, economic and government prospects. In the following sections, these events and trajectories are discussed.

4.2.1. Technological trajectory

Results from the content analysis suggest that the technological trajectory had its starting point in the research activities conducted by the Institute of Aeronautical Technology - ITA in the 1950s. Three out of four interviewees mentioned the creation of ITA as the starting point for the technological trajectory related to the semiconductor industry. Results indicate that, although ITA was not created to foster semiconductors, it has a key role in promoting technology in several industries in Brazil, including the electronics.

Results from interviews also indicate that, in the following decade, there were several initiatives regarding the creation of microelectronics laboratories across the country, such as the assembly of microelectronics laboratories at the University of São Paulo - USP and University of Campinas - UNICAMP. These laboratories were set up in federal universities as a priority action of the government to develop the Brazilian industry. Other agencies also supported the establishment of laboratories, such as FINEP (Financier of Studies and Projects), BNDES (National Economic and Social Development Bank), CNPq (National Council for Scientific and Technological Development), FAPESP (Foundation for Research Support in São Paulo State) and CAPES (Coordination of the Enhancement of Higher Education Personnel). It is worth noting that this action by the Brazilian government has acknowledged the important technical advance, the increased productivity and change in the economic dynamics, as quoted by the evolutionary theory of Nelson and Winter (1982).

It was a consensus among interviewees that the creation of six microelectronics laboratories during 60's, 70's and 80's were fundamental to form a skilled workforce and develop new technologies through applied research. According to Tavares (2001), the federal government made efforts to create infrastructure for research and education in science and technology by devising an information technology policy. The government role was to organize and institutionalize norms, rules and routines. Furthermore, it is important to highlight an action on the part of the private sector, namely the installation of the Philco diode and transistor factory in Sao Paulo. This is one of the very few, if not the only, technology initiative coming from the private sector.

Analysis of documents indicate that during 1990’s there was a technological gap in terms of new installations, specific investments, infrastructure development laboratories and other such resources. Two interviewees suggested that this gap may have caused a rupture in the system of technological development for the electro-electronics and semiconductor industries in the country.

In the 2000s, a new initiative was incorporated into the technological trajectory of the semiconductor industry, namely the implementation of the CI Brazil program. This will be discussed in depth in the
governmental trajectory section, but it is important to highlight that this program aims to develop technology aimed not only at the manufacture of components, but also geared primarily to the design of electronic components and chips used in the semiconductor industry. Table 3 presents a summary of the key initiatives that relate to the technological perspective. In the analysis of the initiatives that make up the technological scenario, it is possible to realize that actions specifically performed by the government have been presented. In this first survey, private initiatives were not identified. The reason for the absence of these initiatives may be associated with difficulty in tracing such actions.

Table 3 - Technological trajectory

<table>
<thead>
<tr>
<th>Main technological events</th>
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<tbody>
<tr>
<td>1950 ITA starts research activities in semiconductors</td>
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<tr>
<td>1960 Top research activities at USP</td>
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<tr>
<td>Philco installs diode and transistor factory in São Paulo</td>
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<tr>
<td>1970 Setting up the microelectronics lab at USP Polytechnic School</td>
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<tr>
<td>Setting up of microelectronics lab at USP Polytechnic School</td>
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<tr>
<td>Establishment of microelectronics lab at UNICAMP</td>
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<tr>
<td>1980 Establishment of microelectronics laboratory at UFPE Physics Institute</td>
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<td>Microelectronics laboratory created at UFRGS Physics Institute</td>
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</table>

4.2.2. Economic trajectory

Results based on analysis of documents reveal that, in the 1960s, the country experienced the establishment of the electronics industry in Brazil and, in the 1970s, Brazil experienced a boom in consumer durables. Multiple sources mention the “miracle” of the Brazilian economy, the period of continuous economic growth. Results from interviews indicate that, during that time, Brazil was beginning to develop more effective actions for the development of the semiconductor industry, such as the implementation of a public policy to protect the market and the respective enterprises throughout the country. This protection seeks to restrict market access to international companies and ban imports of products in order to help the development of the national industry and increase internal scientific research. According to one interviewee, however, the market protection was the two sides of the coin: “It gave Brazilian companies sometime to prepare for international competition in the field of technology, however, it also created an atmosphere of protection that led companies to a comfort zone, reducing their motivation for technology development”.

From the trajectory of evolutionary theory, the market protection provided an economic shift that produced certain events in the environment, such as the establishment of 23 national and multinational companies in the semiconductor area in Brazil in the 70s. The multinationals were attracted by a market protection policy, established in 1977 (Tavares, 2001), and especially by the policies of import substitution.

