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Redefining Brazil's Role in Information and Communication Technology Global Value Chains

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MIT-IPC Working Paper 16-003

June 2016

ACCELERATING INNOVATION in BRAZIL

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Abstract

Brazil's information and communication technology (ICT) sector is a product of a long history of import substitution industrialization that began in the 1970s and has continued to this day. While the industrial policy regime has moved away from the goal of building a national, vertically integrated industry, vestiges of past aspirations remain deeply embedded in the country's industrial structure to this day. Brazil participates in almost all segments of the now globally dispersed and fragmented ICT global value chain (GVC), from semiconductor design and fabrication to final assembly and reverse logistics. However, its broad engagement has been shallow – the country has yet to take on more complex or high value-added functions in any segment of this global industry. Whether it be hardware, software or services, the industry depends heavily on imports, and most domestic production is geared towards the local market. Decades of insular growth, enabled by the country's large and dynamic market, have blunted the motivation for local firms to compete abroad by investing in innovation. But the relatively recent unbundling of key corporate functions like R&D presents Brazil with a unique opportunity to redefine its role in the sector. The country has long sought to encourage local R&D spending through the Informatics Law, and has recently redoubled efforts to attract multinational firms to set up global R&D centers within its borders. This paper explores how Brazil might redefine its role in ICT GVCs, leveraging research and technology organizations (RTO) like the newly established SENAI innovation institutes (ISIs) to encourage innovation and global engagement.

This research was sponsored by SENAI. The IPC is grateful for their support.

Esta pesquisa foi patrocinada pelo SENAI. O IPC agradece pelo seu apoio.

Redefining Brazil's Role in Information and Communication Technology Global Value Chains

1. Introduction

Information and communication technology (ICT) includes all goods and services that make possible the capture, storage and transmission of digital information (Unwin, 2009). ICT can be simultaneously understood as both a set of general purpose technologies (GPT) that enable downstream productivity growth *and* an industry populated by firms that compete and collaborate to sell goods and services. GPTs lend themselves to improvement and elaboration, can be applied across a wide range of uses and offer strong innovation complementarities, which means that their development enables increased productivity in a variety of downstream sectors (Bresnahan and Trajtenberg, 1995; Helpman, 1998). They make an attractive target for government investment for two reasons. In the early stages, the high cost of development, uncertainty associated with eventual commercial viability and perceived inability to capture the aggregate value created may in some cases hinder private sector investment. They are also characterized as having strong forward linkages; inducing investment in a range of downstream activities (Hirschman, 1958).

ICTs also constitute a discrete industrial sector. As is the case in many modern and globalized industries, the ICT sector has undergone a process of fragmentation and geographic dispersion in the last thirty years. While electronics goods were once manufactured within the confines of a single factory, production is now organized into a series of transactions that spans multiple firms located in a number of countries around the world. ICT goods and services are now produced in highly fragmented global value chains (GVCs). Sturgeon and Memedovic (2010) demonstrate that trade in electronics goods grew dramatically between 1988 and 2006, both in absolute and relative terms, and that trade in electronics intermediate goods has outstripped trade in final goods since 1994. Furthermore, a number of important empirical studies have demonstrated that this cross-border trade is not taking place within single multinational firms, but across firm boundaries (Sturgeon, 2002; Dedrick, et al., 2009; Sturgeon and Kawakami, 2011). Product modularity has enabled and incentivized the division of labor among a variety of actors, including lead firms, contract manufacturers and platform leaders among others.

Value chain fragmentation has allowed for the possibility of platform leadership, whereby a supplier is able to successfully implant its technology into the core of a given industry (Sturgeon and Kawakami, 2011). What makes a firm a platform leader is its ability to solve a critical technological problem in a way that allows others to build upon its established 'system of use.' (Gawer and Cusumano, 2008). According to the mirroring hypothesis, platform leadership and product modularity are intimately tied. "In the design of a complex system, the technical architecture, division of labor and division of knowledge will 'mirror' one another in the sense that the network structure of one corresponds to the structure of the others" (Colfer and Baldwin, 2016, pp. 4). Platform leaders create products with clearly defined interfaces, catalyzing the development of complementary modules, as well as innovation in the entire system's architecture. The higher the rate of adoption of a certain platform, the greater the incentive for firms to develop complementary products, thus cementing the firm's importance in a given industry. But as Eisenmann, Parker and Van Alstyne (2011) make clear, Schumpeterian innovation is but one way for platform leaders to gain market share. They can also enact strategies of platform envelopment, accessing adjacent markets with overlapping user bases by incorporating new functions into their existing platforms.

Industry fragmentation produces winners and losers, with some companies, regions and countries capturing high value-added activities like R&D and marketing and others being relegated to low value-added functions like final product assembly. Barriers to entry dictate the value that accrues to each activity. R&D requires scientific knowledge and specialized capabilities that are difficult to imitate, while assembly requires generic capabilities that are relatively easy to substitute. Thus, some find themselves in a race to the bottom, exploiting wage differentials and investment incentives to insert themselves into GVCs, while others capture the majority of the aggregate value produced by specializing in activities with higher barriers to entry, like branding, marketing and R&D (Kaplinsky, 2000; Schrank, 2004). Regardless of their role in GVCs, actors will often create and exploit opportunities to upgrade to higher value niches by investing in new product development, process improvement, acquiring new functions or entering new and more lucrative sectors (Humphrey and Schmitz, 2002). Those that capture valuable assets in the upgrading process are more likely to capture the value created, improving their relative position in GVCs (Sako and Zylberberg, 2016).

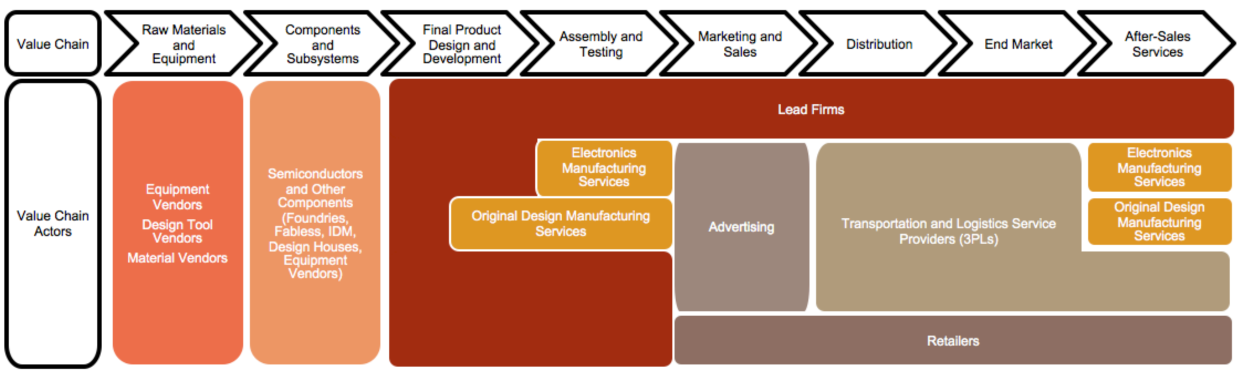
Like other developing countries and emerging markets, Brazil remains well behind the innovation frontier in ICT. Decades of import-substitution industrialization (ISI) have blunted the motivation for local firms to compete through innovation. After decades of protection, the liberalization drive in the 1990s motivated multinational companies to enter the market or to deepen existing investments, despite the creation of complex local content requirements. The modern Informatics Law, passed in 1991, led many multinational lead firms and contract manufacturers to set up local production facilities and purchase components, where possible, from local suppliers. Furthermore, the law incentivized them to conduct R&D in collaboration with local research institutes and universities. But the law's broad coverage and underspecified objectives has meant that while Brazil does participate in almost all segments of the ICT value chain, it has yet to take on more complex activities in any one of them. For example, despite various policies aimed at localizing semiconductor fabrication and integrated circuit design, most foundries produce relatively low-value radio frequency identification (RFID) tags and design houses work on products meant for local, rather than global markets.

This paper has four main goals. The first is to provide a brief overview of the key players in the global ICT industry, including lead firms, contract manufacturers and platform leaders, and to identify the role they play in Brazil. Special attention is paid to the evolving nature of R&D management in the global ICT sector, and how Brazil has become a more important, if still marginal player in ICT firms' global R&D networks in recent years. The second is to identify Brazil's current role in the ICT GVC through the use of trade and production statistics in hardware, software and services. The third is to critique Brazil's ICT-institutional framework as a reason why Brazil's engagement with GVCs has been limited to date. Here I focus on policies that shape the hardware, semiconductor and software and IT services segments of the industry. Finally, this paper aims to identify ways in which R&D service providers like the newly established SENAI Innovation Institutes (ISIs) might carve out meaningful roles in firms' R&D operations and improve Brazil's role in the global ICT industry moving forward.

