INTERNATIONAL
FOOD POLICY
RESEARCH
INSTITUTE

IFPRI

IFPRI Discussion Paper 02245

March 2024

Farm Subsidies and Global Agricultural Productivity

Abdullah Mamun

Markets, Trade, and Institutions (MTI) Unit

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

The International Food Policy Research Institute (IFPRI), established in 1975, provides research-based policy solutions to sustainably reduce poverty and end hunger and malnutrition. IFPRI's strategic research aims to foster a climate-resilient and sustainable food supply; promote healthy diets and nutrition for all; build inclusive and efficient markets, trade systems, and food industries; transform agricultural and rural economies; and strengthen institutions and governance. Gender is integrated in all the Institute's work. Partnerships, communications, capacity strengthening, and data and knowledge management are essential components to translate IFPRI's research from action to impact. The Institute's regional and country programs play a critical role in responding to demand for food policy research and in delivering holistic support for country-led development. IFPRI collaborates with partners around the world.

AUTHORS

Abdullah Mamun (A.Mamun@cgiar.org) is a senior research analyst in the Markets, Trade, and Institutions (MTI) Unit of the International Food Policy Research Institute (IFPRI), Washington, DC, USA.

Notices

[1] IFPRI Discussion Papers contain preliminary material and research results and are circulated in order to stimulate discussion and critical comment. They have not been subject to a formal external review via IFPRI's Publications Review Committee. Any opinions stated herein are those of the author(s) and are not necessarily representative of or endorsed by IFPRI.

[2] The boundaries and names shown and the designations used on the map(s) herein do not imply official endorsement or acceptance by the International Food Policy Research Institute (IFPRI) or its partners and contributors.

CONTENTS

TABLES

FIGURES

ABSTRACT

The agriculture sector receives substantial fiscal subsidies in various forms, including through programs that are linked to production and others that are decoupled. As the sector has reached the technology frontier in production over the last three decades or so, particularly in high- and middle-income countries, it is intriguing to investigate the impact of subsidies on productivity at aggregate level. This study examines the impact of subsidies on productivity growth in agriculture globally using a long time series on the nominal rate of assistance for 42 countries that covers over 80 percent of agricultural production. The econometric results show heterogenous effects from various subsidy instruments depending on the choice of productivity measure. Regression results suggest a strong positive effect of input subsidies on both output growth and labor productivity. A positive but relatively small impact of output subsidies is found on output growth only. Subsidies that are mostly decoupled reveal no significant impact on any of the productivity measures.

ACKNOWLEDGMENTS

This article was written as part of my PhD work on the Role of Farm Support Policies in Agricultural Productivity. The paper was prepared with funding from the Rethinking Food Markets (RFM), a CGIAR initiative. The author is grateful to Antoine Bouët, Director, CEPI, France; David Laborde, Director, ESA, FAO; Keith Fuglie, Economist, ERS, USDA; Rob Vos, Director, Market, Trade, and Institutions (MTI), IFPRI; Will Martin, Senior Research Fellow, IFPRI; and to the participants at an IFPRI policy seminar (3 November 2022) for helpful comments on earlier versions of this study.

1. INTRODUCTION

Global agricultural production has grown manyfold with the development of improved genetic varieties of crops and livestock. The average annual growth rate in agriculture was 2–3 percent during the period 1961–2019 (Fuglie et al., 2021). Developing countries are now catching up with developed countries in agricultural growth, largely driven by productivity growth in Southeast Asia, China, and Latin America (Fuglie, Wang and Ball 2012; Martin, 2019). Over the last 60 years, countries across the world spent substantially on agricultural research and development (R&D) and provided subsidies to producers in various forms. Do subsidies have any role in the convergence process of agricultural growth? Both the theoretical and empirical literature addressing this question report heterogenous findings (Minviel and Latruffe, 2017; Ciaian and Swinnen, 2009; Hennessy, 1998; Garrone et al., 2019). Notably, many of these studies examine the agriculture sector of specific economies, such as the European Union (EU) or the United States, so less is known about the link between productivity and agricultural supports at a global level. This study investigates the role of farm support in global agricultural productivity.