During the 1980s, the country went through a turbulent economic period when three different economic plans were implemented to contain inflation, all without success, which led the country into recession.

In the 90s, the Brazilian economy was transformed by trade liberalization and the establishment of the Real Plan that brought the market into a new competitive era, since foreign competition and monetary stability had demanded new trade policies and the creation of new business strategies. The opening of the Brazilian market made it possible to import products and the implementation of new routines, which can be viewed as a paradigm shift. There was an imbalance in the trajectory of the semiconductor industry, since the import of electronic goods was facilitated, discouraging domestic production. These two events, the Real Plan and the market opening, aimed to include Brazil in the global econ-
omy, and this is what has actually ensued. However, there has been an intensification of global competition and a decline of the Brazilian semiconductor industry. This event definitively marked the history of the semiconductor industry, as the government led a process of learning and knowledge accumulation, since necessity causes adaptation. This corroborates the logic of evolutionary theory that postulates these economic changes that produce changes in the environment (Langlois and Everett, 1993). All interviewees mentioned these years as the most important from the economic perspective, suggesting that the changes in economic policy were fundamental to provoke a change in the semiconductor industry.

The 2000s are marked by fluctuations in the macroeconomic field. First, the continued stability of the Brazilian currency allowed investment planning, both by the government and businesses. This led the country to continuous economic growth and job creation, which, along with wages, provided the necessary input for a virtuous cycle of growth. However, the global financial crisis, which began in mid-2008, caused negative impacts on the economies of countries worldwide, including Brazil, causing a slowdown in economic growth. Table 4 summarizes the main macroeconomic events that impacted the Brazilian economy in some way.

<table>
<thead>
<tr>
<th>Economic main events</th>
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4.2.3. Governmental Trajectory

Results from the content analysis suggest that, after achieving an outstanding stage of development, the semiconductor industry declined at the beginning of the 90s with the end of the market protection policy. Interviewees mentioned that incentives for research and development were reduced and many of the best talents changed area or emigrated. One interviewee reported: “Some of my colleagues left Brazil searching for opportunities in other countries, it was a time of too much uncertainty and lack of resources for high technology research and development”. The end of market protection suggests a rupture in the trajectory of the semiconductor industry. Government actions, such as establishing policies and incentive programs, have an influence on the characteristics and performance of the companies, which ultimately helps to delineate the path of a particular industry.

Analysis of documents shows that most multinational companies shutdown their operations in Brazil in less than six months. The end of the semiconductor industry was caused by the announcement of facilitated importation of equipment by companies, without any tax or legal restrictions, which had been imposed by the Fernando Collor de Mello government. Despite the existence of some evidence suggesting incentives for national production of electronic components (later introduced with the 2nd law of computing), there was clear evidence that importation of equipment was a decision to transfer the production of such components abroad. While Brazil was losing much of its efforts to build its own semiconductor industry, other countries were making progress in the process of establishing their semiconductor industries. The statement of one interviewee summarizes the effect of government on the semiconductor industry. The Brazilian government took decisions that put Brazil in a very bad position to compete in high technology because it allowed importation of electronic devices at no cost and provide no incentive to Brazilian companies and universities to move along with research and development”.

The interviewees also mentioned that the 2000s represent a shift in the government policy because Brazilian government put microelectronics industry as a priority for development. As a result, analysis of documents show that the government has created many programs, such as the Program of Integrated Circuits Brazil to foster an ecosystem suitable for the development and support of this industry. For Holbrook et al. (2000), there is no reason to believe that, without such public policies, the rate of technical advance achieved by Brazilian semiconductor industry would have been so great. This statement reinforces the need for the government as an articulator of policy and arrangements for the development of this industry.

Interviewees also called attention to the experience of other counties, which focused on attracting the integrated circuit industry. According to all four interviewees, the government should be the one the main actors in promoting the development of semiconductor industry in Brazil. For them, public policies should involve high investments so that the minimum requirements of physical infrastructure and human resource training needed by the respective manufacturing companies are met. To a lesser or greater degree, it is possible to identify in other countries’ experiences the adoption of instruments that involve subsidies, tax relief, and financial incentives in a time horizon of not less than 10 years (Gutierrez & Leal, 2004).