2. Key Private Sector Actors in ICT GVCs[1]

Figure 1 offers a stylized view of the electronics GVC, outlining the key private sector actors that comprise each of the steps in the value chain, from raw materials and equipment to after-sales service. Some firms are active in various steps along the value chain. For example, Samsung produces components, such as LCD screens, DRAM and processors, while maintaining control over final product assembly, marketing and after-sales service as well. However, most *lead firms* – branded firms that capture most of the value generated throughout the value chain – outsource production and in some cases, even design to *contract manufacturers*, companies which assemble and sometimes design goods for a range of customers. In most cases, lead firms depend on suppliers for key components. Some suppliers known as *platform leaders* are among the most important in ICT GVCs because their technologies are deeply embedded in a range of products, making them indispensable to any and all companies in a given industry. For example, processors and chipsets produced by companies like Qualcomm, Intel and Google make their way into most personal computers (PCs), tablets and mobile handsets. The following analysis examines each of these critical actors, how they have evolved over time and what role they play in Brazil.

Figure 1: Map of Electronics GVC



Source: Author, adapted from Sturgeon et al., 2013

Lead Firms

Lead firms create and sell branded products and services in a range of end markets by orchestrating and governing often vast networks of affiliates and suppliers (Gereffi, et al., 2005). What distinguishes them from non-lead firms is the financial risk they take on by purchasing components and subsystems as well as their costly investments in branding and marketing. Lead firms buy intermediate goods from their suppliers in the hopes that they will eventually sell their final products and services to consumers for a profit. Furthermore, they face final consumers, whether they are individuals or organizations, meaning that their ability to compete is, at least in part, determined by their ability to position themselves in the market through investments in branding and marketing. These firms invest in technological development for the same basic reason, to differentiate themselves from the competition and justify the profit margins they command on their products. These investments in branding and technology become valuable and difficult to imitate resources, barriers to entry for new competitors, and the sources of power over suppliers (Porter, 1985; Barney, 1991).

[1] This section draws from Sturgeon and Kawakami (2011).

Microelectronics-based products and services are now ubiquitous in a range of end markets, including computers, industrial equipment, medical devices and automobiles among many others (Sturgeon and Kawakami, 2011). Table 1 offers a snapshot of the world's largest ICT lead firms, and shows how many of them operate in a range of end markets. Most of the largest lead firms are based in the U.S., Germany and Japan. South Korea and Taiwan are two of the few countries outside this triad that have successfully launched global brands; companies like Samsung, LG, HTC, Acer and Asus are now among the world's largest ICT lead firms. More recently, Chinese lead firms have begun to venture out to new foreign markets. Traditionally a manufacturing location for global lead firms, China has recently cultivated local brands through acquisition, with Lenovo purchasing IBM's PC division in 2004, and organic growth, with mobile handset and networking equipment providers like Xiaomi, ZTE and Huawei expanding aggressively into other emerging and developed markets.

Table 1: Largest ICT Hardware Lead Firms, by 2014 Total Revenue

Rank	Company Name	HQ	Revenue (USD Mil)	Industry Segments	Production in Brazil?
1	Samsung Electronics	South Korea	$195,845	Consumer Electronics, Communications Equipment, Computers and Storage Devices, Electronic Components	Yes
2	Apple	U.S.	$182,795	Communications Equipment, Computers and Storage Devices	Yes*
3	General Electric	U.S.	$148,321	Industrial Equipment, Medical Electronics, Consumer Electronics	Yes
4	Hewlett-Packard	U.S.	$111,454	Computers and Storage Devices, Computer Peripherals and Office Equipment	Yes*
5	Siemens	Germany	$101,560	Industrial Equipment, Medical Electronics, Electronic Components	Yes
7	Hitachi	Japan	$88,786	Consumer Electronics, Industrial Equipment, Automotive Electronics	Yes
9	Sony	Japan	$74,724	Consumer Electronics, Computers and Storage Devices, Electronic Components	Yes
10	Panasonic	Japan	$70,169	Consumer Electronics, Automotive Electronics	Yes

Source: Fortune Global 500, analysis by author
*through contract manufacturers

As Table 1 indicates, all of the top 10 global lead firms produce in Brazil. Some firms assemble a range of goods in wholly owned factories while others rely on contract manufacturers to maintain flexibility. Top lead firms manufacture in Brazil for two inter-related reasons. The first is the size of the Brazilian market. According to Apex Brazil, the company's export promotion agency, Brazil is the third largest market in the world (behind the U.S. and China) for computers and the 4th largest for mobile handsets with 272 million mobile lines online as of January 2014. Its size and dynamism have long been attractive to foreign firms, which choose to invest despite the well-documented difficulties associated with operating there, sometimes referred to as 'Brazil cost.' These additional costs are often passed on to final consumers. The second reason for local production is the existence local content requirements. Brazil is not a cost-competitive manufacturing location from a labor standpoint. As data from the Bureau of Labor Statistics (BLS) International Labor Comparisons (ILC) dataset shows, hourly compensation for Brazilian workers in manufacturing industries is $11.20 while it is $6.36 in Mexico and $2.10 in the Philippines.[2]

[2] The BLS offers a disclaimer for data on manufacturing cost in China and India, "Due to various data gaps and methodological issues, compensation costs for China and India are not directly comparable to each other or with the

Furthermore, the non-wage benefit component of hourly pay is third highest in the world, behind only Belgium and Austria.[3]

The Brazilian government has long sought to make the country an attractive destination for manufacturing through a range of incentives, among them reductions in industrial product taxes (IPI), reductions in payroll and social security taxes and in some cases, the reduction and even elimination of import tariffs for firms that set up production facilities in the country. But the problem is that these barriers exist in the first place. Instead of reducing payroll taxes, which make Brazil such an expensive location for manufacturing in the first place, the government provides exemptions and reductions in exchange for investment and local sourcing. These fiscal incentives have become necessary for any lead firm that wishes to compete in the Brazilian market. This includes domestic lead firms, of which there are few. Positivo, a local PC manufacturer that has recently expanded into mobile handset production, is among the largest Brazilian lead firms in the ICT GVC. However, much like many other Brazilian firms, it remains focused almost entirely on the domestic market, barring its small presence in Argentina.

Contract Manufacturers

Contract manufacturers fulfill a range of functions for lead firms, including purchasing components and raw materials, assembling circuit boards, assembling final products and even providing after-sales services like reverse logistics, including repair and refurbishment. The rise of contract manufacturers in the 1980s was enabled by product modularity. Eventually, product modularity enabled technical task division along natural or engineered 'break points' across the value chain (Sturgeon, 2002). Thus, lead firms were able to outsource production and a range of other non-core business functions while limiting dependence on their suppliers. There are two broad categories of electronics contract manufacturers: electronic manufacturing service (EMS) providers, which leverage the generic nature of circuit board assembly to aggregate production across lead firms operating in various end markets, and original design manufacturers (ODMs), which on top of offering production services, design final products on behalf of their clients, albeit in a limited number of product categories.

Sturgeon and Lee (2005) describe the process by which lead firms and contract manufacturers co-evolved in the U.S. and Taiwan. They claim that institutional factors like financial market liquidity and managerial capabilities led contract manufacturers in these countries to pursue different strategies in the late 1990s and early 2000s. Taiwanese contract manufacturers became ODMs, expanding value chain scope by upgrading from manufacturing to design, and retaining a narrow geographic and product focus. U.S.-based EMS providers remained focused on manufacturing while expanding their geographic footprint and product catalog. ODMs prioritized knowledge, developing design capabilities, while EMS providers focused on acquiring physical assets. For example, Taiwan-based Hon Hai Precision Industry (Foxconn) is now the largest contract manufacturer (EMS) in the world, with large manufacturing operations in China, the Czech Republic and Brazil among other countries. Its recent acquisition of Japanese display manufacturer Sharp might enable it to capture more of the value generated by its principal client, Apple.

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data for other countries found in this report, and therefore are presented separately. Data are available for China through 2009 and for India through 2010." According to the latest figures available, hourly wages for manufacturing labor are $1.46 in India and $1.74 in China. The full report is available from http://www.bls.gov/fls/

[3] This includes legally mandated social insurance expenditures and direct benefits, which include paid vacation time and bonuses.

A number of EMS providers in other countries have recently emerged as well, including Thailand-based Cal-Comp Electronics (now part of the Taiwan-based New Kinpo Group) and China-based Shenzhen Kaifa Technology.

While most ODMs have historically worked exclusively for global PC manufacturers because of the investments necessary to develop specialized design services, many have ventured into new product categories in recent years (Sturgeon and Lee, 2005). Their push into mobile devices, for example, was first made possible by the development of low-cost platform solutions like Intel's Atom Chipset (Sturgeon & Kawakami, 2011). Furthermore, ODMs like Quanta Computer and Compal Electronics have upgraded by expanding product mix, as well as growing in scale and geographic scope. Compal was highly dependent on clients in the PC industry, and on Taiwan and Mainland China from the mid-1980s until the mid-2000s, when it began to move into mobile phones and LCD TVs. Since 2007, its manufacturing footprint has expanded from Mainland China to Vietnam, Poland, Brazil and Mexico. But while ODMs have slowly expanded their production networks beyond Taiwan, they are not able to spread as widely as EMS providers because of their relatively narrow product focus.

