The Role and Impact of Public Research and Technology Transfer in Brazilian Agriculture

Geraldo B. Martha Jr and Eliseu Alves

Abstract The public sector played a pivotal role in transforming a traditional agriculture in Brazil into a modern one by leading the agricultural research and development (R&D) network in the country and by providing the majority of funds to R&D activities. The spillover effects arising from agricultural R&D were not restricted to the primary sector. A vibrant agricultural sector creates sizable markets for industrial and service sectors if they can deliver quality products at competitive prices. More broadly, the success of this science-based agriculture in Brazil provided the means for ample improvements in food and nutritional security; expanded opportunities for employment and income generation in agricultural (and associated) value chains; a more positive balance of trade; and a substantial attenuation of inflationary pressures. In the coming decades, the value of Brazilian agriculture to society will eventually be even bigger, as the so-called bio-economy gets strengthened. However, it is imperative to encourage a more intense engagement of the private sector in agricultural R&D activities in Brazil.

Successful technological scaling-up will depend upon multi-stakeholder approaches. Knowledge exchange, capacity development and strengthening, technology transfer, extension services, and well-functioning input and market chains, to minimize detrimental effects of market imperfections on technology adoption, are key components to foster the adoption of technologies. In particular, a more widespread and inclusiveness technological adoption in Brazilian agriculture will depend on successful approaches to minimize market imperfections' effects.

Introduction

The importance of the agricultural sector to the Brazilian economy has been demonstrated since the first ventures in colonial times. Despite the role of agriculture in Brazilian history, until the 1960s the country systematically received food donations from abroad, and until the 1980s it was one of the world's largest food importers.

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The traditional agriculture that prevailed in the country until the 1970s, based on the extensive margin, was progressively and significantly transformed in the following decades. A modern and vibrant agriculture, strongly based on science, emerged.

Several factors played a decisive role in this process of transforming Brazilian agriculture. To cite a few, consider (1) the entrepreneurship of Brazilian farmers; (2) the commitment of the Government; (3) the availability of basic infrastructure; (4) the favorable climatic conditions for a productive agriculture; (5) the availability of land suitable for mechanization; (6) the suitable physical characteristics of tropical soils (e.g., oxisols, ultisols, alfisols) and the supply of mineral resources such as limestone and phosphorus; and (7) the recognition of the need and importance of a science-based agriculture, with an ample and solid research system focusing on the adaptation and development of technologies for the tropical environment, in order to make such a transformation a reality (see, e.g., Albuquerque and Silva 2008a, b; Cunha et al. 1994; Martha and Alves 2017).

The achievements in Brazilian agriculture prove that it is possible to produce food, feed, and other agricultural products in tropical environments in efficient, sustainable, and competitive ways. The results of the Brazilian science-based agriculture, such as new varieties adapted to the tropics and agricultural practices tailored to new production environments, such as the Cerrado, among other technologies and innovations avidly adopted in farms, eventually allowed Brazil to become an agricultural power in the period of only one generation.

In this chapter we bring insights into the role of the public sector to Brazilian agriculture, with an emphasis on agricultural research. In the first section, we provide a short introduction to the dynamics of Brazilian agriculture transformation. Then, in the second section, we highlight the importance of research and development (R&D) in supporting these achievements. In the third section, examples of the impacts of public agricultural R&D and associated technology transfer activities on society are provided. In that section we also emphasize key challenges to a more widespread adoption of technologies, stressing the critical role of market imperfections. Finally, in the fourth section, a few thoughts on future possibilities and challenges are discussed.

Agriculture in Brazil

Brazil's Geographic Characteristics

Brazil's geographic area is one of the largest in the world and totals 8,515,767 km^2 distributed among 5570 municipalities (IBGE 2016). Brazil provides vital environmental services to the world through its large availability of land (ca. 13.2% of the world's potential arable land (FAO 2000)) and water (ca. 15.2% of the world's water resources (WRI 2008)).