Currently, Brazil is one of the few among many countries that do not have an electronic industrial complex that includes the manufacturing of integrated circuits (Gutierrez & Leal, 2004). Analysis of documents reveals that, to change this situation, the Brazilian government’s main objective is to make the country a player in the design and manufacturing of integrated circuits (IC). The great challenge to achieve this goal is the need to create a favorable ecosystem for this industry. It is understood as an ecosystem with the dynamism required for the correct development of the semiconductor chain. One interviewee said: “Brazil needs an ecosystem including companies, funding agencies, technology institutes, politics, entrepreneurs that are interlinked to one another by the needs of this industry”. Seeking to create an ecosystem conducive to attracting more companies into the semiconductor industry and developing those already established, Brazil has taken various actions aiming at the development of this industry. The Brazilian government has developed industrial and technological policies articulated and integrated with the various institutions and government agencies, such as the PDP (Productive Development Policy) in 2008 and the PACTI (Action Plan for Science, Technology and Innovation) 2007 - 2010. Some of the key strategic actions taken by the Brazilian government should also be highlighted:
i. PADIS: This is the Support Program for Technological Development and the Industry of Semiconductor Displays. It includes a chapter dealing with the topography of integrated circuits, in line with international agreements in the intellectual property area. PADIS is developed for companies that invest in Research and Development (R&D) and are manufacturers of: information displays used as inputs for electronic equipment and technologies.

i. National Microelectronics Program: This aims to support and promote the consolidation of graduate programs through the provision of scholarships for masters and doctorate research programs related to the Microelectronics area.

Currently, nine companies operating in Brazil focus on the semiconductor industry, of which two produce power devices, three operate in the back-end, one in PV, one focuses entirely on design, and another is dedicated to the design house and foundry area (CI Brasil, 2011). In addition, 22 companies are identified as participating in the Design House Development Project for Integrated Circuits Brazil - BRAZIL CI, and 13 research institutes are involved in semiconductor studies. These institutions are scattered throughout Brazil and receive the cooperation of the government through the CI project to continue operating in the market. In 2011, collaborative action among the government, universities and private companies resulted in the installation of a company to encapsulate semiconductors (Valor Econômico, 2011), the first in Brazil.

The role played by the government is important to ensure the survival of this industry. However, the time elapsed between creation and implementation of these policies rendered survival of the semiconductor companies in the country unviable. According to Freeman and Soete (2008), a major difficulty is to promote public policies for long-lasting technologies within a globalized market economy. Therefore, technological change should be seen as a cumulative process.

Brazil is reintroducing policies, such as the National Program of Microelectronics and CI Brazil, to rebuild this industry (the government behavior seems to be aware of the adaptive types). To implement these policies, the government has made use of the knowledge acquired during the first cycle of the Brazilian semiconductor industry. To do so, the government has relied on documents, norms and institutionalized routines from that period. This statement corroborates the studies of Crossan, Lane and White (1999) with respect to the need for an institutionalization process for the validation of learning. Complementing these authors, Zawislak (2004) argues that the past experience, based on learning and competence as well as the solutions found by individuals or by a firm that builds new routines, undergoes more intensive training to face random factors, that is, situations outside the routine. Table 5 summarizes the main governmental events in the Brazil.

<table>
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<tr>
<th>Main governmental events</th>
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<td><strong>1970</strong></td>
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<td><strong>2010</strong></td>
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4.3. Analysis through the dimension of evolutionary theory

It is worth noting that Brazil, after experiencing a golden age from the 1960s to 1990s, opted for strategies that ended up not prioritizing the preservation and development of the semiconductor industry. Thus, one can conclude that the scenario of the semiconductor industry that exists today is the result of a process of advance and setbacks caused by technological impacts, and especially by political decisions at different historical moments. This is because the essential purpose of policies supporting sustainable development is to encourage the rapid diffusion of technologies (Freeman, Soete, 2008).

Another important point to understand is the relationship of the economic, technological, governmental actions and development cycles of this industry. The explanations for this point can be obtained by analyzing the historical events that gave rise to learning and change in public policy. It can be said that the Brazilian semiconductor industry experienced its first cycle between the 60s and 80s. As a feature of this cycle, the high government investment in the development of applied research and skilled labor can be mentioned. The articulation of the government for the establishment of labs can be seen as a method of “search”, “selection”, “routine” procedures, “adoption” in the face of environmental uncertainty with the intention of achieving success in competitive market performance (Nelson and Winter, 2005). Table 6 presents the main historical events identified as associated with the history of the semiconductor industry.