Table 2. Top Electronics Contract Manufacturers by Revenue, 2013

Rank	Company Name	HQ	Revenue (USD Mil)	Profit as % of Revenue	Primary Service	Production in Brazil? (Number of factories)
1	Foxconn (Hon Hai)	Taiwan	136,024	2.72%	EMS	Yes (5)
2	Quanta Computer	Taiwan	30,300	2.17%	ODM	No
3	Pegatron	Taiwan	29,867	1.50%	ODM	No
4	Compal Electronics	Taiwan	23,840	0.36%	ODM	Yes (1)
5	Flextronics	U.S./Singapore	23,569	1.18%	EMS	Yes (4)
6	Wistron	Taiwan	18,577	1.28%	ODM	No
7	Jabil Circuit	U.S.	18,337	2.79%	EMS	Yes (2)
8	Sanmina-SCI	U.S.	5,917	1.34%	EMS	Yes (1)
9	Celestica	Canada	5,796	2.04%	EMS	No
10	Cal-Comp Electronics	Thailand/Taiwan	3,982	0.44%	EMS	Yes (2)

Source: Digitimes (Chinese Taipei, China) and company annual reports

While some lead firms continue to manufacture in-house, most have outsourced production to contract manufacturers. These firms allow their clients to scale quickly without making costly and risky acquisitions or greenfield investments in new markets. Furthermore, they allow lead firms to outsource supply chain management responsibilities, as contract manufacturers take on component purchasing and inventory management among other critical activities (Sturgeon and Lester, 2004). Although contract manufacturing has grown substantially in recent years, ODMs and EMS providers continue to subsist on razor-thin profit margins relative to those enjoyed by their clients (See Table 2). This is because the production and design capabilities they have developed are found readily in the global supply base, making these firms easy to substitute. Furthermore, the fact that they are easily substituted makes it difficult for them to capture the gains that follow from their investments in upgrading.

Much like in the automotive industry, electronics lead firms tend to rely on *follow sourcing*, whereby suppliers follow lead firms as they expand to new markets (Humphrey and Memedovic, 2003; Sturgeon and Lester, 2004). This explains the presence of most leading EMS firms in Brazil. Foxconn now operates five production facilities in the country, many of which assemble Apple products for the Brazilian market. Flextronics has been expanding its production capacity in the country, recently taking over factories previously owned by Motorola (Jaguariuna) and Microsoft (Manaus) — growth through acquisition of customer manufacturing facilities being one of the main modes of growth for EMS companies. But while EMS firms have expanded dramatically in recent years, only one of the top ODM firms operates in Brazil (Compal). This is largely because the three leaders in the PC market, which include Dell, Lenovo and Positivo, have all taken assembly in-house. Furthermore, the high mix/low volume production that characterizes the Brazilian market lends itself better to the generic EMS model than to the more focused, high volume ODM model.

Platform Leaders

Value chain fragmentation has allowed for the possibility of platform leadership, whereby a supplier is able to successfully implant its technology into the core of a given industry (Sturgeon and Kawakami, 2011). What makes a firm a platform leader is its ability to solve a critical technological problem in a way that allows others to build upon its established 'system of use.' (Gawer and Cusumano, 2008). According to the mirroring hypothesis, platform leadership and product modularity are intimately tied. "In the design of a complex system, the technical architecture, division of labor and division of knowledge will 'mirror' one another in the sense that the network structure of one corresponds to the structure of the others" (Colfer and Baldwin, 2016, pp. 4). Platform leaders create products with clearly defined interfaces, catalyzing the development of complementary modules, as well as innovation in the entire system's architecture. The higher the rate of adoption of a certain platform, the greater the incentive for firms to develop complementary products, thus cementing the firm's importance in a given industry. But as Eisenmann, Parker and Van Alstyne (2011) make clear, Schumpeterian innovation is but one way for platform leaders to gain market share. They can also enact strategies of platform envelopment, accessing adjacent markets with overlapping user bases by incorporating new functions into their existing platforms.

Platform leadership has been critical to the development of various ICT goods like PCs and mobile handsets. Indeed, Gawer and Cusumano's (2002) work initially focused on the role of the Intel Architecture Lab (IAL) in leveraging the company's high-end microprocessors to drive architectural innovation in the PC. Qualcomm has played a similar role in mobile phones, becoming *the* chipset supplier for almost all major handset manufacturers and influencing the development of complementary components. While most platform leaders tend to be based in industrialized countries, China-based MediaTEK has become a global competitor through its 'bottom of the pyramid' strategy. The company has evolved from being a fabless semiconductor design company working on chipsets for reading CD and DVD to developing 'system-on-chip' (SOC) design capabilities used to create chipsets for mobile handsets. Its low-cost chipsets have made it a viable competitor in China as well as other emerging economies (Sturgeon and Kawakami, 2011; Brandt and Thun, 2011). Thus, while it is generally a truism in GVC analysis that lead firms take home a lion's share of profits by governing their suppliers, platform leaders are unique in that they capture a sizeable portion of industry profits and exert influence over the technological trajectories of various final products.

Platform leaders like Intel, Qualcomm and more recently, MediaTEK have carved out unique niches in the hardware segment of the ICT GVC, capturing value by making their products integral in various final goods including mobile handsets and personal computers. But platform leadership is not confined to hardware alone, and is perhaps even more important in the software and services segments of the ICT sector, where firms like Microsoft, Google, SAP and Oracle develop critical and ubiquitous software products. These firms develop enterprise software solutions, mobile platforms and operating systems that power a wide range of goods in similar end markets. For example, Oracle offers an adaptable enterprise resource planning (ERP) platform that companies can modify to fulfill their particular needs, whether they be marketing and sales, inventory management or purchasing. The same logic applies to mobile platforms like Android. Google develops the main trunk of its Android mobile operating system over time, releasing new versions periodically (Android 6.0 Marshmallow is the latest). But consumer-facing firms like Samsung customize these platforms to their handsets by building branches off the main trunk.

Many of the world's largest platform leaders have recently ramped up investments in Brazil in response to government overtures. Chipset manufacturers Intel and Qualcomm have long been active in Brazil, although they have never produced chipsets in the country. Qualcomm first entered the country in 1993 through a local partnership to distribute its Omnitracs mobile satellite communications and tracking system, and Intel first entered through its venture capital branch, setting up a $50 million fund in 2006. Both recently deepened investments through the establishment of local R&D centers, investments in Brazilian universities and the establishment or expansion of local venture capital branches; Intel Capital and Qualcomm Ventures have already invested in various Brazilian startups. Microsoft recently committed to spending $100 million in Brazil on a new Advanced Technology Laboratory (ATL), a Bing development hub, a business accelerator and an investment fund, Microsoft Participações. Finally, some emerging market platform leaders are investing in Brazil. Baidu, the Chinese search giant, recently established an R&D center in Brazil to develop its new Portuguese language search engine, Busca.

These investments are made to secure market share and extend platform dominance in the Brazilian market. Platform leaders like Baidu, Microsoft and Google are battling to become cognitive referents among Brazilian consumers, many of which have only recently gained reliable access to the internet. Nearly all of these platform leaders have recently created or expanded venture capital funds. Again, the primary aim here is to extend their respective platforms to startups with high growth potential, thus getting them in on the ground floor. As was previously mentioned, platform leaders profit when they are able to implant their products into the core of larger systems, shaping system architecture by driving innovation in complementary modules. Increased market share catalyzes a virtuous cycle, as firms begin building on a given platform, making the platform more popular, driving further innovation in complementary products and services, and on and on. The Brazilian government recently ramped up efforts to develop the country's software industry, and sees global platform leaders both as sources of know how and risk capital for ICT startups. These government-led overtures will be discussed in greater depth in the following pages.

3. Global R&D Management in the ICT Sector

Multinational firms have long offshored R&D by setting up subsidiaries in other industrialized countries. US-based electrical equipment manufacturers and European chemical companies began internationalizing their internal R&D operations early on in the interwar period. However, it wasn't until the 1980s that R&D took on a distinctly global flavor. This necessitated a shift from the traditional multi-domestic, hub-and-spoke structure to an intra-organizational network model (Cantwell, 1995; Reddy, 1997). Companies have traditionally offshored R&D services to meet local market demand, to access knowledge, to increase their supply of talent or to engage in wage arbitrage. While the impetus for offshoring has changed little through the years, its geographic scope and consequences for organizational structure have shifted dramatically. In the past, companies would install offshore R&D centers in other industrialized countries. Today, emerging markets constitute a significant destination for new R&D investments (Howells, 2008).

Firms will invest in R&D abroad in order to access established scientific communities and develop knowledge assets that can help them generate and sustain competitive advantage (Cantwell, 1989; Howells, 1990; Florida, 1997; Lewin, et al. 2009). The intense competition for science and engineering talent at home has forced firms to look elsewhere to access the human capital necessary to develop new products. While lowering the cost of R&D was a primary consideration in the expansion of corporate R&D networks to developing countries in the 1990s (Reddy, 1997), the cost advantage of locating in these countries has diminished significantly. Wage arbitrage, while still an important consideration in the offshoring of administrative and other back-office activities, factors little in the decision to offshore technical activities (Lewin, et al., 2009). As the cost of hiring engineers in different countries converges, opportunities for wage arbitrage may all but disappear.

