Agricultural R&D investments in Brazil: global responses and local spillovers[1]

WORKING IN PROGRESS

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Abstract

Brazil has made significant investments in public agricultural research and development (R&D) over the past 50 years. This policy priority has allowed the country to achieve high levels of total factor productivity (TFP) growth, especially in the past two decades[1,2]. These investments have benefitted consumers, both in Brazil and worldwide. Brazil had not fully recovered from a recent economic recession (mid-2014 to 2016) when the COVID-19 pandemic hit the global economy. Before COVID-19 public agricultural R&D expenditures in Brazil had already declined compared to its 2000-2017 levels[2]. The fiscal deterioration in the wake of this pandemic could further jeopardize Brazil's capacity to invest in agricultural R&D. This paper explores the potential consequences of such a slowdown in public agricultural R&D expenditures in Brazil, and hence on productivity growth rates, land use, agricultural output, yields, and food prices at both the national and global levels over the 2017–2050 horizon. This slowdown scenario is contrasted with a more aggressive path of agricultural R&D expenditures that ultimately sustains total factor productivity gains close to its highest historical record (e.g. 2000-2017 average). In this scenario, national and global food and environmental security benefits through a combination of greater agricultural output and yields, lower crop prices to consumers, and diminished cropland expansion. In contrast, when diminishing global agricultural R&D expenditures are considered in our baseline scenario[3], the world will face its worst-case scenario. Cropland would have to increase globally by more than 100 million hectares, by 2050, to sustain a crop output

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that is only 59% of the level projected in the historical high TFP growth scenario. The impact at the national level is projected to be even worse, and it will be aggravated in the scenarios in which Brazil's response to COVID-19 pandemic further reduces agricultural R&D expenditures over the next decade. Public and private initiatives strengthening agricultural R&D fueling productivity gains and the widespread adoption of sustainable intensification approaches, are critical to Brazil's and global food and environmental security.

Introduction

There is still much uncertainty about the magnitude of COVID-19's impact on public health and the economy. Vaccines are being developed and distributed at record speed, but challenges related to their widespread availability, especially in poor countries, public acceptability, and logistics have emerged, imposing threats to the global health and economic recovery. As a result, the recovery process is likely to be uneven and slow in some countries and specific sectors of the economy.

The COVID-19 lockdown policies have caused disruptions in supply chains, economic recessions, and an environment prone to social disruption and deepening inequalities. Changes in agricultural production and in the food environment, and food price hikes are being observed[4]. As a result, have been significant pressures placed on global agriculture and food markets, heightening the relative importance of food in household consumption, especially in the poorest and most vulnerable regions of the World[5]. Furthermore, the ensuing increases in poverty and food insecurity are jeopardizing efforts to meet Sustainable Development Goal (SDG) 2: "Zero hunger" [4].

International trade in food products is essential for economic development and food security[4]. Within the global agricultural trading system, Brazil is a major player[6]. Therefore, developments in Brazilian agriculture can have a significant impact on global food security and prices. Historically, strong public investments in agricultural research and development (R&D)[1,7] have played a key role in permitting Brazil to develop one of the best-available science and technology foundations for agriculture[1]. This has been reflected in high total factor productivity (TFP) growth rates in agriculture over the past two decades[5,8], allowing Brazil to become a key agricultural exporter[6] and, ultimately, an important contributor to global food security. However, there have also been concerns voiced about the impacts of agricultural expansion on land-use changes and deforestation in Brazil[9,10]. Simultaneously increasing agricultural production while protecting natural resources and biodiversity requires strong productivity gains[11,12] with minimal land area expansion (e.g. leakage) to other regions[13].

Sustained investments in R&D constitute a major driver of agricultural productivity and output over the long term, lessening the pressure to expand cropland area as well as to maintain and enhance the environmental dimension of sustainability over the long term[14,8]. For example, considering the 1991 – 2010 period, land area expansion would have had to be 173 million hectares (Mha) larger, roughly 10% of the area covered by tropical rain forests, in the absence of the observed growth in TFP[12].