Table 1 Area covered with native vegetation in Brazilian biomes

Biomes	Total area (km²)[a]	% Remaining (natural cover)[b]
Caatinga (2011)	844,453	53.2
Cerrado (2013)[c]	2,036,448	51.1
Pantanal (2009)	150,355	35.9
Pampa (2009)	176,496	83.1
Amazônia (2014)[d]	4,196,943	82.4
Mata Atlântica (2011)	1,110,182	54.5
Total (Brazil)	8,514,877	61[e]

[a]Area of Brazilian biomes (available at http://brasilemsintese.ibge.gov.br/territorio.html); further information at http://www.ibge.gov.br/home/geociencias/areaterritorial/historico.shtm and http://www.ibge.gov.br/home/geociencias/cartografia/default_territ_area.shtm
[b]Control and prevention of deforestation in Brazilian biomes (available at http://www.mma.gov.br/florestas/controle-e-preven%C3%A7%C3%A3o-do-desmatamento)
[c]TerraClass Cerrado (available at http://www.dpi.inpe.br/tccerrado/index.php?mais=1)
[d]TerraClass Amazônia (available at http://www.inpe.br/cra/projetos_pesquisas/arquivos/TerraClass_2014_v3.pdf)
[e]Brazilian agriculture overview (available at https://polcms.secure.europarl.europa.eu/cmsdata/upload/f312ee34-a6e1-4cf1-8a21-d21040a321fd/Brazilian%20Minister_Presentation.pdf). All the above mentioned information were accessed on April 24th, 2017

The country's diverse climatic regimes (from tropical to subtropical), combined with such natural capital, have evolved over the ages to create six diverse biomes, from semiarid to Amazon rainforest. As of today, over 60% of the Brazilian territory is still covered with native vegetation (Table 1). Brazil's biodiversity potential is outstanding: among the world's 250,000 species of higher plants, nearly 60,000 are native to Brazil (Lopes 2012; MMA 2017).

Agriculture in Brazil: From Colony up to Mid-Twentieth Century

Brazil was a colony from Portugal from 1500 to 1822. And since colonial times, agriculture was important to the country. In the sixteenth and seventeenth centuries, sugar exports were prominent and peaked during the 1650s, with profitability declining shortly thereafter, owing to the decline in international prices and competition imposed by the colonies in the Caribbean (Furtado 2005). Due to the collapse of the gold cycle in the country by the end of the eighteenth century, by 1822, at the time of Brazil's independence from Portugal, exports of agricultural products – cotton, sugar, and coffee – once again represented the main source of income to the country (Maddison 2011).

From mid-nineteenth century until the 1920s, coffee production was by and large the main economic activity in the country (Bacha 2004). Coffee and some other agricultural commodities (rubber, cocoa, and cotton) destined for foreign markets accounted for over 55% of exports until the 1960s (Thorp 1998). Because of this economic model, Brazil repeatedly faced volatile economic growth and considerable external vulnerability for much of its history (Baer 2008; Gremaud et al. 2004).

Up to late 1960s, Brazilian agriculture was still trapped in cycles of low productivity and was heavily dependent on area expansion as a strategy to increase food production. The shift toward the modernization of Brazilian agriculture had its origins in the import substitution industrialization strategy adopted after the 1950s and 1960s up to the early 1980s. Nevertheless, in that period the industrial sector was granted a series of advantages that strongly discriminated against agriculture.

The persistent food supply crisis throughout the 1960s and early 1970s led to several hypotheses being formulated to explain the lack of a more substantial increase in agricultural productivity. Three policies turned out to play a central role in Brazilian agricultural modernization process: (a) rural credit, mainly for capital goods and purchasing of modern inputs; (b) rural extension; and (c) support to agricultural research.

The role of rural credit in the modernization of Brazilian agriculture was of pivotal importance in the 1970s and the 1980s, by boosting the production and adoption of modern inputs (seeds, fertilizers, etc.), machinery, and equipment. Interest rates were subsidized, particularly from late 1960s to 1985 (Coelho 2001). Martha and Alves (2017) estimated that rural credit in Brazil, in 2016 Brazilian reals, averaged R$ 154.53 billion per year, from 1969 to 1985; R$ 76.40 billion per year, from 1986 to 2000; and R$ 113.60 billion per year, from 2001 to 2015.[1]

Until the early 1970s, Brazilian policy makers emphasized rural extension and neglected efforts in agricultural research. As discussed by Martha and Alves (2017):

> … The belief that strengthening human capital was key to better utilize available resources and to increase the impact of the investments made in capital goods and modern inputs was, of course, in the right direction. The flaw emerged in not recognizing that agricultural problems – and the demands posed to the sector – were not static, they were actually quite dynamic. A successful strategy would inevitably embrace a robust research system to continuously generate knowledge and technology to be transferred to extension services that, in turn, would be better positioned to support a sustained innovation process at the farm level.