Consumers in foreign markets often have idiosyncratic needs that multinational firms must address to compete. True, these markets will always have a small group of consumers that prefer global products – those designed to meet the needs of the company's home market. The iPhone is a classic example. But once multinationals wish to penetrate the lower rungs of the market, they must begin to produce and market goods that conform to local tastes (Vernon, 1966; Kuemmerle, 1999; Khanna and Palepu, 2005). Mansfield and colleagues (1979) lend empirical support to this assertion, correlating percentage of sales derived from abroad and overseas R&D expenditures. They posit that R&D carried out overseas is aimed primarily at tailoring existing products to new markets. This has the dual effect of making global goods more palatable to new markets and ensuring that core technologies remain at home, where they can be better protected than in foreign locations. Accessing new markets is but one of many reasons why firms offshore R&D activities.

The traditional north-north FDI route still accounts for a majority of new R&D investments. However, certain emerging markets have begun to capture a larger share of global spending in recent years, especially in technology intensive sectors like ICT and biopharmaceuticals. Three fifths of new global R&D investments between 2002 and 2004 were made in developing counties. Some of these investments included new Intel R&D labs in China and India, a new IBM R&D lab in India and a Fujitsu development center in Malaysia (UNCTAD, 2005). China, India and Brazil are now among the leading destinations for new MNC R&D investments (Howells, 2008). Data collected for this project demonstrates that since 2010, companies have invested, or have committed to invest, $2.9 billion into new or existing R&D centers in Brazil. Many of these investments are oil and gas-related, including GE's new global R&D center and IBM's new center for natural resource analytics and computation. The second most important sector in terms of investment has been ICT, with firms like Samsung, Microsoft and Intel making high profile investments in new R&D centers in the last few years.

4. Brazil's Current Role in ICT GVCs

This section examines available trade statistics in hardware, software and services to create a comprehensive picture of how Brazil fits into the ICT GVC today. For hardware, the definition established by Sturgeon and colleagues (2013) is employed. The definition is based on the 2007 Harmonized System (HS) classification. The six-digit, product-level HS codes have been aggregated into sub-sectors based on classifications developed by both the Brazilian Electrical and Electronics Industry Association (ABINEE) and existing academic literature (Sturgeon and Memedovic, 2010). UN Comtrade data is used to construct Brazil's trade profile. Given the well-documented lack of reliable, granular statistics on trade in services, I rely on data collected by the Brazilian Association of Software Companies (ABES) as well as a dated but relevant survey run by the Brazilian Institute for Geography and Statistics (IBGE) to explore Brazil's trade in software and services.

Hardware

Our examination of the goods trade data reveals two broad and inter-related trends. Firstly, Brazil's trade balance is negative across all eight identified sub-sectors. Furthermore, the trade deficit has grown in seven of eight sub-sectors in the last five years, computers and storage devices being the only exception (See Table 3). Brazil exports computers and storage devices regionally – Argentina, Paraguay, Chile and Mexico are among the top ten export destinations – and globally, with the United States and various Western European countries among its largest partners. Secondly, Brazil depends heavily on intermediate goods imports, and exports very little in terms of final goods (See Table 4). The country's trade competitiveness in all final goods sub-sectors aside from computers and storage devices has deteriorated significantly in the last five years, encouraging many policymakers to continue supporting programs aimed at building industrial capacity. I will examine each of these trends in the following paragraphs.

Table 3: Trade Balance by Sub-Sector (in USD Mil), 2010-2014

Sub-Sector	2010	2011	2012	2013	2014	CAGR
Computers and Storage Devices	-$1,848	-$2,116	-$2,020	-$1,706	-$1,534	5%
Consumer Electronics	-$3,493	-$3,975	-$3,983	-$4,057	-$3,564	-1%
Medical Electronics	-$1,177	-$1,237	-$1,258	-$1,306	-$1,326	-3%
Electronic Components	-$2,373	-$2,567	-$2,512	-$2,613	-$2,733	-4%
Computer Peripherals & Office Equipment	-$1,614	-$1,715	-$2,311	-$2,102	-$2,101	-7%
Industrial Equipment	-$1,667	-$2,010	-$2,105	-$2,514	-$2,201	-7%
Communications Equipment	-$2,117	-$3,606	-$3,338	-$4,559	-$5,396	-26%
Automotive Electronics	-$208	-$368	-$445	-$712	-$754	-38%
Total	**-$14,497**	**-$17,596**	**-$17,971**	**-$19,569**	**-$19,609**	**-8%**

Source: UN Comtrade

Brazil imports far more than it exports across all ICT sub-sectors. The gap has widened in all sub-sectors apart from computers and storage devices, as Table 3 illustrates. Communications equipment, which includes base stations, telephones and parts thereof, among other goods, made up more than a quarter of the sectoral trade deficit in 2014. Despite efforts to localize production, the country has relied on imports to improve its sparsely populated and antiquated mobile telecommunications network. The country's trade deficit in electronic components is also growing, albeit at a much slower pace. Again, despite government efforts to localize semiconductor fabrication and display manufacturing, the country continues to rely on imports. Semiconductor devices are produced in large-scale, capital-intensive facilities and are easy to transport, limiting the likelihood that Brazil will one day compete with countries like Taiwan and Korea. There are clear fault lines in government, with some clamoring for more protection in order to reduce the trade deficit, and others seeking to ease restraints on trade in order to support and encourage niches of global competitiveness.

Table 4: Brazil ICT Trade in Final and Intermediate Goods (in USD Mi), 2010-2014

	Total	2010	2011	2012	2013	2014	CAGR
Final Goods	Imports	$8,821	$10,893	$10,289	$11,478	$11,568	7%
	Exports	$1,791	$1,550	$1,254	$1,124	$898	-16%
Intermediate Goods	Imports	$8,160	$9,233	$9,857	$10,055	$9,609	4%
	Exports	$693	$980	$920	$839	$670	-1%

Source: UN Comtrade

Imports have grown faster than exports for both final and intermediate goods. The country's lost competitiveness is laid bare most clearly when looking at final goods exports. In the computer peripherals and office equipment sub-sector, a trade surplus of $30 million in 2010 became a trade deficit of $20 million by 2014. Upon closer look, it becomes clear that Brazil's widening trade gap in final goods can be attributed largely to its shrinking export base. This problem is less pronounced with respect to intermediate goods, where the widening trade gap is largely a result of growing imports, especially in sub-sectors like automotive and medical electronics. The most important findings associated with Table 4 are that final goods exports are shrinking dramatically and intermediate goods imports are growing steadily. These trends suggest that Brazil is integrated into GVCs mainly on the import and inward FDI side. Brazil ranked 8th in total inward FDI flows from 1970-2014, and 31st in outward flows.

Furthermore, this integration is uneven. Large multinational firms have an easier time importing intermediate goods than do Brazilian firms, especially SMEs. Large exporters (minimum of $10 million in annual exports) can use instruments like RECOF to avoid paying import taxes, even if 30 percent of production is directed towards the domestic market. Of the 33 companies that use RECOF, only one is Brazilian (Embraer). In aggregate, Brazil was the 18th largest hardware importer in the world in 2014 with $21.2 billion spent. The story is different on the outbound side, as Brazil ranked 39th in the world with a total of $1.6 billion in hardware exports. This, despite efforts by government bodies like Apex Brazil to encourage Brazilian firms to increase exports. Nearly 30 years of protection through the Informatics Law and other industrial policies have done little to change this serous imbalance. In summary, the central finding on the hardware side is that Brazil relies on the import of intermediate goods to produce for the local market, and has seen its export performance plummet in the last five years.

Software and Services[4]

The available data on software and ICT services suggest that, much like in hardware, most production is geared towards the domestic market. A survey conducted by the IBGE finds that Brazil's software and ICT services sector grossed $22.6 billion in 2009. The survey only attributes $1.2 billion, equivalent to 5.4 percent of total revenue, to exports. The development and licensing of customized and non-customized computer programs accounted for the majority of exports, comprising 75 percent of the total. As is the case with hardware firms, only a small percentage of software and services firms export: 11.3 percent in 2009. As one might expect, the percentage was lower among small firms – nine percent among firms earning less than BRL 30 million (equivalent to USD 17.2 million) – than it was among large firms – 29 percent among firms earning more than BRL 30 million.

Table 5: Brazil Software and Services Market (USD Bi), 2010-2014

	2010	2011	2012	2013	2014	CAGR
Services	10.1	11.4	12.6	13.6	14.6	10%
Software	6.4	7	8.6	10.1	11.4	16%
Total	**16.5**	**18.4**	**21.2**	**23.7**	**26**	**12%**

Source: ABES

More recent data provided by ABES confirms that the domestic market continues to be the focus. As Table 5 shows, software and services brought in $26 billion in 2014, with $11.4 billion accruing to software and $14.6 billion to services. In 2014, a vast majority of the software market was dominated by imports – 76 percent – while only 8.7 percent of local production was exported. Applications made up the largest market segment at 44 percent of the total, with just 4.3 percent exported. Outsourcing (39.1 percent), support services (19.2 percent) and systems integration (15.4 percent) were the largest market segments. There has been a strong government-led push to localize more software production, whether it be through broad programs like 'TI Maior' or through efforts to court large, global software firms like Microsoft and SAP to set up local R&D centers.

