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Monitoring agricultural productivity for sustainable production and R&D planning

David Laborde and Valeria Piñeiro

Abstract
Argentina's G20 presidency has emphasized the need to improve soil management and sustainably increase agricultural productivity to achieve an inclusive and resilient food future. While increased agricultural productivity can improve economic welfare and help address food security problems by benefiting both consumers and producers simultaneously, it also must address the depletion of already scarce natural resources. In the context of a changing climate, sustainable and resilient agricultural production forms a major cornerstone of both adaptation and mitigation strategies. The global community needs to have the proper tools with which to monitor sustainable agricultural productivity gains, identify countries and sectors lagging behind, and commit R&D efforts accordingly to address the challenges ahead. As such, it is suggested that 1) an international consortium should monitor agricultural total factor productivity (TFP) to provide international comparisons and track performance over time; 2) the G20 should acknowledge and address the issue of sustainable productivity measurement, and; 3) the G20 should support more in-depth research into the relationship between agricultural TFP and agricultural R&D.

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Authors
David Laborde, International Food Policy Research Institute (IFPRI)
Valeria Piñeiro, International Food Policy Research Institute (IFPRI), v.pineiro@cgiar.org

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1 The Challenge

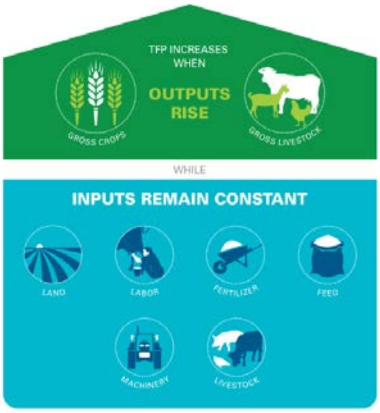
The relationship between agricultural productivity and agricultural R&D lies at the core of any long-term sustainable agricultural development strategy. Only a combination of the right set of innovations to protect soil, water, and other natural resources will deliver the increase in production needed to feed the world's ever-growing and ever-richer population while still achieving the Sustainable Development Goals (SDG).

1.1 What do we know about TFP and how do we measure it?

"Total Factor Productivity (TFP) is the portion of output not explained by the amount of inputs used in production. As such, its level is determined by how efficiently and intensely the inputs are utilized in production" Comin (2008).

In its broader sense, agricultural TFP refers to increases in agricultural output resulting from an overall increase in the efficiency of production processes, rather than from an intensification of input use.[1] TFP is the ratio of agricultural outputs (gross crop and livestock output) to the factors of production used to generate those outputs (land, labor, machinery, feed, fertilizers, and livestock; see Figure 1). As an economy-wide concept, agricultural TFP could be defined as the ratio between value added in agriculture and the factors of production used in the production process.

Figure 1: Schematic representation of Agricultural Total Factor Productivity



Source: 2015 GAP report

Since total factor productivity in agriculture is strongly influenced by policies, institutions, socio-economic forces, and environmental conditions, having a proper estimate of TFP can help policy makers, researchers, and farmers gain a better understanding of the effect of those variables on the level of production.

TFP growth is usually measured by the Solow residual. As shown in the landmark article by Robert Solow (1956), long-run growth in income per capita in an economy with an aggregate neoclassical production function must be driven by growth in TFP. However, TFP growth has also been classified as a "measure of our ignorance" (Abramovitz, 1956), since it is a residue: the part of growth we could not explain through an increase in input use.

Both institutions and technological innovations have been used to explain this residual. However, if fully captured in the value of inputs, R&D should not

[1] Partial productivity measures such as growth in labor productivity or land productivity (yields per hectare) are a misleading indicator in this respect, as an increase in these partial productivity measures can be achieved by increasing the intensity of use of other inputs (for example, crop yields can be increased by applying greater amounts of fertilizer or using more labor).

appear in the residuals except when a wedge exists between the social and private rates of return of the agricultural activity. By linking the TFP growth rate to innovation, endogenous growth models can shed light on the determinants of TFP growth (Romer, 1990; Aghion and Howitt, 1992). R&D subsidies and an abundance of skilled labor reduce the marginal cost of conducting R&D and increase the rate of innovation development and, therefore, the TFP growth rate.