However, to observe a sustained growth in TFP a persistent investment in agricultural R&D is necessary. In the past 30-40 years, middle-income countries, such as China and Brazil, have substantially increased their expenditures in agricultural R&D[14]. Gasques *et al.* (2019)[15] estimated accumulated response functions to understand the major drivers of TFP in Brazil. For each 1% increase in research spending, TFP in Brazilian agriculture is expected to increase by 1.1% over the ensuing decade. By comparison, the corresponding increases in TFP in a 10-years period in response to 1% increase in rural credit, or in terms of trade, or in exports were 0.42%, 0.61%, and 0,80%, respectively.

Public and private investments tend to support different, and often complementary, types of agricultural R&D[14]. However, the economic and financial challenges imposed by COVID-19 have been seriously compromising both sources of investments, not only in agriculture but in the entire economy.

In this paper, we explore the relationship between agricultural R&D and sectoral TFP growth, and food and environmental security outcomes, both in Brazil and worldwide. We build on earlier work by Hertel and Baldos (2016)[16], developing a new version of the SIMPLE model ("*Simplified International Model of Prices, Land use and the Environment*") with a focus on Brazil. This is dubbed SIMPLE-BR. To our knowledge, there is no study that has simultaneously investigated the endogenous responses of both global and Brazilian agriculture to TFP growth rates in Brazilian agriculture. Considering the long-lasting impacts of the fiscal deterioration scenario imposed by COVID-19, that might significantly and negatively impact public investment in agricultural R&D, we addressed those issues in the horizon up to 2050.

Methods

We employ a newly developed model, SIMPLE-BR (additional information in SM - Fig. S1), to examine the impacts of different pathways of TFP growth in Brazil. We use the agricultural R&D capital and spillover model developed by Fuglie (2018)[3] with several spending paths and capital accumulation schemes to create scenarios of TFP growth in Brazil and worldwide. The SIMPLE-BR model base year is set to 2017 and the main source of data is FAOSTAT[17]. SIMPLE-BR disaggregates the world economy into seventeen regions (see Table A1 in SM), each one producing an aggregate crop commodity using a variable combination of land and nonland inputs (see Fig. S1 in SM). The demand for agricultural output is derived from consumption in each region and is driven by per capita income and population in each region. Representative consumers in each region demand four commodities, including both non-food and food products, differentiating food between direct consumption of crops and indirect consumption through the demand for livestock products, and processed food products (see SM for additional information).

We first validate the model over the historical period: 2000-2017. Following earlier work by Hertel and Baldos (2016), this involves specifying exogenous changes in regional population and per capita income, as well as TFP growth rates for crops, livestock, and processed food production (Tables A2 and A3 in SM). The validation process consists of comparing the endogenous projections with the changes observed in some variables of the model. Overall, the model does a reasonable job in predicting observed changes in crop production and price, although it understates observed global cropland expansion (Fig. S5 in SM). As we move from global to regional projections, regional drivers become more relevant[18]. The model generated reliable predictions for Brazil as well (additional information SM section 1.2).

The focal point of this paper involves TFP projections for Brazilian agriculture (Table A4 in SM). Our **baseline scenario** projects trends in agricultural R&D expenditures and knowledge capital accumulation up to 2050 using Fuglie's model. The resulting TFP growth rate for Brazilian agriculture in the 2017 – 2050 period is 1.73% per year. Two additional scenarios are considered to investigate the importance of productivity growth for food and environmental security. The **low-growth scenario** (1.20% per year) assumes that R&D spending in Brazil is held at its nominal value of 2020 for ten years (2021-2030), reflecting the fiscal challenge imposed by COVID-19 that could directly affect capital accumulation and, hence, TFP growth rates. The **high-growth scenario** (3.08% per year) reproduces the observed TFP growth rate over the 2000–2016 period[2]. These complementing scenarios are considered to investigate how a different economic recovery speed could impact food and environmental security trajectories in the next decades. The **asymmetric scenario** combines "high-growth" rates for developed regions and "baseline" rates for developing regions. And the **asymmetric-BRA-low-growth scenario** uses the same rates incorporating a different TFP growth rate only for Brazil (same from low-growth scenario). In a nutshell, these scenarios explore the importance of maintaining sustained levels of agricultural R&D expenditures in an imbalance World. In addition, the **low-growth scenario** allows us to evaluate the endogenous response of Brazilian and global agriculture to a deterioration of R&D expenditures in Brazil relative to current downward trends (e.g. "baseline") or historical high levels of TFP growth (2000–2016) over the long-run (additional information in SM).