5. Institutional Context

Brazil's reliance on foreign inputs and lack of export competitiveness are rooted in the country's long-standing approach to industrial development. Unlike Korea and Taiwan, Brazil never successfully shifted from import substitution industrialization (ISI) to export-oriented industrialization (EOI) (Gereffi and Wyman, 1990). During the 1950s to the 1980s, Brazil engaged in ISI, attracting multinational firms to produce durable consumer and capital goods locally (Baer and Rangel, 2001). Among the many sectors targeted for localization was the informatics (computer) sector, which the government saw as paramount to the country's long-term development project.

[4] This section only analyzes data on software and ICT services. It does not examine ICT-enabled services, a newer category that includes services that can be delivered remotely as a result of advances in ICTs. This is because there is no harmonized, internationally agreed upon definition of these services. As a result, there is little in the way of systematically collected, internationally harmonized data to analyze.

Since the early 1990s, the country has enacted a number of programs aimed at developing capabilities across the vertical spectrum of ICT GVCs, from semiconductor fabrication to software development. Table 6 outlines the major ICT-related policies and ensuing programs that are currently in force. This section briefly examines Brazil's ICT-relevant institutional framework, identifying the key pieces of legislation that have shaped the country's role in ICT GVCs. It begins by examining the evolution of the Informatics Law, which has shaped Brazil's ICT sector for more than 20 years. It follows by outlining the major policies in semiconductor fabrication as well as software and services.

Table 6: Brazil's Major ICT-Related Policies

Hardware	Informatics Law (1991)	Established the Basic Production Processes (PPBs) to encourage local production and increase local content in hardware, as well as stimulate investments in local R&D through captive centers and partnerships with Brazilian partners. The law was renewed in 2001, 2004 and most recently, in 2014
Microelectronics	Brazil Integrated Circuit Program (2005)	Forms part of the Brazilian Microelectronics Program (2002). Created a network of integrated circuit design houses to work on behalf of domestic and foreign firms. Also sought to attract foreign IC design houses like Freescale and Smart. There are currently 22 IC design houses in the country
	Program for the Development of the Semiconductor and Display Industry (2007)	The policy's aim has been to develop the local semiconductor fabrication and display production segments of the ICT industry. PADIS simplifies the process of acquiring equipment, raw materials and design tools
Software and Services	Strategic Program for Software and IT Services (2011)	The program had various aims, including: training IT personnel, upgrading Brazilian firms, encouraging exports, supporting startups and attracting R&D centers. The most prominent pillars include 'Startup Brasil' which supports software startups and 'Innovate in Brazil,' which aims to attract global software R&D centers

The Informatics Law – 1984 to Present

The unlikely development of Brazil's homegrown computer industry in the 1970s was the result of converging interests among key state and non-state actors, urged on by a cadre of entrepreneurial technicians (Evans, 1995). Top technical universities like the Instituto Tecnolológico de Aeronáutica (ITA) and the Politécnica da Universidade de São Paulo had begun to produce engineers with training in electronics as early as the 1960s. According to Peter Evans (1986), some of these newly minted engineers developed a deep-seated desire to produce microcomputers at home, rather than tinkering with IBM's imported products. They quickly became 'frustrated national technicians,' as they found Brazil to be quite unlike Silicon Valley, where some had completed some of their graduate studies (Evans, 1986, pp. 792). Brazil had no domestic informatics firms to speak of. As a result, many embraced the nationalist sentiment ushered in by the *Brazilian Miracle* and decided to build microcomputers in Brazil.

These individuals' desire to construct a national computer industry coincided with and often incited broader shifts in the military regime as well as a number of important national funding agencies and research bodies. The Brazilian Navy was undergoing a process of modernization. It had purchased a number of advanced British warships in the late 1960s, but was wary of leaving the technology behind the ships' electronic control systems in the hands of the British. Therefore, it became sympathetic to calls for increasing domestic technological capabilities. The National Economic Development Bank (BNDE), led by José Pelúcio in the formative period of the 1960s, saw the source of Brazil's underdevelopment as technological dependency (Adler, 1986). This view was supported by economists trained in Raul Prebisch's former pulpit, the Economic Commission for Latin America (CEPAL), many of whom now worked in various planning agencies, and by technicians that had taken up roles in the BNDE, the National Council for Research (CNPq) and the Funding Authority for Studies and Projects (FINEP).

Created in 1972, the Commission for the Coordination of Electronic Processing Activities (CAPRE) eventually came to regulate the import of components on which local and multinational firms depended for their manufacturing and assembly operations. The organization created and defended a market reserve, granting national firms exclusive access to the minicomputer market segment while excluding IBM from competing. While CAPRE had been able to craft and enforce industrial policy because of the support it received from pockets within the federal government as well as the Navy, it wasn't long before those favoring market-oriented solutions ended their experiment. CAPRE was replaced by the Special Secretariat for Informatics (SEI) in 1979. But CAPRE had left behind a vibrant set of organizations eager to protect and expand Brazil's emergent informatics sector. These actors shaped the 1984 National Informatics Law, which favored indigenous technology development, protecting newly established lead firms and component manufacturers. But by 1991, those favoring open access to global technologies had taken over. The 1991 Informatics Law was a radical departure from its predecessor in that it flouted the nationalist proclivities that has dictated informatics policies in the past.

The Informatics Law of 1991 enshrined the ethos that has governed industrial policy in Brazil's ICT sector to this day. It effectively ended the market reserve and opened the market to foreign companies. The first law had established that for a company to be considered 'national,' 100 percent of its voting interest had to be held domestically. This was reduced to just 51 percent in 1991, prompting many multinational firms like Compaq and Acer to enter into joint ventures with Brazilian firms. However, while the market did open up nominally, the government enacted a set of provisions to ensure that some productive activities would remain in Brazil. The government encouraged firms to manufacture locally through product-specific PPBs – "the minimum group of operations, within the industrial plan, which characterizes real industrialization of a certain product" (Egypto, 2012). A PPB is effectively a nationalization index; it outlines which electronic components and intermediate goods the government would like to see produced at home. These indices now exist for more than 3,000 products.

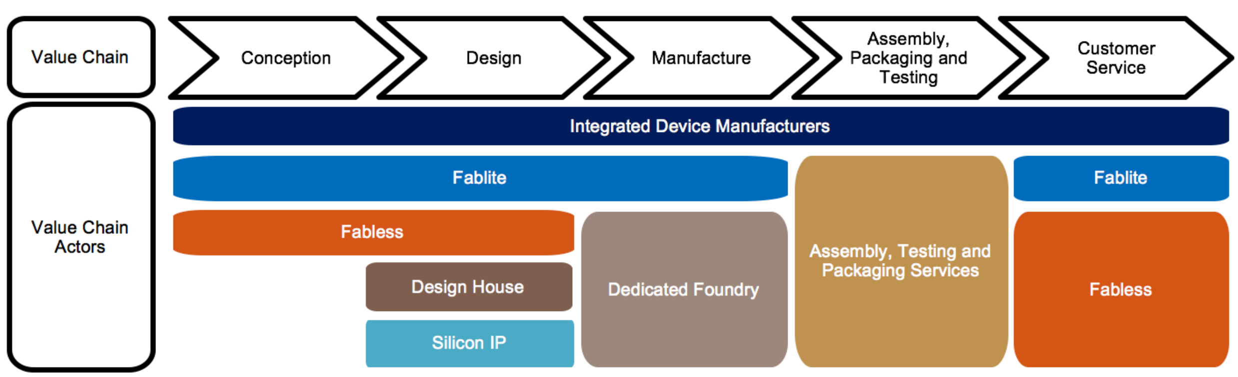
In addition to component localization, the government encouraged firms to conduct R&D locally. These R&D requirements were seen as a means of mitigating the impact the end of the market reserve had on local technical capacity (Tigre, 1993). Firms were told to invest five percent of gross annual revenues on local R&D. The law stipulated that two percent had to be spent through Brazilian research centers and universities and that the rest could be spent internally. The law created an ecosystem of R&D services providers equipped to absorb the R&D outsourcing requirement. While firms were by no means obligated to localize production and R&D, the fiscal incentives made available to those who did were too attractive to pass up. Firms that applied for and received PPBs were granted significant reductions on Industrial Product Taxes (IPI) for final goods and an exemption on IPI for raw materials and components. In addition to these federal incentives, PPBs granted firms a reduction in ICMS (state VAT) in many states (Sales, 2012).

The law's sunset clause has been extended various times (in 2001, 2004 and 2014). However, the spirit of the law has not changed much since 1991. To this day, firms assemble goods with varying degrees of local content and establish local R&D operations in exchange for fiscal incentives. The law's longevity can be attributed to various factors, the most important of which is the government's desire to encourage economic development in the relatively impoverished north and northeast. The Manaus Free Trade Zone (ZFM) was first established in 1957, and has since become a massive industrial pole. It has long been an attractive location for electronics assembly, given the ease with which firms can import components while still producing for the local market. The modern Informatics Law (1991) came about in order to assure manufacturers outside the ZFM that they would not remain at a competitive disadvantage for not relocating. As one professor interviewed for this study confirms, the Informatics Law has survived, in large part, because it ensures that the Southeast remains a manufacturing hub alongside the ZFM. Some interview respondents have remarked that the expiry of either the ZFM's mandate or the Informatics Law would likely incite a mass migration of manufacturers from one to the other.