There are two main approaches for measuring TFP: parametric and non-parametric (Griliches, 1996).[2] The parametric approach involves econometric modeling of production functions and estimates the relationships between total output and inputs. The residual (unexplained) output from these regressions can be used as a measure of TFP. The non-parametric approach, widely used by national statistical agencies, is a “growth accounting” measure in which output and input prices are used to aggregate quantities to form a ratio of total output to total input, which is defined as TFP (Caves et al., 1982, Diewert, 1992). Because of its strong theoretical properties (Diewert, 1976) and empirical robustness, the Törnqvist[3] appears to be the most popular method for measuring TFP.

In the context of agriculture, given that the key to sustainable growth is more efficient use of land, labor, and other inputs through technological progress, agricultural productivity estimates should include the use of environmental goods and services in agricultural production to represent the long-term sustainability of agricultural productivity growth; however, these goods and services often are excluded from traditional accounting approaches (see Figure 1).

While the topic of agricultural productivity was emphasized for the G20 Meeting of Agricultural Chief Scientists (MACS) during the Turkey G20 presidency (Fuglie et al., 2016), no significant actions have since taken place. For example, while the MACS white paper mentioned the need to extend the measure of TFP to include non-market goods and services (i.e. environmental inputs and by-product pollutants), current methodologies still do not properly account for non-marketed, or poorly marketed, factors of production, such as water and soil.

Finally, while agricultural TFP indices have been estimated for most countries, it is difficult to make cross-country comparisons. This challenge stems directly from data limitations and differences in methodologies. In Figure 2, we compare two widely used sources of TFP estimates for agriculture: ERS-USDA and IFPRI. These two approaches rely on a similar growth accounting methodology and have significant overlap regarding the data used. However, even though they appear to be positively correlated, they provide significantly different pictures for specific countries and for relative performance between pairs of countries.

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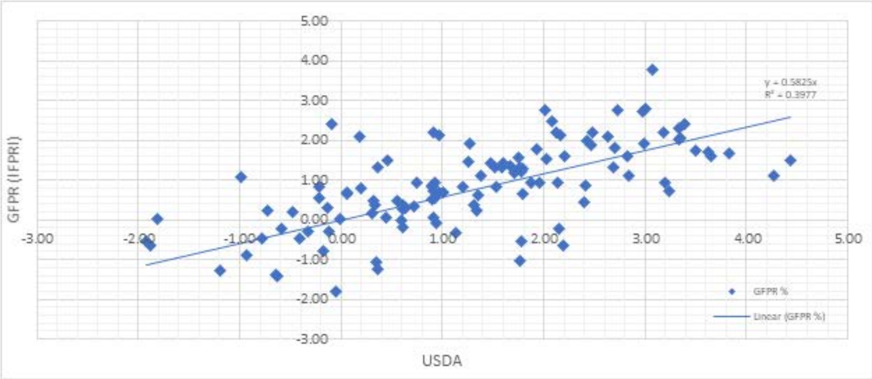
[2] Laborde (2017) proposed a mixed-approach using a multisectoral computable general equilibrium (CGE) model. It uses back-casting techniques on a set of time series, as in the accounting approach, to identify TFP drivers for various sectors of the economy, including various agricultural activities. Therefore, the parametric structure of the model and sectoral production functions are combined with the market clearing conditions from the CGE model to deduct an unobservable breakdown of factors of production across activities.

[3] The Törnqvist index makes use of logarithms for comparing two entities (e.g. two countries) or for comparing a variable pertaining to the same entity at two points in time. In the literature of productivity measurement, the index is used to compare inputs for two time periods, using an average of cost-share weights for the two periods being considered.