Support for food and agriculture is widespread, with US$700 billion per year going to producers in the period 2013–2018 (FAO et al., 2022). About 70 percent of this support goes to farmers through trade and market policies and fiscal subsidies that are largely tied to production and inputs, according to the UN Food and Agriculture Organization (FAO). A large share goes to staple foods, dairy, and other protein-rich foods. Given that governments spend taxpayers' money to support farmers, it is important to understand which policy instruments are effective in increasing productivity and which are not.

Agricultural support policies have evolved over the past 50 years or so and have played an important role in stabilizing farm incomes. Farm support policies influence farmers' decisions on land allocation, borrowing, and expansion of farming activities. Subsidies and price support may also impact the technical efficiency of farming by providing incentives for increased productivity, though the empirical evidence is inconclusive (Kumbhakar and Lien, 2010; Zhu and Oude Lansink, 2010). Several studies find that overinvestment in subsidized inputs or in relatively less productive activities and adoption of cost-optimizing farming can reduce productivity (Alston and James, 2002).

Other studies investigate the link between subsidies and productivity with reference to market imperfections (Gardner, 2005; Ciaian and Swinnen, 2009; Rizov, 2005; Garrone et al., 2019). These studies argue that with imperfect markets and information asymmetry, subsidies can help farmers overcome credit constraints and mitigate risks, which will affect their decision to invest in certain inputs. This channel of influence can thus trigger productivity growth. Garrone et al. (2019) studied the European Union's Common Agricultural Policy (CAP) using a conditional convergence model for 213 regions of the EU-27. Their study found that subsidies have increased productivity but have had heterogenous effects depending on the types of subsidies considered.

Farm policies have undergone reforms over the past three decades, particularly in large economies, which shifted from input and output subsidies toward decoupled payments to farmers, which are often regarded as less distorting. Linking production efficiency and subsidy type is an important consideration for designing farm policy in the face of climate change. Recent studies on farm policy instruments and greenhouse gas emissions shed light on the impact of producer support and transfer efficiency (Laborde et al., 2021; Gautam et al., 2022).

It is important to understand the current policy mix of farm subsidies and their impact on productivity growth, environment, and farm resilience. As most studies only focus on regional or country-level productivity analysis, a gap exists in the understanding of the role of farm subsidies on productivity at a global level. To this end, this paper uses (1) improved data on subsidies and nominal protection rates covering six decades (since 1961) provided by Laborde and Mamun (2022), and (2) productivity data from the U.S. Department of Agriculture's Economic Research Service (ERS), which covers 182 countries from 1961 onward.

The paper follows an estimation approach implemented in Garrone et al. (2019), who use a conditional β-convergence model in a dynamic panel data framework to estimate the relationship between subsidies and labor productivity growth in the EU. Their model relies on the neoclassical growth model (Solow, 1956) and includes a set of covariates. Along with arguments put forward in other studies (Garrone et al., 2019; Rizov, 2005; Rizov et al., 2013), the study tests convergence in productivity at the global level based on a larger set of subsidy instruments and wide coverage of data.

This paper contributes to the literature on the subsidy-agricultural productivity link by extending the convergence growth model to a global dataset. The current literature covers either large economies—such as the United States, Australia, and Norway—or economic blocs—such as the EU or the countries in transition in Europe. Also, prior studies analyzed either total or partial productivity measures, many relying on limited datasets available on farm subsidies, specific to countries or regions, and covering short time series (Rizov, 2005; Rizov et al., 2013; Haque et al., 2019; Zhu and Oude Lansink, 2010; Mary, 2013; Cuerva, 2011; Garrone et al., 2019). This study models the agricultural growth of 42 developed and developing countries (the EU is treated as one region) from 1991 to 2018. The total value of farm support (subsidies only) analyzed in this study amounts to US$242 billion per year. The subsidy policies used as explanatory variables in the model include output subsidies, input subsidies, factors of payment, and subsidies decoupled from production. Therefore, this study is a significant addition to the current literature as it examines subsidy-productivity (both total and partial measures) links for a large number of countries, with a longer time series, and covering all subsidy policies.

Findings from the econometric models indicate the existence of conditional or β-convergence in agricultural growth. The speed of convergence ranges from less than 1.0 percent to 5.6 percent, which is low compared to that observed by Garrone et al. (2019). Regression coefficients suggest a heterogeneous effect of subsidies on agricultural productivity. The results reveal the high positive impact of input subsidies on both agricultural output growth and labor productivity. The impact of input subsidies is more pronounced in labor productivity. On the other hand, output and “other” subsidies have a positive but low impact on both growth indicators.