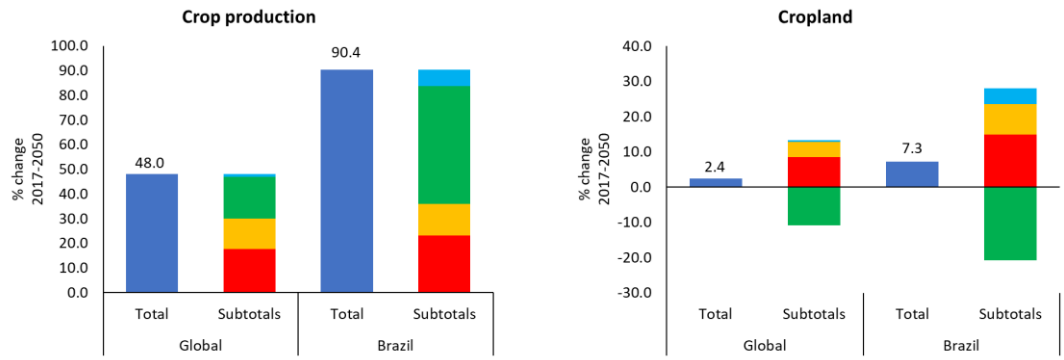
Results

Global impacts of productivity gains in Brazilian agriculture.

Over the historical validation period for SIMPLE-BR, 2000-2017, Brazilian agriculture increased its crop yields by nearly 300%. This enabled the value of production to rise by more than 300% (Fig S9 in SM) while cropland area increased by just 15%. This was less than the rate of cropland expansion in Sub-Saharan Africa, South America, Australia-New Zealand, and Southeast Asia (Fig. S9 in SM). This emphasizes the role of public R&D system supporting a science-based agricultural development as was broadly adopted in Brazil over this time period. It also reinforces the importance of continued investments in agricultural R&D to sustain agricultural productivity over the coming years[1,8].

Fig. 1 summarizes the projected impacts of TFP gains in Brazilian agriculture at global and national scales for the 2017-2050 period, under the **baseline** scenario. The higher the growth in TFP, the greater the benefits to Brazilian and global agriculture, as output and yields are increased, the need for cropland expansion is reduced. Decreasing agricultural prices make food more affordable and contribute to national and global food security

(a) (b)



(c) (d)

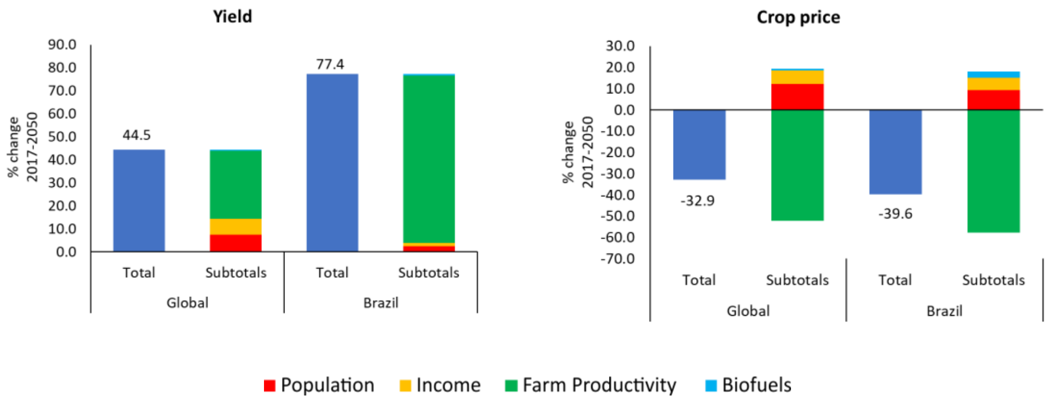


Figure 1. Global and Brazilian results for the baseline experiment (2017-2050). The panels show the cumulative per cent changes (blue bars) in crop production (a), cropland (b), yield (c), and crop price (d). The subtotal bars show the decomposition of total result factored in population, income, farm productivity, and biofuels demand.