Figure 2: Alternative measurements of annual growth rate of TFP for the 1993–2014 period between two main sources (USDA and IFPRI)



Note: Each data point represents the annual average TFP growth rate estimated by each source of a given country

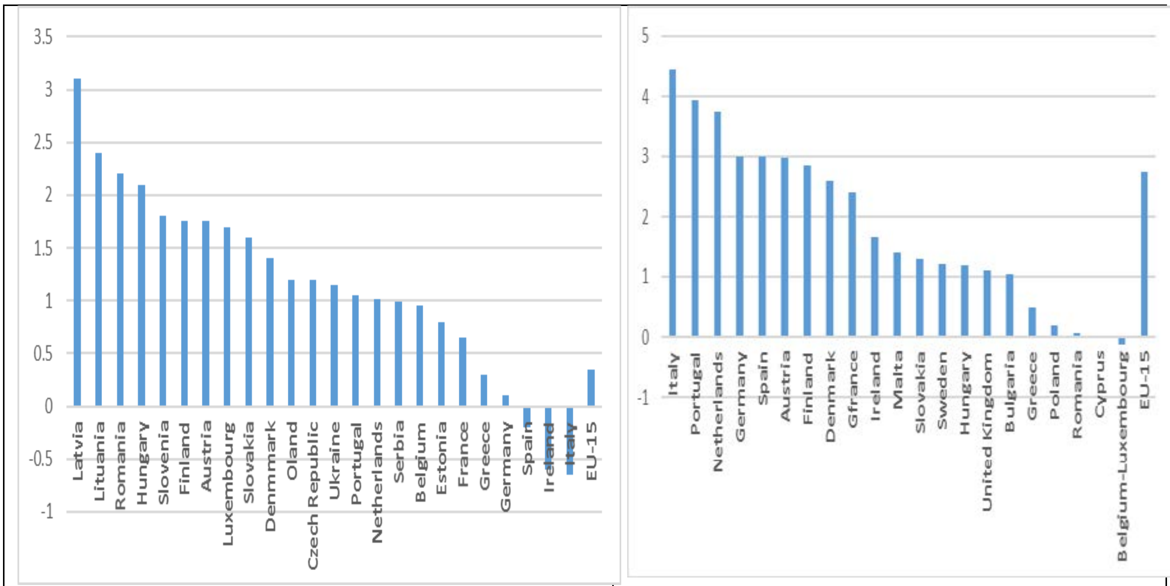
Source: Authors' computation based on USDA Agricultural total factor productivity dataset and IFPRI Global Food Policy Report (GFPR) 2018.

This methodological challenge can be also seen in Figure 3 (Matthews, 2014), which shows TFP growth in EU countries from 2001 to 2010 based on estimates from DG-AGRI and USDA. Although the two panels of this figure show the same set of countries and cover the same period, the two sources tell differing stories about agricultural productivity growth in the EU when looking at specific countries and the comparison between them. The first panel shows that new EU members have the highest TFP growth for the covered period, while the second set shows that new EU member states have a lower TFP growth than the old member states. Italy presents a particularly striking case. In the first panel, Italy appears to have experienced negative TFP growth of around 0.5 percent; however, in the second panel, Italy has the highest TFP growth rate of any country for that period (around 4.5 percent).

Both estimates use data on the growth of agricultural outputs and inputs from 2001 to 2010. These data are then weighted to form the aggregate total output and total input indices, from which TFP growth is derived as the change in the ratio over time. We posit the differences in these estimates may stem from several possible factors: differences in the volume measures for the individual outputs and inputs, differences in the weights used for aggregation, and differences in the index number methodology adopted to create the TFP index.

Clearly, there is a strong need for the measurement of sustainable agricultural productivity in a manner that is both comprehensive and comparable between countries. The issues facing global agricultural productivity are growing, and many sustainable targets have been identified at the country, G20, and global level. For agriculture in particular, a proper measurement of productivity performance would form a key metric with which to track progress toward the various sustainable goals in a consistent framework (see Appendix).

Figure 3: Agricultural TFP growth: EU countries, 2001–2010



Source: DG-AGRI. Matthews 2014.	Source: USDA estimates. Matthews 2014.