Major developments in agricultural research only got traction in the post-WWII period and especially in the 1970s. The research-driven approach in Brazilian agriculture experienced a very important milestone in 1973, when the Brazilian Ministry of Agriculture boldly established its agricultural research arm – the Brazilian

[1] Despite those incentives, it is important to note that the overall level of incentives to Brazilian agriculture has been low compared to other countries. For example, considering the metric provided by the Organization for Economic Cooperation and Development (OECD), the producer support estimate (PSE), Brazilian farmers received incentives averaging only 1.6% of total gross farm receipts from 1995 to 2014. The corresponding values to the farmers in the USA and Europe in the same period were 13.5% and 28.3% of the total gross farm receipts, respectively (data available at https://www.oecd.org/tad/agricultural-policies/producerandconsumersupportestimatesdatabase.htm)

Agricultural Research Corporation (Embrapa)[2] – to strengthen agricultural research in the country.

This overall broad picture was summarized by Martha and Alves (2017) as follows:

> … the development of a modern agriculture in Brazil was initially prompted by the import substitution industrialization policy from late 1960s to mid-1980s. The accelerated growth in population, urbanization, and per capita income at that time posed a clear and strong demand for the agricultural sector. The expansion of agricultural output enabled larger export volumes, as well as more diverse exports, which in turn provided the means to finance imports of technology and capital goods for the emerging national industry. The increased opportunity cost of labor for farmers, and the sustained migration from rural areas to cities additionally led to a favorable environment for agricultural growth and modernization ... A science-based approach, based on the continuous generation of new knowledge and technologies, played a crucial role in transforming Brazilian agriculture from mid-1970s on.

A Few Highlights on Brazil's Agricultural R&D

Innovation activities take different forms (technology embedded in capital goods, "hardware," "software," licenses, technology training, other forms of services, OECD 2005) and, of course, are not restricted to R&D activities. Nevertheless, in targeting Brazil's science-based agriculture, R&D activities have been playing a central role in increasing the sector's sustainability and competitiveness over the past few decades.

There are no alternative means to sustain this knowledge generation flow but to support both basic (fundamental) and problem-solving (applied) research. To that end, continuously improving and strengthening human capital plays a central role to overall innovation goals. Giving up on this approach – e.g., to quit playing a key role in basic and applied research and to quit investing in a highly qualified human capital to run those activities which boost the innovation process over time – will inevitably result in losing the national capacity to design directions to be pursued by key sectors in the economy over the medium and long run.

From the mid-1970s on, Brazil improved its research structure and capacity substantially by developing a two-tier system of federal and state-based agencies, called the "National Agricultural Research System (SNPA) (Lopes 2012). The Brazilian SNPA includes state agricultural research organizations, university agricultural colleges, and Embrapa, which coordinates the SNPA.

Embrapa has a nationwide mandate, is decentralized in the territorial dimension, and is organized into product, resource, and theme research centers. The successful

[2] More precisely, Embrapa was created by the federal law 5851, from December 1972, and effectively installed on April 26, 1973. When Embrapa was created, it incorporated the former research structure of the Brazilian Ministry of Agriculture, the "Departamento Nacional de Pesquisa Agropecuária."

Embrapa model centers heavily on continued strengthening of human resource capacity and on excellence research centers (Alves 2010; Martha and Alves 2017).

As of 2013, Embrapa represented 42% of the SNPA's research capacity, followed by state research organizations (29%), agricultural colleges (26%), and nonprofit organizations (3%). The full-time research equivalents in 2013 (FTE – 5869.4) were composed by 72.5% of researchers with PhD, 21.5% with MSc, and 6.0% with BSc (Flaherty et al. 2016). At Embrapa, as of 2015 only 0.7% of researchers had a BSc degree and 13.5% had an MSc degree. The share of researchers with a PhD was 85.8% (Martha and Alves 2017).

Public funds have traditionally accounted for more than 90% of Brazil's agricultural research effort. Thus, the financial support of the Brazilian government to SNPA – and, thus, to the agricultural sector – has been of overwhelming importance. The level of investment in public agricultural R&D, from 1981 to 2013, has averaged USD 1.9 billion per year. This was translated into an average intensity of agricultural R&D expenditures of 1.2% of the agricultural gross domestic product (GDP), in the 1980s, and ca. 1.85% in the 1990s and 2000s.[3]

The support to Embrapa, which has traditionally accounted for ca. 55% of public agricultural R&D expenditures in Brazil, has been of paramount importance. In absolute terms, and considering 2016 constant Brazilian real values, Embrapa's budget progressively increased from 1973 onwards to reach R$ 2.44 billion in 1982; then it sharply decreased to R$ 1.58 billion (1984), to gradually increase again and reach R$ 2.77 billion in 1996. Embrapa's budget progressively dropped (again) to R$ 1.77 billion in 2003. After a couple of years around this budget level, Embrapa's budget resumed a positive trend and progressively increased in the following decade to peak at R$ 3.37 billion in 2015. In 2016, it totaled R$ 3.2 billion. This later amount would be equivalent to approximately USD 940 million, or perhaps, more correctly, to ca. USD 1.75 billion, when appropriate expenditures are expressed as USD purchasing power parity.