Section 2 presents a review of the literature on the subsidy-productivity link. Sections 3 and 4 provide stylized facts on agricultural productivity, its trend and evolution, and an overview of farm support policies. Section 5 considers the theoretical arguments for an impact analysis of farm support and describes the estimation approach. Section 6 discusses the data and variables. Section 7 contains the results while Section 8 offers conclusions.

2. SUBSIDIES AND AGRICULTURAL PRODUCTIVITY: RELATED LITERATURE

Evaluation of the effectiveness and distributional impacts of agricultural policies requires consideration of a wide range of issues, including design and implementation of policies, coverage of farmers and commodities, and type of policies and their reach, among others. Economists frame this question in terms of whether domestic subsidies and trade policies have any impact on production by causing allocative and technical efficiency.

Important theoretical works that explain the negative impact of subsidies on technical efficiency and hence productivity in agriculture include Leibenstein (1966), Alston and James (2002), and Rizov et al. (2013). The key argument for the negative impact is that farmers may not choose input-cost optimizing behavior in production activities due to the influence of subsidy programs. Other researchers argue that subsidies have production- and productivity-enhancing impacts because they mitigate market imperfections and credit constraints (Hennessy, 1998; Blancard et al., 2006; Roche and McQuinn, 2004; Ciaian and Swinnen, 2009).

In the stochastic world of agriculture, farmers face uncertainty in both production and price, and risk aversion behavior is prevalent. Hennessy (1998) introduces farmers' risk preferences into an economic model and provides a theoretical argument for the heterogenous effect of income support programs provided through domestic subsidies. In the presence of uncertainty and imperfect insurance markets, farmers' risk behavior can be altered when they are supported by subsidies, he argues, and thus can have three different effects: wealth, insurance, and coupling. Roche and McQuinn (2004) present a similar theoretical and analytical approach, examining the impact of the 2003 EU CAP reform. They show that farmers tend to allocate more land to riskier products as a response to decoupled payments due to their increased appetite for risk.

The traditional view on supply response to subsidies suggests the possibility of overuse of factor inputs in production always exists, which ultimately leads to misallocation of resources (Alston and James, 2002). Researchers suggest understanding farmers' supply response when investigating the role of subsidies in productivity. They also argue that their intended outcome may not be achieved, as farmers may opt for less productive activities, and thus some distortion may occur. Increased output can be achieved by input intensification that is supported by subsidies, and hence subsidies can have a production effect but not a productivity effect, as Alston and James explain.

Several studies point to farm behavior related to cost minimization with and without income support programs (Leibenstein, 1966; Minviel and Latruffe, 2017). In subsidized sectors, producers may not operate on an outer-bound production possibility frontier when they receive any form of payments that allow them to make up the difference between the cost they incur and the market price (Leibenstein, 1966). This then leads to technical inefficiency that hurts productivity.

Market imperfections are cited as one reason why producers may not optimize inputs and factors in agricultural production (Ciaian and Swinnen, 2009; Ciaian and Kancs, 2012). Consider rural factor markets where constraints on buying capital goods, accessing credit from banks or accessing land can hinder achieving potential productivity. Ciaian and Kancs (2012) note land constraints in many economies due to market imperfections, and farmers lack capacity to attain desired productivity. Credit markets are another bottleneck, forcing farmers to choose suboptimal levels of capital, land, and labor, as Ciaian and Swinnen (2009) illustrate. Programs such as decoupled payments based on area harvested historically can remove these financial constraints and increase farmers' land rents. As a result, their paper argues, decoupled subsidies are likely to aid farmers in using credit and make them risk neutral.

Empirical evidence on the link between productivity growth and subsidies is ambiguous. Some studies find a negative impact or no significant impact (Rizov et al., 2013; Latruffe and Desjeux, 2016; Haque et al., 2019; Mary, 2013; Zhu and Oude Lansink, 2010; Zhu and Milán Demeter, 2012), while several others find a positive and significant effect on productivity (Kazukauskas, Newman, and Sauer, 2014; Garrone et al., 2019).