Semiconductor Fabrication and Integrated Circuit Design

The fragmentation of the semiconductor value chain has allowed for participation on the part of developing countries traditionally walled off from this capital- and technology-intensive sector. For reference, one of the leading semiconductor firms in the world, Taiwan Semiconductor Manufacturing Corporation (TSMC), recently announced a $16 billion investment in a new mega-foundry that will produce some of the most advanced semiconductor devices in the world.[5] While some firms known as integrated device manufacturers (i.e. Intel) continue to design, manufacture, assemble and test chips in-house, and others maintain some capabilities in-house while outsourcing others ('fablite' model), most of the industry has moved towards the fabless model, whereby dedicated foundries like the TSMC invest in building advanced wafer production facilities, allowing firms to design and market hardware devices and semiconductor chips without having to invest in production. See Figure 2 for a diagram of the semiconductor value chain.

Figure 2: Semiconductor Value Chain



Source: Author, based on Gutierrez and Mendes 2009

[5] See full Bloomberg article here: http://www.bloomberg.com/news/articles/2015-02-06/tsmc-to-invest-about-16-billion-building-chip-plants-in-taiwan

The Brazilian government made its first explicit push into the semiconductor industry with the Brazil Microelectronics Program in 2002. At the time, electronic components were imported in much higher quantities than they were exported. As has often been the case in the broader ICT sector, as well as in other industries, government policy tends to encourage breadth rather than depth. In the early 2000's, the federal government sought to create a network of local design houses. Most were incubated in previously existing research institutions like the Integrated Systems Technology Laboratory (LSITEC) and the Renato Archer Center for Information Technology. There are now a total of 22 design houses in the country. The problem, as articulated by industry executives, is that the design houses have had limited success in courting large domestic and foreign clients. Demand comes largely from local SMEs, which do not constitute a viable market for customized chips (Sturgeon et al., 2013).

Another niche that has received a great deal of attention from the Brazilian government is semiconductor packaging, a stage of semiconductor manufacturing in which the silicon-based chip is encapsulated by a ceramic or plastic case to prevent damage (Sturgeon et al., 2013). The two big players in this niche are HT Micron and SMART Modular Technologies. HT Micron began operating in 2011, but was conceived in 2009 when a Korean chip assembly firm named Hana Micron expressed its interest in Teikon, a Brazilian EMS provider owned by Parit Participações, a Brazilian holding company. Most of the high value-added processes take place in Korea. For example, the epoxy resin is formulated in Korea. One of the SENAI ISIs wanted to engage HT Micron to collaborate on developing new resins, but found that the Korean partners had little appetite for developing new polymers in Brazil. SMART Modular Technologies, is a U.S.-based firm that designs and manufactures electronic subsystems, including memory cards and modules for clients in a range of markets that include aerospace, consumer electronics and industrial automation. The company assembles and tests its modules in Brazil. Much like in the case of Hana Micron, SMART keeps high value-added activities like design and engineering in the U.S. and parts of East Asia while leaving the lower-value added production segments in Brazil.

Finally, there have been some demonstration and small-scale foundries established in Brazil. The National Center for Advanced Electronic Technology (CEITEC) was established in 2008 as part of the Brazilian Microelectronics Program. Its principal aim is to produce semiconductor devices and provide a platform for education in microelectronics. It has largely been limited to the production of simple, low cost RFID tags to track cattle, automobiles and blood products. The only other foundry in Brazil is Unitec (formerly SIX Semicondutores), an IDM that resulted from a public-private partnership. The company's strategy has been to produce customized, low-volume mixed signal chips that suit local needs. Both CEITEC and Unitec operate outdated equipment, with CEITEC using 20-year old equipment donated by Motorola. Needless to say, these projects have done little to upgrade Brazil's role in the semiconductor value chain. Nor have they led to an appreciable reduction in imports. As the trade data demonstrate, Brazil imported $2.8 billion in components and exported just $54.4 million in 2014.

Software Development

The Brazilian government did relatively little to encourage local software development until 2011. In the early days, it was the country's big banks that led the charge. The government started pushing for greater concentration in the country's financial sector in the 1960s; it saw scale as critical to attracting foreign funding and encouraging better public sector debt management. The number of banks in Brazil decreased dramatically between 1964 and 1986, from 336 to 105. The country's four largest banks in 1965 held just

15 percent of total deposits, 14 percent of all loans and 11 percent of net assets. By 1986, the four largest banks held 34 percent of total deposits, 23 percent of all loans and 37 percent of net assets (Schmitz and Cassiolato, 1992). The transformation of the financial sector from fragmented and regional to consolidated and national necessitated dramatic changes in data processing practices.

Commercial banks had started purchasing medium-sized and mainframe computers as early as 1962. Data entry and processing were concentrated in a centralized data processing center, with branches generating and sending documents overnight. As branch networks expanded and overnight delivery became impractical, banks began to establish data entry subcenters, which would collect documents from regional branches and transmit data via telephone line to the main processing center. Given the high transaction costs associated with operating this intermediated model, banks soon began investing in branch automation, which allowed them to deliver clients a more seamless banking experience (Frischtak, 1992). While banks had enjoyed a supportive policy framework for hardware development, they were on their own in terms of developing the software they needed to drive automation efforts.

It wasn't until the early 1990s that the government began to support the creation of software development capabilities in the country. For the government, there had been little need to do so earlier. Customers spent 20 cents on software for every dollar they spent on hardware in the 1970s. But by the early 1990s, the ratio was one to one (Evans, 1995). The first explicit software policy was created in 1992 as part of the Program for the Development of Informatics (DESI). It was called the National Software Export Program, otherwise known as Softex 2000 (Stefanuto, 2004). But lackluster results led the government to hand Softex 2000 to the private sector in 1996. The program was renamed the Brazilian Society for the Promotion of Software Exports and the acronym was shortened to Softex, partly to reflect the changing goalposts for Brazil's growing software industry (Stefanuto, 2004). The program's modified objectives included making Brazil one of the world's top five software exporters, branding Brazil as a global leader in the software industry and matching international quality standards.

But by the year 2000, the private sector had not fully embraced Softex. While the program had been beneficial in the domestic market, it had largely failed to make Brazil a globally relevant software producer. The export orientation was dropped; it was renamed the Brazilian Society for the Promotion of Excellence in Software (still Softex). Stefanuto (2004) argues that Softex failed to meet its lofty goal of orienting Brazil's software companies outward because it lacked focus and did little to create the environment necessary for newly established firms to compete abroad. Furthermore, "the relatively small size, newness, and geographic dispersion of the emerging Brazilian software industry meant that it did not possess the political clout relative to other industrial sectors to obtain differentiated financing for exports" (Botelho et al., 2005). For a long time, software development was seen as an ancillary activity to be undertaken by hardware manufacturers rather than an industry in its own right. Therefore, the government never put together as comprehensive a set of instruments as it did for hardware manufacturers.

While efforts to export software and services remain afloat, the country's industry remains internally oriented. It wasn't until 2011 that the government established a robust national program for software and services as part of the 2012-2015 National Strategy for Science, Technology and Innovation (ENCTI 2012-2015). The stated goals of the recently established Strategic Program for Software and IT Services (TI Maior) are to build a strong digital ecosystem by training IT personnel, to bring Brazilian firms up to international standards, to insert Brazilian firms into the global innovation network and to encourage the establishment and growth of startups (Startup Brazil). In addition to building up Brazilian firms, the MCTI has focused on attracting foreign R&D centers, in part to induce knowledge spillovers, and in part to palliate the skewed trade balance in software.

Industrial Policy Agenda Moving Forward

On the whole, firms in Brazil (local and foreign owned) are active in many segments of the ICT value chain. But for the most part, activities undertaken in the country tend to be on the low value-added side of the spectrum. However, the lack of substantive upgrading in not for want of trying. In fact, the country's broad and shallow participation in this global industry can be seen as a direct result of its industrial policy agenda through the years. The lifting of the market reserve precipitated the end of the line for many of the country's national champions. Once foreign ownership of local firms became legal, various multinationals expanded their presence in the Brazilian market. For example, after years of minority ownership, hardware manufacturer Edisa Eletrônica Digital was finally bought by HP in 1996. Today, the electronics sector has come to be dominated by global lead firms. The PPB was instituted as a means of ensuring that Brazilian suppliers would have opportunities to participate in these firms' local, and perhaps even global supply chains. But the instrument has proven to be too rigid and unyielding to accomplish its stated aim. The PPB for notebooks, netbooks and ultrabooks outlined in Table 7 demonstrates the degree to which the state has sought to specify the degree and rate of nationalization.