From an institutional point of view, Brazil operates with a R&D model of responsibilities that converges to the ones practiced in developed countries. Universities tend to focus on basic research, although not exclusively. Research organizations are more engaged in problem-solving (applied) research, although in strategic areas they play a key role in basic research and in development efforts as well. Private companies concentrate their efforts in development, but sometimes present initiatives in research, occasionally even in basic research.

Brazil has maintained an appropriate path in balancing expenditures in basic and problem-solving research. And the justification for that is simple: one type of research nourishes the other. Basic/fundamental research expands the pool of knowledge necessary for problem-solving/applied research to respond to more specific real-world opportunities and challenges. At the same time, such feedbacks from perceived sectoral opportunities and challenges provide relevant signals and demands for knowledge expansion on fundamental questions, the object of basic research.

[3] Based on ASTI-IFPRI's database on agricultural research (available at www.asti.cgiar.org/data). Values based on constant 2011 PPP dollars

R&D and Technology Transfer Impacts

Once the technology, process, or agricultural practice has been generated by the research system, it needs to be properly "decoded" (e.g., "the transfer of technology phase"). In a subsequent stage typically represented by public and private rural extension/consultancy activities, end users get to understand the technology, process, or agricultural practice and are thus better positioned to analyze advantages and disadvantages among available options and decide toward adopting (or not) any given innovation.

In other words, research and technology transfers are components of the innovation flow, and their impacts on society will inevitably be linked to each other's success. Ultimately, perceived outputs and outcomes will be influenced by end users' ability to understand and successfully implement novel methods, tools, and courses of action in a desirable direction and in a timely manner.

Public Research-Driven Impacts

The choice of a technology will vary according to the priority problem to be solved. Hayami and Ruttan (1985) indicated that agricultural technologies can broadly focus on land- and/or labor-saving technologies. In the first group are biological and chemical technologies, while the latter includes mechanical technologies. The so-called product-saving technologies, linked to reduced losses along the food chain, are additionally perceived as crucial to the agricultural sector's outcomes for society.

The research model adopted by Embrapa facilitates the interaction between researchers and farmers (and more broadly with society) by establishing an interesting way to identify research priorities – a typical case of induced innovation. Among the strategies used to accomplish that end is the direct researcher-farmer interaction (field days, on-farm research, etc.), as well as connections through permanent and temporary committees and councils, in which stakeholders' and overall society's needs and demands might be captured and translated into problems to be solved by the research system (Martha and Alves 2017). Present and future challenges can then be timely identified and thus incorporated into research activities that properly provide for adaptation and/or generation of technologies. Thus, for public research, the market influence is indirect, since to a great extent, it is derived from farmers' and/or society's lens. For the private research market, it acts directly; otherwise the technology developed would not find buyers (Hayami and Ruttan 1985).

Over the past four decades, Brazilian public agricultural research, in many instances led by Embrapa, decisively contributed to sizable achievements in agriculture, whether in land-, labor-, or product-saving technologies. There is little doubt that the payoffs to agricultural R&D have been high over the past 60 years (Alston et al. 1998; Pardey et al. 2006, Avila et al. 2010).

The internal rates of return (IRR) to investments at Embrapa have averaged 25%–30% over recent decades, ranging from 20% to 74% in the studies reported by Avila and Souza (2002). From 1997 to 2015, Embrapa's aggregated IRR was estimated at 39.1%.[4] While such high IRR values are thrilling, in a recent reassessment encompassing more than 2000 evaluations from 1958 to 2011, Hurley et al. (2014) indicated that a median of around 10% (versus a median of ca. 40% previously reported) was perhaps a more reasonable estimate to agricultural R&D's IRR. However, an IRR of 10% is still substantial enough to justify massive investments in public agricultural R&D.

Another metric commonly used to evaluate the impacts of public agricultural R&D is the benefit/cost ratio (Avila et al. 2008). Over the past two decades, where annual impact evaluations are available, Embrapa has shown a benefit/cost ratio to society's investment ranging from 7.5:1 to 14.8:1. On average, Embrapa's benefit/cost ratio is 11:1 – that is, for each dollar invested at Embrapa, Brazilian society has received 11 dollars back in the form of knowledge and technologies fueling the innovation process.