2 Proposals

2.1 What should we know? Assessing the knowledge gaps.

There are still some issues to be studied and improved related to the measurement of TFP. In this section, we list some of the major issues and challenges that require a collective response.

Agricultural TFP measurement

First, deficiencies remain in terms of proper agricultural data and data for the measurement of capital, labor, and land. While the issue of measuring capital stock and services is a common issue in growth accounting, existing solutions in the literature, which rely mainly on FAOSTAT time series on machinery inventory, face major limitations.[4] Similarly, the issue of agricultural labor, which often includes a large share of family labor or hidden employment (undeclared workers) or unemployment (people staying on farm by default), increases these methodological difficulties. In terms of land, only minor challenges need to be addressed in terms of crops (e.g. multi-cropping); however, accounting of pasture land remains more problematic. This can result in very different TFP growth figures being obtained by different institutions using similar approaches but applying different solutions.

[4] See Fuglie (2012) for a discussion of the limitations on estimates of capital stocks and services and incompleteness of information on input prices.

Second, most estimates are only available for the agricultural sector as a whole. The lack of TFP estimates for various individual agricultural products may limit our capacity to identify which crops are lagging behind in terms of productivity and require additional efforts in terms of innovation.

Third, a good productivity measure should account for differences in the quality of outputs and inputs and how that quality changes over time.[5] While the evolution of output quality is less preeminent in agriculture than in the rest of the economy (but still not totally absent – e.g. fortified varieties, animal welfare, etc.), the evolution of input qualities (seeds, pesticides, fertilizers, and human capital), and how much of that quality change is captured by the change in price, is an important issue, especially if we want to properly study the contribution of R&D.

International comparisons and benchmarks

As a direct consequence of both data limitations and differences in methodologies, while agricultural TFP indices have been estimated for most countries, it is difficult to make cross-country comparisons.

As discussed previously, even when comparing two approaches (ESR-USDA and IFPRI6) that rely on a similar growth accounting methodology and that have significant data overlap, we obtain significantly different pictures for specific countries and for relative performance between pairwise of countries. This raises a very important concern: some sources may provide a too optimistic situation regarding recent trends in agricultural productivity and may lead to a serious underestimation of the need for sustained efforts and investments, in particular in R&D.

Toward a Green TFP measurement for agriculture

The limitations of traditional economic growth measurement were raised as early as 1972 by Nordhaus and Tobin in their improved measure of Economic Welfare (MEW), which was adjusted to consider environmental damages. These authors introduced the notion of sustainable MEW (MEW-S) into their model. Despite this improvement, however, the incorporation of natural resource use with limited market representation on the input side and of the value of production net of environmental damages on the output side continue to face various political and analytical challenges.

After 18 years of technical work, the UN Statistical Commission's 2012 adoption of the System of Integrated Environmental and Economic Accounting offered new opportunities. While some challenges remain (see Obst (2015) for a discussion), promising ongoing work has incorporated the concept of sustainability in TFP measurement. This move toward a *Green* TFP, or Total Resource Productivity (TRP), could help close a major gap in existing metrics of TRP in the coming years, as discussed in the 2016 MACS white paper.

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[5] There have been two approaches to tackle this issue in the literature. One approach accounts for differences in quality by disaggregating the measure into finer and finer units (Ball et al. 2015). The second approach determines how the price of input relates to input characteristics (Ball et al., 2010).

[6] USDA Agricultural total factor productivity dataset and IFPRI Global Food Policy Report (GFPR) 2018. Materials available on demand.

Improving Agricultural TFP through proper R&D investments: Quantifying the linkages

Both at an economy-wide level and in agriculture specifically, there is large consensus regarding the key role of R&D as an engine for long-term sustainable productivity growth. However, quantitative evidence regarding the intensity of this linkage are still limited. Thus, improved information on this mechanism, either in terms of crops or geographical regions, is needed for mobilizing and directing the necessary investments at national and international levels.