Table 7: Notebook, Netbook, Ultrabook PPB

Components	2013 Quotas	2014 Quotas	2015 Quotas	2016 Quotas
Motherboard	80%	90%	90%	90%
Communication interface	50%	80%	80%	80%
Wireless communication interface	45%	70%	80%	80%
AC/DC converters (with PPB)	30%	50%	50%	50%
HDD (with PPB)	10%	20%	30%	30%
Battery (with PPB)	60%	80%	80%	80%
RAM memory produces with PPB	30%	10%	10%	10%
RAM memory assembled in Brazil	0%	50%	60%	80%
Integrated DRAM circuit produced with PPB	0%	40%	30%	10%
Integrated DRAM circuit assembled in Brazil	30%	40%	40%	40%
SSD integrated circuit module produced with PPB	40%	50%	50%	50%
SSD integrated circuit module assembled in Brazil	30%	50%	60%	60%
LPDRAM integrated circuit	0%	10%	30%	40%

Source: Positivo Informatica

Needless to say, the unrealistic expectations embodied in the table above have not been met. Companies have localized production of simple components like chargers and plastic injection molded parts by engaging with local suppliers. More complex components like solid state drives (SSDs) and dynamic random access memory (DRAM) are either imported or assembled and packaged locally. Either way, local value added remains marginal. It is worth noting that increasing local content requirements has made Brazil a more attractive investment location for global component suppliers, crowding out the very local firms that sought protection in the first place. Further, the issue of digital convergence will continue to render the policy largely ineffectual if left unchanged. These detailed local content requirements do not evolve with the technologies they aim to codify. Overspecification means that these lists are obsolete soon after they are published. Some have argued that more flexible PPBs would better withstand technological change (Sturgeon, et al. 2013). Finally, the issue of monitoring is critical. With more than 3,000 PPBs on the books, it is difficult for any government agency to ensure that local content requirements are being met. Thus the threat of sanction for non-compliance is non-existent. Brazil's political and economic crisis has meant, among other things, large cuts to the MCTI's budget, which will only make it more difficult to ensure that requirements are being met.

Industry representatives now claim that the Informatics Law is on the verge of radical change. While the law is one of the most enduring features of the country's industrial policy agenda, it has come under pressure from the inside – the law is costly in terms of foregone tax revenues – as well as the outside – local content requirements have long been a source of contention in the international community. But for now, the law remains in place, grounded by the balance it achieves between the ZFM and the rest of the country, as well as by the large employment base, and by extension, political constituency, it supports. Policymakers would do well to continue bolstering the country's participation in the software and services segments of the ICT GVC. One local software company executive claims that the country's software sector has developed in spite of the government. Improving access to global platforms, investing in workforce training for the 21st century and rekindling efforts to create globally competitive software companies make sense if Brazil is to transition away from dependence on low value added hardware assembly to high value added software and services.

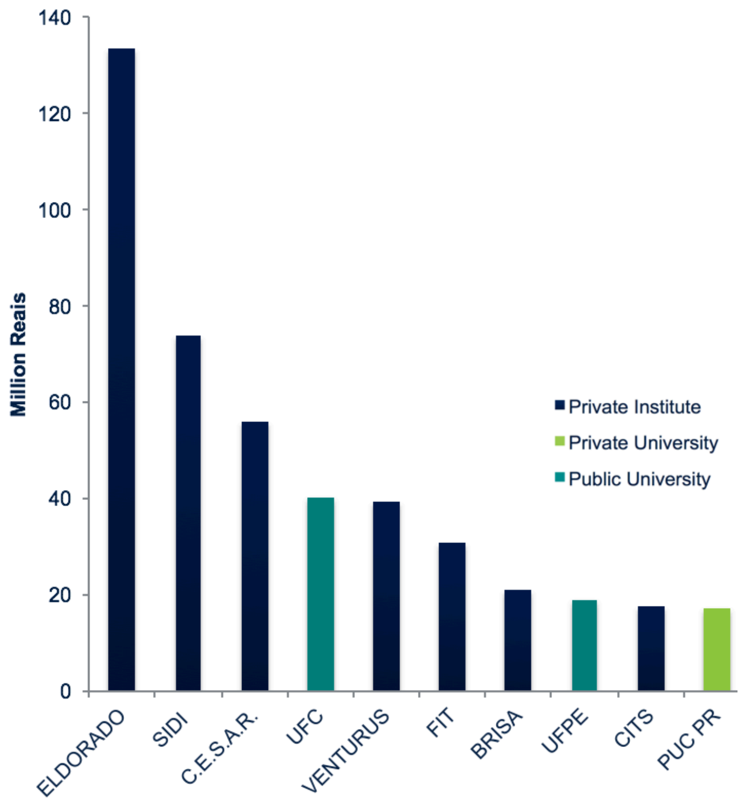
6. Implications for SENAI ISIs

Given the current state of Brazil's ICT sector, what opportunities exist for the newly established SENAI innovation institutes (ISIs)? This section outlines two distinct strategies that ISIs can pursue in the Brazilian market and beyond. Firstly, the ISIs can take on the role of **contract research organizations (CROs)**, either by becoming certified to receive funds associated with innovation policies like the Informatics Law as well as similar policies in automobiles, electricity distribution and telecommunications, or by using the SENAI innovation calls to fund client-directed research projects. This strategy implies working with large firms on discrete modules of larger products and services, or on pilot projects that may be beyond the client's core activities. These relationships are largely transactional, but can evolve over time as competence trust between the two parties is established. Secondly, they can become **innovation partners**, targeting startups and SMEs, and building partnerships over time. When pursuing resource-constrained firms, ISIs could leverage the SENAI innovation call to catalyze collaboration. This strategy implies tightly coupled partnerships, where organizational boundaries remain intact, but task structure becomes interwoven.

Contract Research Organizations (CROs)

The 1991 Informatics Law was the first piece of Brazilian legislation to offer firms attractive fiscal incentives in exchange for local R&D spending. Firms were obligated to spend a significant portion of their total R&D quota through external partners, which had to be certified by the Committee for the Area of Information Technology (CATI), a public-private body chaired by the Ministry of Science, Technology and Innovation (MCTI) and the Ministry of Development, Industry and Trade (MDIC). In 2013, 126 certified university institutes and RTOs worked on projects in collaboration with industry. This regulated market for R&D services is fairly crowded and concentrated. Today, the ten largest RTOs and universities account for 63 percent of all outsourced R&D linked to the Informatics Law. See Figure 3 for a list of the top ten CATI-certified institutions. Applying for CATI certification would give ISIs access to this market. Alternatively, certified RTOs must spend 80 percent of project funds internally. However, 20 percent can be outsourced, which could give ISIs an opportunity to take on some work without applying for certification themselves.

Figure 3: Top 10 CATI-Certified R&D Services Providers, by 2013 Revenues



Source: MCTI, 2014

The Informatics Law has been on the books for a very long time, hence the established market for R&D services. However, the law has proven to be an attractive template for other industries seeking to bolster investments in R&D. The National Agency for Electric Energy (ANEEL), the National Agency for Telecommunications (ANATEL) and the National Petroleum Agency (ANP) are just three government agencies that have recently begun to require that firms invest a certain percentage on R&D. In the case of ANEEL, companies generating electricity must spend 0.4 percent of net operating revenue on R&D while those in distribution are required to spend 0.3 percent and those in transmission must spend 0.4 percent. In the case of ANATEL, operators must spend three percent of net annual revenue on R&D. ANP requires that operators spend 1 percent of net annual revenue generated from large oil fields on R&D. Up to half of the earmark can be spent internally, while at least half must be spent through universities and research institutes certified by ANP. Finally, Inovar Auto, a program established in 2012 to incentivize innovation in the automotive industry, requires that lead firms spend 0.5 percent of gross operating revenue on R&D. SENAI ISIs stand to gain through participation in these captive markets.

The problem with this strategy is that while most multinational ICT firms conduct some R&D in Brazil, it is often of marginal value relative to their R&D centers at home, or even centers in other emerging markets. The reason is that Brazil does not have the globally competitive talent pool, nor does it have the low cost engineering workforce necessary for firms to consider making R&D investments. Firms invest in Brazil because of the Informatics Law. Without the fiscal incentives offered, there would be little foreign R&D investment in the country. Given that there is little incentive to localize competence creating investments, much of the R&D taking place in the country is market-facing. The same holds true for firms applying for funds through the annual SENAI innovation call. Thus working with large multinational firms with R&D quotas or SENAI funding may not yield highly complex, high value-added work. The ISI role associated with this strategy is that of a regulated **contract research organization (CRO).** It involves low-value added work on behalf of large domestic and foreign firms in one of many large and regulated markets for R&D services.

Innovation Partner

The client base for R&D services in Brazil is dominated by large, mostly foreign multinational firms, as has already been mentioned. According to the MCTI, only nine percent of firms receiving fiscal incentives through the Informatics Law in 2013 were large (more than BRL 300 million in gross annual sales), but these firms accounted for 85 percent of total revenues associated with incentivized goods (those that had PPBs). Given the size of the market, it makes sense that existing RTOs like Eldorado, CESAR and FIT would direct their attention towards these firms. But this also means that Brazilian startups and SMEs are currently being underserved by RTOs for R&D services. Startups and SMEs are starting to receive attention from the Brazilian government, albeit in limited ways. Startup Brasil is one of the main pillars of the government's latest ICT policy framework (TI Maior 2012-2015). The government has induced foreign firms like Microsoft and Qualcomm to set up local venture capital funds aimed at investing in local ICT startups. But while some of these will be university startups, universities do not have the internal capacity nor the funding to solve all of the problems early stage firms tend to face, especially in regard to commercialization and scale up. In these cases, ISIs can serve as **innovation partners**, supporting Brazilian SMEs and startups in product and process innovation, but also with business models related to finance, human resource development, marketing, partnerships, and organization.