In the **baseline** scenario, population growth is expected to slow down, with per capita income growth becoming a more dominant driver of food demand compared to the last few decades[19]. However, the sustained growth in per capita income and biofuels demand are such that global crop output is projected to increase by 48% over the projections period. Cropland area, in turn, remains relatively stable at the global level (+2.4%) and shows modest growth in Brazil (+7.3%). As shown in Fig. 1 panel (b) and (d), farm productivity is a key factor in moderating cropland expansion and food prices.

Table 1. Projected impacts of productivity gains in Brazilian agriculture on global and national scales, 2017 – 2050, alternative scenarios.

Scenarios	**Cropland**	**Crop production**	**Yield**	**Crop price**
	Global impacts, per cent change (2017-2050)			
Baseline	**2.4**	**48.0**	**44.5**	**-32.9**
Low-growth	2.8	47.5	43.5	-30.6
High-growth	-4.4	81.4	89.8	-56.6
Asymmetric	-1.5	65.5	68.0	-44.4
Asymmetric-BRA-low	-1.2	65.1	67.2	-43.2
	Per cent differences relative to baseline scenario			
Low-growth	0.4	-0.5	-1.0	2.3
High-growth	-6.8	33.4	45.3	-23.7
Asymmetric	-3.9	17.5	23.4	-11.5
Asymmetric-BRA-low	-3.6	17.1	22.6	-10.3
	Impacts in Brazil, per cent change (2017-2050)			
Baseline	**7.3**	**90.4**	**77.4**	**-39.6**

Low-growth	1.9	51.1	48.3	-31.4
High-growth	-1.3	168.5	172.1	-63.7
Asymmetric	-6.6	63.0	74.4	-46.3
Asymmetric-BRA-low	-11.0	29.8	45.9	-38.8
	Per cent differences relative to baseline scenario			
Low	-5.4	-39.3	-29.1	8.3
High	-8.6	78.1	94.6	-24.1
Asymmetric	-13.9	-27.4	-3.0	-6.7
Asymmetric-BRA-low	-18.3	-60.6	-31.5	0.8

In the **baseline** scenario Brazilian agricultural output is projected to increase 90.4% by 2050 – much higher growth rate than the global rate. An interesting feature of SIMPLE-BR is that it takes into account the key drivers of cropland expansion and intensification, and incorporates economic responses to scarcity, as emphasized by Hertel (2018)[20]. We project a 7.3% increase in Brazil's cropland, equivalent to 4.6 Mha in the whole 2017-2050 period (e.g. 140,552 ha per year), equivalent to 54% of the cropland expansion rate registered during the validation period. Its absolute value is actually small for Brazil, given its sizable cropland (and geographic) area. Furthermore, productivity gains coming from sustainable intensification approaches, such as crop-livestock systems, offer the opportunity to free up more than enough land to offset this cropland expansion.

Reis et al. (2019)[21] found that over a seven-years evaluation period, soybeans in integrated crop-livestock systems had a higher average yield (+490 kg/ha/year) compared to conventional systems (3610 kg/ha vs. 3120 kg/ha). Considering the livestock phase of those mixed systems, Martha (2021)[22] estimated that a conservative increase in stocking rates and animal performance (e.g. animal productivity in pastures), given the technology available for integrated crop-livestock systems, could easily free up 3 ha for each ha of low-productive pasture recovered. Farm productivity is, again, of paramount importance, reinforcing the pivotal role of agricultural R&D in driving sustainable food production in the coming decades.

We also expect that R&D investments, and hence productivity gains, will contribute to the downward trend in crop prices over the projected period. Therefore, foreseeing income-effects due to lower relative prices of food would boost other sectors in the economy, a welcomed outcome in a post-COVID-19 pandemic world in economic recovery.

The differences between the **low-growth** and **baseline** scenarios bring a perspective of the importance of productivity gains in a large agricultural producer and exporter country, such as

Brazil, for global (and national) agriculture. The negative impacts on world's crop output of a reduced productivity growth in Brazilian agriculture would be eventually compensated in the long run by an increase in production in other regions. Overall, global crop production would be 0.45 p.p. lower by 2050 (Table 1).