To get a better understanding of the relationship between R&D and productivity growth, we must first discuss two methodological challenges. First, due to the problems surrounding the measurement of agricultural TFP discussed previously – proper agricultural data, aggregation issues and input quality changes overtime –, there is inherent difficulty in understanding how R&D efforts (the explanatory variable) impact agricultural TFP. Addressing previous issues raised regarding TFP and sustainable TFP will significantly strengthen the case for improved understanding of the role of public R&D.[7] Second, the problems that arise with the way the stock of knowledge is measured in existing literature.[8]

These methodological weaknesses may strongly underestimate the positive contribution of agricultural R&D to productivity and, combined with other challenges, may limit policy makers' ability to make informed decisions regarding the right amount of resources to allocate to R&D.

2.2 Outstanding issues for the G20

In summary, since the Turkey G20 presidency when G20 MACS looked at the issue of agricultural productivity, the challenges faced in measuring agricultural productivity have remained generally the same.

First, the WORLD KLEMS initiative[9] does not have enough information on the agricultural sector, as it uses only one aggregate estimate for the whole agricultural sector (agriculture, hunting, forestry, and fishing) and does not consider land as a factor of production. In addition, to date, Saudi Arabia, Indonesia, and Turkey (all G20 countries) are still not covered by the World KLEMS dataset.

[7] We can argue that proper accounting for quality and price effects in terms of marketed inputs while doing TFP accounting can properly capture the role of private R&D. However, public R&D contribution requires additional treatment and analysis.

[8] Using lagged flows of expenditures without doing a true perpetual inventory and mixing two separate problems: adoption delays and knowledge depreciation using small weights for early years and for the most recent periods. Using one distribution to mimic two different behavioral issues has clear limitations from a structural point of view and policy recommendations. It also implies that analysts using this method, assume a complete decay of some innovation over time. For instance, the lag assumptions made in most of the literature lead to the implicit conclusion that Dr. Norman Borlaug's work on semi-dwarf wheat varieties have no impact on existing stock of knowledge, and therefore productivity.

[9] The World KLEMS initiative was established to promote and facilitate the analysis of growth and productivity patterns around the world, based on a growth accounting framework. See the G20 MACS report (p.15) for a longer introduction to the project, or visit their website at http://www.worldklems.net/.

Second, the previously described data and methodological issues have led to various and heterogeneous rankings across countries (including among G20 members) and periods. This has created significant noise regarding analytical conclusions and policy recommendations. As shown in our earlier example (Matthews, 2014), although both the USDA and EC DG AGRI used similar approaches and data to calculate the EU's TFP growth figures between 2001 and 2010, their results differ in terms of both magnitude and country ranking.[10]

Third, researchers and policy makers have made little systematic efforts to improve the data and technical specifications used to calculate TFP for agriculture, especially in terms of controlling for environmental impacts. In addition, few efforts have been made to assess TFP for sub-sets of crops and or livestock products.

Proposal 1. We propose that the G20 mandates a global consortium of international organizations and national statistical and agricultural research institutions to systematically monitor Agricultural Total Factor Productivity in order to provide international comparisons and track performance over time. This initiative could be inspired by the World KLEMS project and the Ag-Incentives Consortium.[11] It will have a high level of complementarity with the AMIS inter-agency platform, initiated by the G20 Ministers of Agriculture following the agricultural price hikes of the last decade. While AMIS provide valuable information for short-run fluctuations and drivers of world agricultural markets, monitoring sustainable agricultural productivity is needed to track long-term price dynamics.

Proposal 2. Given the irreversibility of the depletion and degradation of natural resources caused by some agricultural activities, it is important to go beyond a standard measurement of productivity (Proposal 1). The issue of sustainable productivity measurement should be acknowledged by the G20 countries and integrated into their monitoring mechanisms, as discussed in the G20 Macs white paper "*Metrics of Sustainable Agricultural Productivity*". Such a commitment will fully support the goal of Argentina's G20 presidency for improving soils and increasing agricultural productivity, both key drivers in achieving a sustainable food future. Using the G20 umbrella,[12] significant synergies (data and methodologies) can be generated with new initiatives addressing soil quality monitoring and sustainable soil management, as well as sustainable agricultural productivity measurement.