Brazilian firms spend relatively little on R&D.[6] Interview respondents argue that the lack of R&D spending stems directly from the government's protectionist policies. Why invest in developing new products and services when your current offering does well in Brazil's large and protected market? Resource-constrained startups and SMEs simply cannot invest in R&D without external support. The ISIs could leverage the annual SENAI innovation call to engage with startups and SMEs with high growth

[6] While figures are not published regularly, IBGE's latest PINTEC survey shows that Brazil's private sector spent just 0.55 percent of GDP on R&D in 2008, a paltry figure next to the U.S. (1.87 percent) and South Korea (2.45 percent). The figure has not changed very much since 2000.

potential. In this scenario, the ISI would collaborate with Brazilian firms on projects ranging from the development of clearly defined modules to applied research on broad ideas farther from market. The opportunity to take on more complex work would be greater with Brazilian firms as partners than it would be with large multinational firms. This role involves ISIs building tight bonds with Brazilian firms that do not have the necessary internal capacity to develop technologies on their own. In fact, some ISIs are already employing this strategy. The ICT ISI in Recife is collaborating with Up Biomedical, a Recife-based startup working on biofeedback training, and Serttel, a medium-sized firm that specializes in urban mobility solutions.

Up Biomedical was spun off from the Federal University of Pernambuco's (UFPE) Neurodynamics Research Group in 2014. They were one of the first to make it through the 'Startup Brasil' program, earning a place in CESAR's accelerator, and were granted 150,000 reais (USD 43,000) through the 2016 SENAI innovation call. They have developed a platform for muscular training and rehabilitation, but have had trouble designing the electroencephalography (EEG) headset, which translates brain activity into data. Tariffs make it too expensive to import this specialized piece of hardware, and while they can produce it locally, productivity is low; it takes them two months to manufacture a headset domestically. To solve this problem, they have directed the SENAI funds towards a team in Minas Gerais that will design for manufacturing. Serttel is a much larger firm, with 157 million reais (USD 44.4 million) in revenues last year. They have established a number of partnerships with professors at UFPE and USP, as well as with research institutes like CESAR and the MCTI's Center for Strategic Technologies of the Northeast (CETENE). They did not receive funds through the latest SENAI innovation call, but used FINEP funding to collaborate with the ICT ISI in Recife on a smartphone application that assimilates traffic data to give consumers accurate arrival times. The project has required the organizations operate as an integrated team, as Serttel feeds the ISI the data with which to test the application. In both of these cases the ISI network has collaborated with Brazilian firms on core projects.

Between Contract Research and Knowledge Brokerage

Each of these strategies requires that the ISI leverage both internal capabilities and external resources to varying degrees. As a CRO working on behalf of large firms, an ISI would largely rely on internal capabilities to produce short-term deliverables for clients. Projects could involve testing a given software application, or developing a prototype according to clearly articulated specifications. The CRO may seek external resources, both from within or outside of Brazil, if they do not have the internal capabilities necessary to meet the client's demands. As innovation partners to Brazilian startups and SMEs, the ISIs would also need to leverage both internal capabilities and external relationships and inputs to support clients. Here, I conceptualize the ISI as having two relevant sets of operational partners: clients, which purchase R&D services, and input providers that furnish technology platforms, intermediate inputs, standards and best practices and knowledge.

The ISI would act mainly as a broker, passing pass along details about best practices, standards and other knowledge inputs that Brazilian firms need to upgrade and meet international standards. Each strategy implies elements of knowledge production, which involves ISIs leveraging their in-house assets to develop new products and services for their clients, and knowledge brokerage, which involves activating the ISIs network of clients and collaborators to bring knowledge from where it is to where it is not

(Hargadon, 2002).[7] The innovation partner model would require the ISIs act as intermediaries in more than one sense. Their primary role would require they foster linkages with global technology centers and be conversant in global standards and regulations. This would create a bridge to the rest of the world, and access to critical inputs for Brazilian firms with little exposure to global markets. But a brokerage model could also be conceived of as a means of acquiring 'know how' through contracts with large multinational firms and then using it to serve small Brazilian firms.

Leveraging knowledge acquired from one client to serve another is clearly a source of tension in R&D services contracting, and well as in other knowledge-intensive services such as design and management consulting. But while much of the work that RTOs do on behalf of large, well-resourced firms is subject to confidentiality agreements, the 'know how' acquired can be leveraged across clients. As an RTO director said in an interview, "if I learn how to write better throughout the course of a project; if my handwriting improves; does that mean I need to go back to having terrible handwriting afterwards?" Whether ISIs adopt the CRO model or the innovation partner model, they will likely be working for various clients, some of them direct competitors. They will need to learn to leverage the know how acquired from different clients to build internal capabilities, while remaining cognizant of the confidentiality issues that information brokerage raises. As Kawakami (2011) finds, some Taiwanese ODMs have successfully overcome barriers to intra-organizational knowledge transfer, learning from clients and platform leaders to improve their competitive position vis-à-vis their clients.

RTOs in Brazil have often succeeded in engaging in knowledge brokerage when they span various industries. For example, the Eldorado Research Institute first diversified from its anchor client, Motorola, by filling its board with representatives on non-competitors like HP and Celestica, and then offering these firms R&D services. As innovation hubs with dominion over a particular set of transversal technologies (i.e. sensors, embedded systems, manufacturing automation), the ISIs would be well placed to engage in a knowledge brokerage strategy. Indeed, some have already begun collaborating with clients across a range of industries. For example, the ICT ISI in Recife has already engaged with large global firms like Accenture (ICT-enabled business services) and Fiat (mobility platforms), as well as Brazilian startups and SMEs in areas as diverse as medical devices, mobility solutions and leather processing equipment. In this role, ISIs have opportunities to help bring Brazilian firms in line with global standards and grant them access to knowledge-intensive inputs residing in the global supply-base. ISI's can also coach clients about how to best leverage expertise in particular transversal technologies to develop new markets in adjacent industries. To be clear, these strategies imply different ways of thinking about the roles that the ISIs should play in Brazil's innovation ecosystem. While these strategies can be seen as poles of a spectrum between loose and tight coupling, between large foreign clients and small local clients, with many options in between, the ISIs can and should pursue different strategies simultaneously.

7. Conclusions

ICTs simultaneously comprise both a dynamic global industry and a transversal set of technologies that increase productivity in a range of downstream sectors. The ICT sector is highly fragmented, with a different set of actors in each of the major GVC nodes. Fragmentation is not limited to hardware alone, as

[7] Hargadon (2002) defines knowledge brokers as organizations that exploit "fragmented social structure by bridging multiple domains and moving ideas from where they are known to where they are not" (pp. 44).

firms have been offshoring ICT services and ICT-enabled services for decades, both through foreign direct investment and through engagement with an increasingly important cadre of global suppliers, consultants, and services providers. While there are a number of important companies along the value chain, this note has focused on three key actors: lead firms, contract manufacturers and platform leaders. While fragmentation has processed along vertical lines, and well as geographically, there has been a great deal of horizontal consolidation, with large, multinational firms arising at each state of the value chain. On the other hand, constant rapid technological change continues to create new applications and new markets for ICT and this opens space for new entrants.

Lead firms orchestrate global supply chains to produce goods and services for a range of end markets. These firms often rely on global suppliers for manufacturing and design services as well as other non-core business functions like reverse logistics. Contract manufacturers have come to play an increasingly important role in the ICT sector; they are the largest purchasers of electronic components and the largest producers of computers, peripherals and consumer electronics. Furthermore, they make the majority of greenfield electronics manufacturing investments (Sturgeon, 2002). Lead firms may govern ICT value chains, but specialized suppliers called platform leaders are often able to command substantial profits because their products are integral to industry goods. This is the case in both the hardware segment, with companies like Intel and Qualcomm producing the majority of the processors and chipsets used in a range of downstream applications, as well as the software segment, with companies like Google, Oracle and Microsoft developing ubiquitous platforms of their own.

Brazil participates in almost all segments of the ICT value chain, from integrated circuit design to final good assembly. However, participation is rather shallow and import-dependent across the board; there is no specific node or market segment in which Brazil is globally competitive. I argue that this is a symptom of the country's broad and unfocused industrial policies. By encouraging firms to localize production of a wide range of components rather than focusing on a few, the country has created a supply base with no discernible specialization on which it can build towards global competitiveness. Furthermore, the country's ICT sector depends heavily on multinational firms; most of the country's largest lead firms, contract manufacturers and platform leaders are foreign. For the most part, these firms conduct R&D in Brazil in exchange for fiscal incentives offered through the Informatics Law. Brazilian firms invest relatively little in R&D; there is no need to invest in R&D when you operate in a closed market with limited competition.

While the market for R&D services is crowded because of Informatics Law's R&D quotas, there is still room for participation by ISIs. This paper has outlined two distinct strategies that ISIs can pursue separately or in tandem. The ISIs can approach clients as CROs, offering large clients R&D services on the low end of value added. This could serve as a way into these large firms' Brazilian R&D networks. Or they could approach clients as innovation partners, working with client engineers in tandem to solve core problems. This approach is likely to be best suited to Brazilian startups and SMEs. These strategies can and should be pursued in tandem. They imply different sorts of clients, different end markets and different ways of engaging with the external environment. The ISIs can and should help industry move beyond dependence on the local market, reorienting it outwards both for inputs into the innovation process and for new markets for its goods and services.

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