Over the past 19 years (1998–2016), the net accumulated benefit (e.g., the sum of benefits minus the sum of expenditures) of Embrapa's research was approximately R$ 460 billion in 2016 values[5] (Fig. 1). After a decrease in R&D funding, a decreased return (benefit) to society is expected within a few years. However, if R&D funding is resumed relatively shortly, the flow of R&D benefits to society is expected to resume a positive trend within a few years (Fig. 2).

On the "cost side" of benefit/cost analyses, no major value change is expected. However, one must keep in mind that on the "benefit side," such values are a fraction of Embrapa's contribution to society. The 11:1 ratio considered around 100 technologies and some 150–200 plant cultivars, whereas in fact over the past 45 years, Embrapa has contributed with considerably more knowledge and technologies than those. The point to note here is that there is imprecise evidence regarding the impacts of agricultural research over an ample array of technologies. In part this reflects the difficulties in attributing adequate weights to benefits and costs among different agents involved in the process.

Another impact metric that might be considered is, of course, the direct economic benefit (Avila et al. 2008). Taking the seed market as an example, Embrapa was a major player in Brazil up to the mid-1990s. This happened because at that time the private sector, in the country and also abroad, was not sufficiently developed to meet Brazilian farmers' needs. As exemplified in Embrapa's 1998 social balance report,[6] in the 1995/1996 season, Embrapa's seeds held sizable market shares: 8.1%

[4] Please see Embrapa's 2015 social balance, available at http://bs.sede.embrapa.br/destaques.html (information accessed on April 10th, 2017).

[5] Such a social return is very impressive to the overall Brazilian economy. For example, in 2016, the gross value of agricultural (crops + livestock) production totaled ca. R$ 552 billion, according to Brazil's Agriculture and Livestock Confederation (CNA 2017). Thus, Ceteris paribus, Embrapa's returns to society would potentially generate such an innovation flow that would eventually be translated into doubling the size of agriculture's annual gross value of production every quarter of a century.

[6] Available at http://bs.sede.embrapa.br/1998/tdtsoc4.htm (information accessed on April 10, 2017)