Rizov et al. (2013) investigate the impact of subsidies under the CAP in EU countries (EU-15) and compare results for two periods: before the reform in 2003 and after the reform, when most subsidies were decoupled from production. Their study, based on a structural model of unobserved total factor productivity (TFP), employs a semiparametric estimation approach to the farm-level data. They adopt a novel idea of generating aggregate farm productivity that directly incorporates the effects of subsidies into the model of unobserved productivity (TFP). This paper finds a negative correlation between subsidies and TFP when subsidies are coupled with production.

Several important studies examine subsidies and productivity growth in agriculture using a neoclassical economic growth framework and test for conditional convergence of productivity in an economic bloc (Gardner, 2005; Cuerva, 2011, 2012; Rizov, 2005; Garrone et al., 2019). These studies present a framework of analysis for examining the impact of subsidy instruments on productivity in the presence of other economic covariates. Inclusion of relevant instrumental variables in econometric estimation avoids the problem of not having theoretical and objective selection criteria for explanatory variables. In one of the initial studies of this kind, Rizov (2005) examines the agriculture sector of transition economies in Europe and investigates if economic as well as farm structures have an important role in productivity convergence. Though Rizov's model does not include public subsidy variables, it does provide a basis for evaluation of domestic policies.

Gardner (2005) provides an excellent early convergence study on the factors affecting agriculture sector growth, raising an important discussion on the topic. In his econometric estimation, growth is modeled on the initial level of agricultural GDP per worker along with several control variables, such as fertilizer and tractors per hectare, illiteracy rate, agricultural research spending, political economy variables, trade in goods (as a percent of GDP), and the producer support estimate (PSE). A regression model focusing only on 27 OECD countries reveals conditional convergence in agricultural growth and finds a positive impact of subsidies in agriculture. As this study estimates a simple ordinary least squares (OLS) model, with data limited to OECD countries, it does not properly address endogeneity. Moreover, it uses a gross estimate of farm support (PSE), which is problematic in that it includes both price support and subsidies. Thus, it cannot be concluded that subsidies are effective in raising productivity.

Garrone et al. (2019) further advances the study of productivity convergence, introducing more robust economic variables such as employment in agriculture, investment, share of large farms, GDP growth, population density, and the grassland ratio. Moreover, their econometric estimation methods, such as the general method of moments (GMM) estimation technique, avoid overestimation of coefficients. They conclude that, on average, CAP subsidies increase agricultural labor productivity. They also find that the effects are not uniform across policy instruments and show that coupled subsidies have a negative effect, while decoupled subsidies have a positive effect, somewhat similar to findings in Rizov et al. (2013), who tested the impact of subsidies on TFP.

Minviel and Latruffe (2017) conduct a meta-analysis of empirical studies on subsidies and technical efficiency. Their analysis reveals mixed results: subsidies are commonly negatively associated with agricultural productivity, but some studies show a positive impact. The results are sensitive to the way subsidies are modeled. The authors suggest that investigating the effect of subsidies on farms' technical efficiency should rely on careful selection of subsidy instruments, and when possible, sensitivity analyses should be carried out.

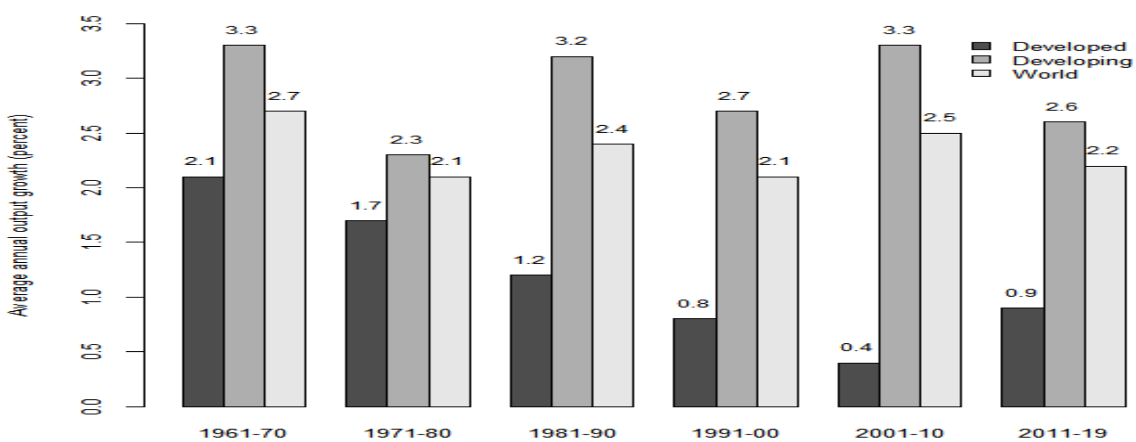
This review of both the theoretical and empirical literature on the role of subsidies on productivity suggests that empirical investigation is merited on the grounds of economic integration and technological innovation in various regions of the world. No study has yet evaluated the impact of subsidies at the global level. Now that data on various types of subsidies is available for 62 countries and 1 region (EU) that cover 90 percent of global agricultural production, it is possible to test productivity convergence (conditional), with subsidies and their types as key explanatory variables.