Proposal 3. In order to reaffirm the need for investments in agricultural R&D and promotion of international cooperation to guarantee benefits for less advanced economies, the

[10] The differences can be the result of discrepancies in measurement of the variables involved, the volume of the individual inputs and outputs and the weights used for aggregation. The USDA figures are based on FAOSTAT while the DG AGRI are from the Eurostat EAA accounts. Having the latter one a bigger disaggregation (or granularity) particularly for the input use.

[11] While maintaining the autonomy and ensuring the consistency of each International Organization's role with its mandate, the Ag-incentives Consortium (FAO, IDB, IFPRI, OECD, World Bank) organizes further collaboration among IOs to provide a database of well-documented common indicators on agricultural policy monitoring, facilitates the expansion of country and product coverage and to provide a forum for tackling new issues and improving methodologies.

[12] While the priority should focus on primary production sustainable productivity measurement to address the most urgent data gaps, the framework proposed here could be expanded to address the more holistic G20 agenda and provide metrics for the sustainable productivity of the food system, that will capture the effects of the losses and waste along the value chain measurements.

G20 should instruct the MACS to coordinate a white paper on the relationship between Agricultural TFP and Agricultural R&D to promote a research agenda on this issue.

2.3 Final comments

A proper measure of TFP will help us to understand and link the actions and investments that have a positive impact on agricultural TFP. This measurement will allow us to avoid a too optimistic scenario based on recent trends in agricultural productivity, which may lead to a serious underestimation of the need for sustained efforts and investments, in particular in R&D. In addition, it will allow us to identify countries and regions that are lagging behind and that will need special attention from the international community.

We need to go beyond a standard measurement of productivity in order to understand the technologies and policies needed to ensure that productivity is not gained through the sacrifice of natural resources. This understanding is a major element in designing strategies and policies for sustainable development in agriculture.

The global community needs to have the proper tools to monitor sustainable agricultural productivity gains to be able to face the challenges ahead.

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Appendix: Agricultural TFP and SDGs

Table 1: Agricultural TFP and SDGs

Sustainable Development Goals		*Specific Targets (simplified)*	*Relevance of tracking sustainable agricultural TFP*
	SDG2 End hunger, achieve food security and improved nutrition and promote sustainable agriculture	2.3 on doubling the agricultural productivity of smallholders, and 2.4 on ensuring sustainable food production	*Monitoring and improving sustainable agricultural productivity is explicitly linked to achieve SDG2.*
	SDG 6 Ensure availability and sustainable management of water and sanitation for all	6.4 regarding the water efficiency across all sectors	*Adjusting the TFP methodology to track the water use contributes to provide a proper metric for agriculture efficiency.*
	SDG 8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	8.1 on sustain per capita economic growth, 8.2 on higher level of productivity through diversification, and 8.4 in improving global resource efficiency and endeavor to decouple economic growth from environmental degradation	*Sustainable TFP gains in agriculture has to be an important component of the income growth strategy and the income diversification opportunities. Environmental considerations have to fully included in TFP accounting.*
	SDG 10 Reduce inequality within and among countries	10.1 on achieving and sustaining income growth of the bottom 40 per cent of the population	*Agriculture remains an important source of income for the lower income segment of the population.*
	SDG 12 Ensure sustainable consumption and production patterns	12.1 on sustainable consumption and production, and 12.2 on achieving the sustainable management and efficient use of natural resources	*Monitoring and improving sustainable agricultural productivity is explicitly linked to achieve SDG12.*
	SDG 13 Take urgent action to combat climate change and its impacts	13.1 on strengthening resilience and adaptive capacity to climate-related hazards	*Climate change contributes to an important slowdown in TFP trend.*
	SDG 15 Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	On ensuring the conservation and sustainable use of freshwater (15.1) and forest (15.2) ecosystems and their services.	*Adjusting the TFP methodology to take into consideration ecosystem services as inputs, and potential damages done to them for output valuation.*

Source: Authors' compilation.

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