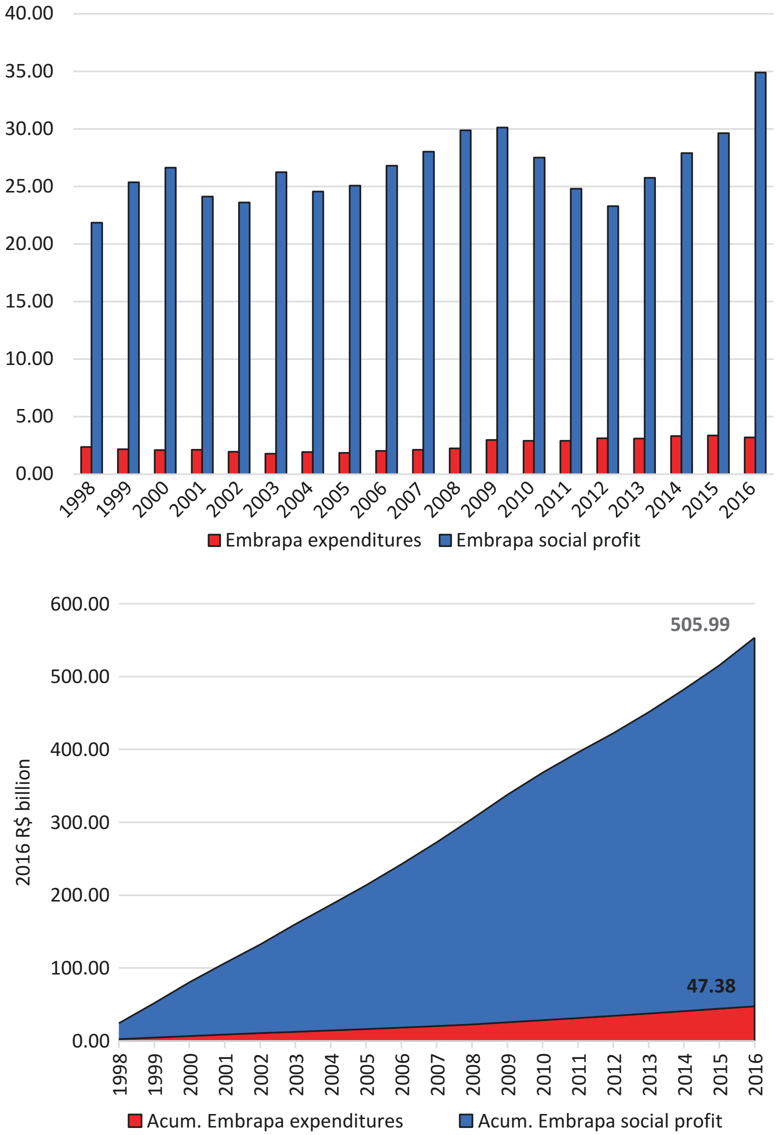

Fig. 1 Embrapa expenditures and social profits, on a yearly basis (top) or accumulated over the 1998–2016 period (bottom). Values are in 2016 Brazilian reals (Source: Expenditure values from Embrapa-DAF database. Social profits from Embrapa's social balances (data available at http://bs.sede.embrapa.br//2015/). Authors' calculations and elaboration)

for cotton, 63.23% for irrigated rice, 98.04% for upland rice, 38.68% for common beans, 21.07% for corn, 55.01% for soybeans, and 58.04% for wheat. In that harvest season, 44% of Brazilian cropland was estimated to be planted with Embrapa's seed.

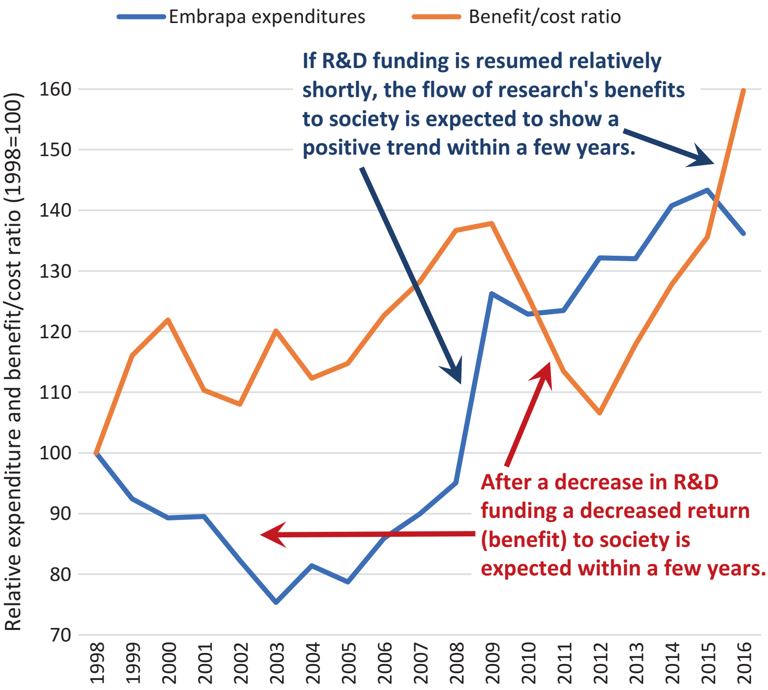

Fig. 2 Dynamics of Embrapa expenditures and benefit/cost ratios over the 1998–2016 period (Source: Expenditure values from Embrapa-DAF database. Social profits from Embrapa's social balances (data available at http://bs.sede.embrapa.br//2015/). Authors' calculations and elaboration)

Pardey et al. (2006) presented a study aiming to evaluate the impact of soybean, dry beans, and rice varietal improvement at Embrapa as compared to non-Embrapa investments. In the aggregate, varietal improvement in these crops from 1981 to 2003 yielded benefits of US$ 14.8 billion at 1999 prices. Attributing all the benefits to Embrapa, the benefit/cost ratio would be 27 for upland rice, 15 for dry beans, and 149 for soybeans. Under alternative distribution rules, which indicate Embrapa was given partial credit for the varieties developed jointly with other partners, the ratios would drop to 5, 3, and 31, respectively. Despite of the alternative distribution rule considered, the role of public research to Brazilian agriculture is obviously enormous.