Table 6 - Historical events during the trajectory of the semiconductor industry

<table>
<thead>
<tr>
<th>Order</th>
<th>Period</th>
<th>Historical event</th>
</tr>
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<tbody>
<tr>
<td>1st Event</td>
<td>1960s</td>
<td>The articulation of Brazil for the establishment of microelectronics laboratories.</td>
</tr>
<tr>
<td>2nd Event</td>
<td>1970s</td>
<td>Implementation of a market protection policy.</td>
</tr>
<tr>
<td>3rd Event</td>
<td>1990s</td>
<td>The opening of the Brazilian market to imports of capital goods and consumer products.</td>
</tr>
<tr>
<td>4th Event</td>
<td>2000s</td>
<td>Resumption of the Brazilian government’s development of policies to revive the semiconductor industry.</td>
</tr>
</tbody>
</table>

However, the industry did not grow after the 1980s because Brazil was passing through a historical moment of profound change in its political structure, which had an impact on the economy. In 1985, the military government, pressured by public opinion, decided to promote democratic reform, and the first president was elected in more than 20 years since the last democratic election. This change in the political system had an influence on the economy because the president did not have the environmental conditions to minimize the uncertainty in the market. For this reason, the semiconductor industry supply chain in Brazil could not sustain its evolutionary growth process.

The second cycle of development of the semiconductor industry began in the 2000s, when the government again stressed that this industry was a priority, and promoted action to attract foreign companies and generate interest from national companies. In parallel to the evolutionary theory, one can say that the routines, norms and rules developed by the government were the genetic inheritance of the first cycle, as discussed in evolutionary theory and path dependencies. Additionally, one can add that the learning process is still viewed at an institutional level. It is this development heritage that has encouraged the government to redevelop this industry. However, it seems that, since 2007, with the creation of PADIS, the government, in a continuous process of devising public policies to guarantee development of the sector, has presented the first favorable results of attracting foreign companies.

5. CONCLUSION

In order to deepen understanding of the semiconductor industry outlook in Brazil, this study has sought to describe its development trajectory from three trajectories of analysis: scientific-technological, macroeconomic and governmental.
As for the scientific-technological trajectory, it is clear that Brazil has created an infrastructure for both the development of new products, as well for the training of human resources. The 50s marked the beginning of scientific research by the Technological Institute of Aeronautics - ITA. Especially in the 60s and 70s, new laboratories were established at the University of São Paulo - USP and the University of Campinas - UNICAMP. In the 80s, other laboratories were established at the Federal University of Rio Grande do Sul - UFRGS and the Federal University of Pernambuco - UFPE. These five institutions have formed a major center of excellence for the training of teachers and doctors, and especially for the development of basic research in the country. However, these actions were too focused on the academic field and took a long time making the technology transfer to the Brazilian industry, either through applied research or by stimulating the creation of new businesses. We can notice that, in Brazil, a further step was missed, that aimed at creating technological institutes to support the national semiconductor industry, bringing closer the basic research carried out in the centers of excellence mentioned above to the efforts of the R&D industry.

The macroeconomic trajectory was, no doubt, the dimension that had most impact on the current scenario of the Brazilian semiconductor industry. The economic instability, the lack of a robust, long-term national policy for the micro-electronic field impacted this industry in Brazil very negatively. In the 70s, Brazil created a market protection policy in order to protect the domestic industry, which represented a major initiative for the first microelectronic industrial plans to emerge. Nevertheless, because of the instability caused by the economic plans in the 80s and 90s, and the end of market protection in the 90s, the domestic industry was weakened and nearly led to extinction.

Regarding the governmental trajectory’s impact on the development cycle of this industry, it is possible to notice a series of efforts, especially with the creation of the National Program of Microelectronics in 2003 and the Supporting Program for the Technological Development of the Semiconductor Industry and Displays - PADIS, in 2007. While the former program aimed to develop the academic area, especially research and postgraduate studies in Brazil, the latter aimed to assist development of the industry, especially in the R&D conducted in conjunction between industry and national research institutions.

It is also important to mention the contribution of our paper to the supply chain literature. By demonstrating the historical evolutionary path of the semiconductor industry in Brazil, we have been able to show how environmental factors, such as technology, economics and governmental actions can be related to and interfere with the development of a supply chain. By adopting an evolution theory perspective, we have been able to provide a macro perspective of the supply chain and demonstrate how it can be constrained by other factors, such those presented in this study. Thus, for a supply chain to emerge, it is necessary for there to be more than just companies capable of providing inputs for other companies.

Finally, it is important to mention that the Brazilian semiconductor industry is somewhat fragile, despite the efforts in the academic, governmental and business fields; it still has insufficient production to meet the needs of the national market. However, in the last five years, by attracting some international companies, especially from the United States and South Korea, the idea of owning a significant production of semiconductors in the following years, bringing new hope for the domestic industry, has begun to be revived.

REFERENCES


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