The comparison between the **low-growth** scenario (+ 43.9 M ha) and the **baseline** scenario (+ 37.6 Mha) also reveals global cropland would have to expand 0.41 p.p., an additional 6.4 Mha compared to 2017 values, due to a lower crop yield level (e.g. -1 p.p.). Conversely, with a stronger focus on agricultural R&D, cropland in 2050 is expected to be lower than in 2017: -69,7 Mha, in the **high-growth** scenario; -23,1 Mha, in the **asymmetric** scenario; and -19,4 Mha, in the **asymmetric-BRA-low-growth** scenario.

Despite endogenous production adjustments in global agriculture, a lower R&D expenditure scenario in Brazil (**low-growth** scenario), in addition to a lower output, would result in a slightly higher real crop prices relative to baseline. We project a 2.3 p.p. increase in global real crop price by 2050. Again, focusing on sustained R&D expenditures, and hence, sustained high TFP levels, is key. Real crop prices by 2050, in the **baseline** scenario, would be 23.7 p.p. higher compared to the **high-growth** scenario, which would inevitably increase economic and food security challenges, especially to the poorest and most vulnerable regions of the World.

Country impacts of productivity gains in Brazilian agriculture

Relative impacts at the country-level are of a higher magnitude than those at the global level. Output growth in Brazilian agriculture, in the **baseline** scenario, is projected to increase 90.4 p.p. by 2050 (Table 1).

Fig. 2 summarizes the decomposition of the drivers behind Brazil's farm output into the contributions (left to right) from world population, world income, world biofuels and farm productivity improvements in the rest of the world and in Brazil, respectively. World population and income are important sources of growth, but by far and away the major driver of output growth in Brazilian agriculture is projected to be farm productivity. Indeed, with solid and sustained investments in agricultural R&D, the increase in Brazilian agriculture output would amount to 168.5 p.p. by 2050. In contrast, with reduced R&D expenditure (and, hence, a low TFP growth), especially in a world asymmetric in terms of agricultural R&D expenditures (**asymmetric-BRA-low-growth** scenario), would limit the output growth in Brazilian agriculture to a relatively modest 29.8 p.p. over the next three decades. The likely reduction in output growth is largely attributable to the lower yield increase. For example, yields in Brazilian agriculture would be 29.1 p.p. lower in the **low-growth** scenario compared to the **baseline** scenario (Table 1).

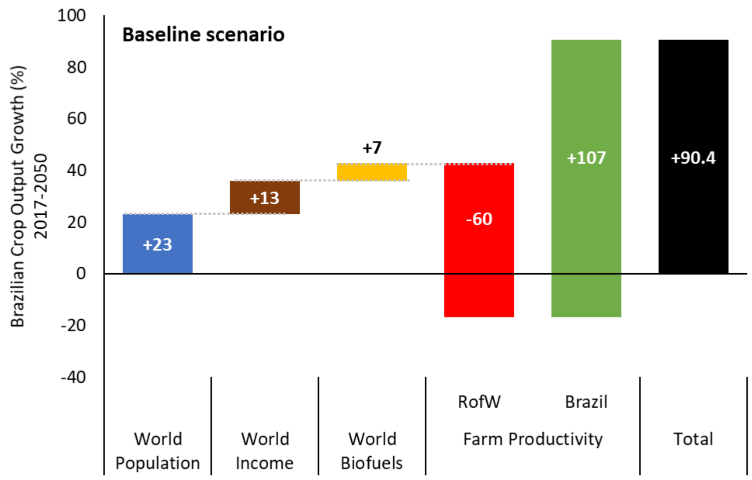


Figure 2. Sources of output growth in Brazilian agriculture in the baseline scenario (2017 – 2050). The figure shows the breakdown of output growth in Brazil by different sources, i.e., (+) by source means higher output growth whereas (-) by source means lower output growth. The net effect of all sources is 90.4%.

Overseas farm productivity in the **baseline** scenario, although large, is not sufficient to offset crop output growth in Brazil in the projected period (Fig. 2). For comparison, consider the differences between the **low-growth** scenario and the **baseline** scenario. Real crop prices to Brazilian consumers would be 8.3 p.p. higher by 2050. When the **low-growth** scenario is compared to the **high-growth** scenario, the situation is far more critical: crop prices would be 32.4 p.p. higher in the former scenario. Such an outcome would have a significant impact on Brazilian consumers, especially the poorest households, which have a higher share of their budget expenses devoted to food acquisition.