Another example comes from the forage seed market, where Embrapa plays a very important role up to today. Three of the most adopted forage cultivars in the country – *Panicum maximum* cv. Mombaça, *P. maximum* cv. Tanzania, and *Brachiaria brizantha* cv. Marandu – are directly linked to Embrapa's research. Embrapa's returns to society in this case have provided an estimated economic benefit of R$ 6.67 billion in 2015 alone. In 2014, the estimated contribution was even higher – R$ 10.89 billion.[6]

Other tangible inputs generated by the agricultural research system might be considered. For example, soybean varieties that require no nitrogen have been selected for use in Brazil (Dobereiner 1997), and production contests have recently recorded potential yields exceeding 6 metric tonnes/hectare. Such achievement reflects important R&D contributions on biological nitrogen fixation (BNF) led by public agricultural research especially after the 1970s. In 2016, the soybean area with BNF was estimated to be 33.25 million hectares. In 2016, Embrapa's returns to society considering solely this technology were estimated at R$ 14.7 billion.[6]

It is worth of noting that a research organization such as Embrapa provides society not only with tangible deliverables (say, "crystalized knowledge"), such as seeds and other inputs. Embrapa and other research organizations benefit society with non-tangible contributions – the "non-crystalized forms of knowledge."

Non-tangible products may represent a considerable portion of public agricultural R&D organizations' benefits to society. However, they are more difficult to be adequately estimated. For example, what are the private (e.g., to farmer) and social (e.g., to other stakeholders and to society as whole) value and costs of knowing how to properly manage any given input, solely or in combination with other inputs? What are the private and social value and costs of knowing how to adequately implement agricultural practices for a better resource use efficiency, improved water quality, reduced erosion and runoff, smaller environmental pollution, and higher economic return? Definitely, there is no easily quantifiable metric to those questions.

Tentatively, the total factor productivity (TFP) may provide a few insights on that matter. The TFP is a productivity measure taking into account the partial productivities of land, labor, and capital; it is thus defined as a ratio of output to inputs. Put simply, TFP is the portion of the product not explained by the inputs.

Over the past four or five decades, the yearly TFP growth of Brazilian agriculture has been estimated at 2.24% (Gasques et al. 2010) and 2.31%.[7] Considering that a 1% increase in Embrapa's research spending would increase Brazilian agricultural TFP an estimated 0.2% (Gasques et al. 2009), one could probably say that over the long-run, public research, in this case represented by Embrapa, has been associated with at least 10% of overall agricultural sector productivity.

The Increasing Role of Technology to Inclusiveness, Sustainability, and Competitiveness Goals

The future, by definition, brings uncertain outcomes. However, if one was to bet on the most influential factor for future agriculture, it would probably be technology. Alves et al. (2013), working with data from the 1995/1996 and 2006 agricultural

[7] These estimates were based on the USDA-Economic Research Service's database, assumptions, and methods. This work is led by USDA-ERS's researchers Keith Fuglie and Nicholas Rada. Data available at www.ers.usda.gov/data-products/international-agriculture-productivity

census, found that in the first period, land and labor accounted for about 50% of the variation in gross income in agriculture; the other half was the result of technology. That is, technology was already important to Brazilian agriculture in the 1990s.

In just one decade, according to the 2006 agricultural census data, the contribution of technology grew by about 35% and accounted for roughly two-thirds of the gross income variation in Brazilian agriculture. Of course technology does not occur in an "empty space," so farmer entrepreneurship, public policies, and available stocks of knowledge and technologies all contributed to that outcome. It is worth of noting, however, that given the long maturation period inherent to agricultural research, such a result was only possible because of persistent and focused agricultural R&D efforts toward innovation that have been actively developed in Brazil since the 1970s.

Furthermore, it is important to note that the contribution of land to income variation dropped by 50% (from around 18% to 9%) between the agricultural censuses of 1995/1996 and 2006. Similarly, the contribution of labor to income in agriculture dropped by ca. 30% (from 31% to 22%) in this period. Those facts highlight that in a science-based agriculture, such as was established in Brazil, land and labor progressively lose their power to explain income over time. Technology, for at least two decades, has been the main factor explaining income in Brazilian agriculture. In addition, technology, together with market imperfections, is a key factor to be looked at when targeting inclusiveness, sustainability, and competitiveness policies and regional development approaches.

Put a bit differently, a more widespread dissemination and effective adoption of modern technologies by a more significant number of farmers in Brazil may represent a disruptive, but substantially positive, contribution to agricultural product in the coming decades. Alves et al. (2012) estimated that 44% of the 4.4 million farms that have declared income in the 2006 agricultural census (out of a total of 5.2 million farms) were able to pay for all inputs. Nevertheless, only about 500,000 farms had a monthly income of more than 10 minimum wages. There were approximately 2 million farms with monthly incomes of up to 10 minimum wages, which may have a solution in the agricultural sector.