Under the **low-growth** scenario, cropland would expand 1.87 p.p. (1.2 Mha) compared to a cropland expansion of 7.3 p.p. (4.6 Mha) in the **baseline** scenario (e.g. a 5.4 p.p. difference, equivalent to -3.4 Mha). Again, a far more interesting situation would occur under the **high-growth** scenario. Cropland would be slightly reduced (-1.3 p.p. by 2050), because the sizable increase in yields (+172.1 p.p. by 2050) that is able to sustain a solid increase in output, as already mentioned.

Factoring global dependency and integration

Fig. 3 shows crop TFP effect in output growth. Negative per cent changes may be viewed as a proxy for the contribution of Brazilian agriculture (Fig. 3, upper panel) to global food security. A higher TFP growth in Brazil's agriculture alleviates the pressure for other regions in the World to increase their own agricultural output. Our results show that the cumulative effect of Brazilian TFP growth would greatly reduce agricultural pressure in South Africa (13.2 p.p.), Australia and New Zealand (12.3 p.p.), European Union (11.1 p.p.), Central America and Caribbean (13.3 p.p.) in the period 2017-2050.

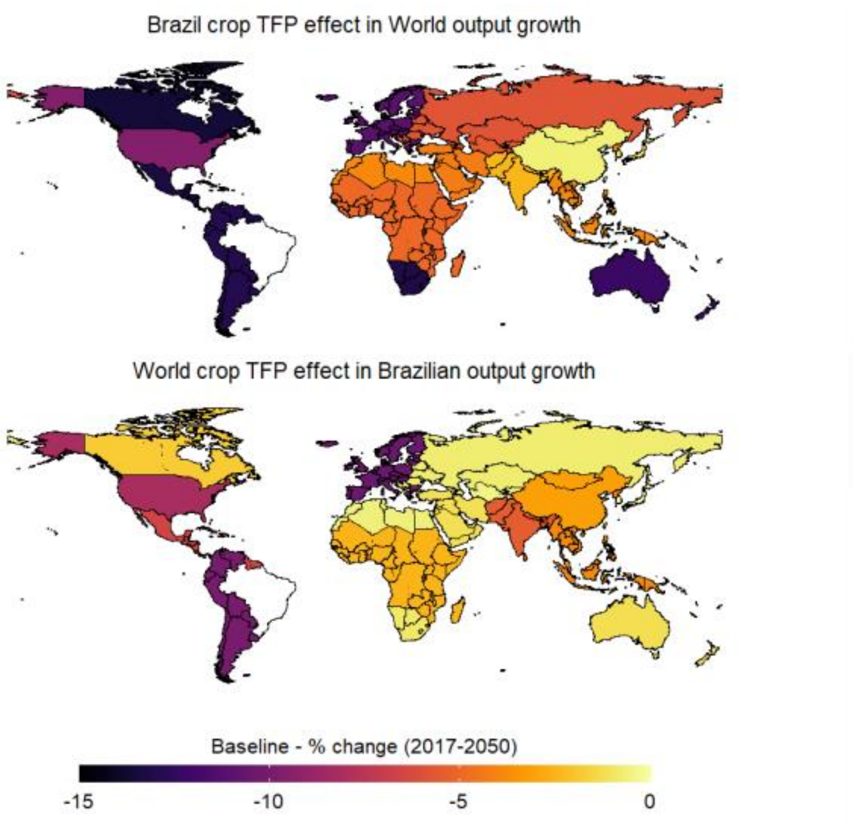


Figure 3. Crop TFP effect by region on agricultural output growth. Negative per cent changes portray the contribution of Brazilian agriculture to global food security and trade, i.e., higher TFP growth in Brazil alleviates the pressure for other regions in the World to increase their own agriculture output. Brazil is set to white since we are not considering its own effect.

Although, some of these regions/countries also have a large agricultural output, Brazil's importance emerges for other developing regions, especially those under some sort of food security vulnerability. Over the past decades Brazil has pursued a science-based approach for agriculture in the tropics and subtropics, and such knowledge and technologies have proved to be valuable to other countries in the tropical belt. Indeed, Brazil has partnered with several countries with the goal of developing a sustainable agriculture in recipient countries, helping them to improving food security for their people[1].

The **low-growth** scenario would reflect a deterioration in Brazil's ability to advance agricultural R&D, and hence to keep up with sectoral productivity in the long-run. In that situation, the country lags behind in the introduction of new knowledge and technology, slowing down the pace of innovation and farm productivity, and then loses importance in world agriculture. The contribution of crop output growth in Brazil to global crop output growth, in the 2017-2050 period, would drop from 10.8% in the **baseline** scenario to 6.2% in the **low-growth** scenario, and to only 2.6% in the **asymmetric-BRA-low-growth** scenario, reflecting asymmetries in agricultural R&D expenditures across the world.

Other regions in the World would step-in to alleviate pressures for agricultural output growth in Brazil, and the country would be dependent on global agricultural production for its food security, especially an increased agricultural supply coming from the European Union (10.5 p.p.), the United States (8.2 p.p.), and other countries in South America (10 p.p.) (Fig. 3, lower panel).

Conclusions

In this paper, we explored how Brazilian and global agriculture would be affected in the long-term given the trends in the main drivers of world farm and food systems. In our analysis we have considered different levels of agricultural TFP growth, reflecting differences in R&D expenditures. In particular, we investigated the long-term impacts of contrasting TFP growth in a large producer and exporter country like Brazil. We used the SIMPLE-BR model to assess the contribution of these drivers, as well as the global and national impacts of a deterioration in agricultural R&D expenditures over the long run.

Agricultural R&D investments have been under pressure around the world in the past years[8], a condition further aggravated by the economic and financial challenges imposed by COVID-19 pandemic. Our results highlight high levels of agricultural TFP growth, that are dependent on sustained high levels of R&D expenditures, are crucial to ensure food and environmental security in different regions of the World, especially in the most vulnerable ones.

A strong focus on agricultural R&D across the regions, represented by our high-growth scenario, delivers the greatest output and yields, avoids cropland expansion to its greatest extent, and results in the lowest real crop prices by 2050. In contrast, our baseline scenario that incorporates the recent trends of diminishing rates of agricultural R&D expenditures (and, hence, sectoral TFP growth), compared to the high-growth scenario, reveals a lower crop output (- 33.4 p.p.) by 2050, reflecting reduced yields (- 45.3 p.p.) that were only partially compensated by a cropland increase (6.8 p.p.). In the baseline scenario crop prices are 23.7 p.p. above the scenario with a strong focus on agricultural R&D. The bottom line is that even the baseline scenario is not good enough for global food and environmental security.

Agricultural R&D expenditures in Brazilian agriculture, when sustained at high levels and boosting productivity gains over the long run, are strategically important for the country and are also quite relevant from a global food and environmental security perspective. Considering an annual demand of 500 kg of corn-equivalent per person[23], the sustained investments in Brazilian agriculture, e.g. our **high-growth** scenario, would feed more than 2.5 billion people in the 2017-2050 period compared to the most restrictive condition (e.g. **asymmetric-BRA-low-growth** scenario).

Indeed, if TFP gains in Brazilian agriculture lags far behind from other key regions, reflecting a world asymmetric in terms of agricultural R&D expenditures, Brazil loses much of its importance to world agriculture in the long run. In such extreme case, other regions in the World would step-in to alleviate pressures for agricultural output growth to Brazilian consumers. A successful past history is by no means a guarantee of a prosperous future, especially when long-term maturing investments, such as the ones involved in agricultural research, are considered. Hence, the only rational choice is to nourish over the next decades the science-based approach that transformed Brazilian agriculture over the past 40 years in order to deliver a reliable food and environmental security in the 2020–2050 horizon. It is reasonable to expect that similar national and global effects would be the case if other large agricultural producer and exporter countries were analyzed. In other words, a more solid R&D effort over the next three decades, capable of sustaining global agricultural TFP levels at least similar to those observed in the recent past (2000 – 2016), is necessary and urgent.

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