As emphasized above, the success of such a strategy would depend on the adoption of modern technologies, which reinforces the importance of effectively minimizing market imperfections. For the purpose of this discussion, we understand market imperfection not only as a market power concentration (monopoly, oligopoly, monopsony, and oligopsony). It also refers to non-technological asymmetries (such as the availability of infrastructure and education) that restrict a more widespread assimilation and adoption of modern technologies (for additional details, please see Alves and Silva 2013; Martha and Alves 2017). Therefore, market imperfection, given its several channels of interference in the overall decision-making process and its influence in altering the relative prices to farmers and thus the return to investment in technologies, needs to be reduced to increase the effectiveness of policies targeting technology adoption by the farmers and to allow agricultural production to expand in a more inclusive way (Martha and Alves 2017).

Final Thoughts

Spillover effects of agricultural R&D and on-farm agricultural innovations are, of course, not restricted to the primary sector – they are much bigger and can benefit other countries as well.

A sustainable and competitive science-based agriculture can provide transformation industries with a continuous flow of quality raw materials at declining real prices, potentially increasing its own competitiveness over time. The data provided by CEPEA ("Center for Advanced Studies on Applied Economics"), hosted at the University of São Paulo (USP), "Luiz de Queiroz" College of Agriculture (ESALQ), provides unique insights on that matter. In 2015, Brazilian agribusiness gross domestic product (GDP) totaled R$ 1.267 billion (2015 Brazilian reals). The agro-industry accounted for 27.5% of agribusiness GDP, contributing R$ 348.149 million to the Brazilian economy.[8]

In addition, such a competitive and sustainable science-based agriculture demands modern inputs with high technological content, which are provided by urban activities. Thus, a vibrant agricultural sector creates sizable markets for industrial and services sectors if they can deliver quality products at competitive prices. Calculations by CEPEA, at ESALQ/USP, have showed that in 2015 the input industry in agribusiness contributed R$ 151.133 million to the Brazilian economy.

Brazil's benefits from agriculture are not only due to expanding opportunities for employment and income generation in the sector but also to the effects of increased production in attenuating inflationary pressures. In addition, agriculture in Brazil has generated income effects of demand which brings positive spillovers to other sectors in the economy and especially benefits the low-income population (Martha and Alves 2017). The country has also gained from substantial surpluses in the agricultural balance of trade over the past two decades. Among other things, a trade balance surplus contributes to government funds and in this way might play a role in implementing and maintaining social and development programs in Brazil.

In the coming decades, the value to society of Brazilian agriculture and its research and innovation system will eventually be even bigger, as the so-called bio-economy gets strengthened. The ample variety in the supply of biomass in the country offers real opportunities for the development of value chains based on high value-added materials and substances targeted for food, feed, flavors, and non-food uses. Chemical biocatalytic processes lead to the development and use of microbial catalysts that directly convert raw materials into a range of products and chemical intermediates that can be subsequently converted into new products with a high value-added potential (Embrapa 2014). Such a bio-economy strategy may eventually boost the growth of associated capital goods industries, engineering services, and biomass suppliers in food, feed, chemistry, and pharmaceutical value chains, among others, creating opportunities for expanding higher value-added exports (Lopes and Martha 2016; Martha and Alves 2017).

[8] http://www.cepea.esalq.usp.br/br/pib-do-agronegocio-brasileiro.aspx

However, such thrilling outcomes from agriculture are constantly being challenged by biotic and abiotic pressures and, increasingly, by an intricate economic, political, and legal framework. Ultimately, there are no alternative means to an inclusive, sustainable, and competitive agriculture but strengthening the agricultural research system.

In addition to increasing research investments in agriculture to ensure the continuity of past decades' virtuous cycles on innovation, it is imperative to encourage a more intense engagement of the private sector in agricultural R&D activities in Brazil. Coordinated and expanded public, public-private, and private efforts are necessary to increase our current ability to understand and respond to present and future risks and challenges in diverse areas of knowledge and to more fully meet Brazil's potential in agriculture and bio-economy in the coming decades.

Successful technological scaling-up will depend upon multi-stakeholder approaches. Knowledge exchange, capacity development, technology transfer, extensions services, and well-functioning input and market chains, to minimize detrimental effects of market imperfections on technology adoption, are key components to foster the adoption of technologies.

In order to make such views a reality, it is key to expand investments in human resources training at all levels (Martha and Alves 2017). As pointed out by Alves (2008), the most severe restriction in boosting the production capacity of the agricultural sector is human capital, and that requires time to be removed. Capital restrictions embodied by the new technology are an outstanding deficiency, but they can be solved by credit policies, while access to more complex machinery and equipment can be solved by amending leasing legislation (Alves 2008).

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