3. AGRICULTURAL PRODUCTIVITY

Over the past half century or more, the world has seen tremendous growth in agriculture, thanks largely to the Green Revolution in wheat, maize, rice, and other staples. Prices fell until 2010 because of rising food production, although the trend in food prices has been increasing recently (Fuglie et al., 2021). Agricultural production experienced growth in TFP from 1961 to 2019. During the same period, the growth rate of inputs steadily declined. This section reviews the source of this productivity growth, convergence, and location.

Developing countries led output growth over the entire period of 1961–2019 (Figure 1). Though the growth rate for the developing world began slowing in the last decade (2010–2019) compared to the previous decade, output growth remains 1.3 percentage points faster than in developed countries. However, an upward trend in the growth of agricultural production also exists in developed countries. In developing countries, agriculture employs a large population, but mechanization still has not occurred at the same pace as seen in developed countries. Developing countries' output growth of over 3 percent in most decades was due to expanding input use, rather than mechanization. Countries such as China, Brazil, and India, and parts of Southeast Asia have advanced rapidly in agricultural production since the 1990s because of expanded use of inputs and mechanization.

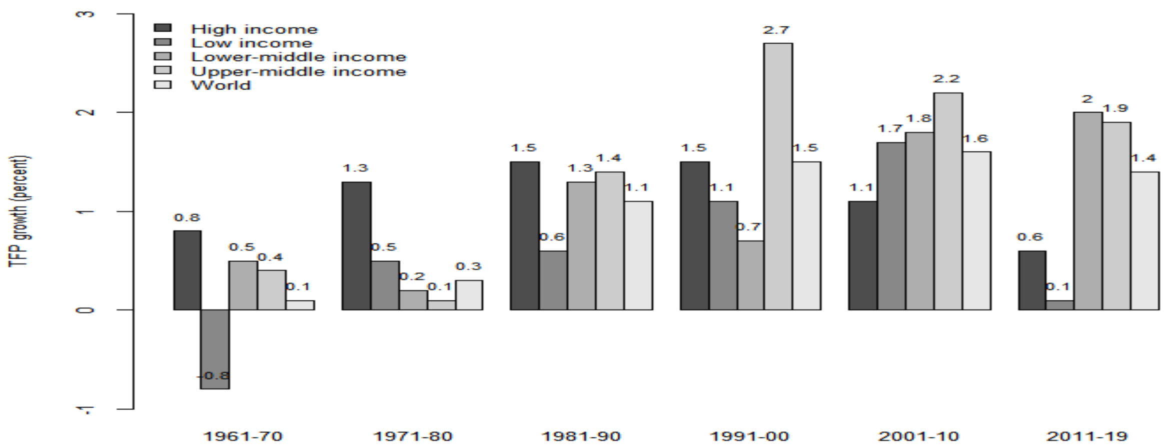
Figure 1: Trends in agricultural output growth by income group, 1961–2019



Source: Author's calculations. Data are from USDA, Economic Research Service (ERS) International Agricultural Productivity data product.

TFP reflects the productivity of all factors combined—land, labor, capital, and materials input. In the decomposition of agricultural growth, TFP accounts for the largest share, followed by input intensification, irrigation, and area expansion. Robust TFP growth is observed in high-income countries, at about 1 percentage point up until 2010 (Figure 2). However, the TFP growth rate has slowed since then: average TFP growth fell from 1.1 percent in the period 2001–2010 to 0.6 percent in 2010–2019. TFP growth in developing countries is largely dominated by lower- and upper-middle-income countries, specifically China and Brazil, and those in Southeast Asia, North Africa, and Latin America.

Figure 2: TFP growth by income group, 1961–2019

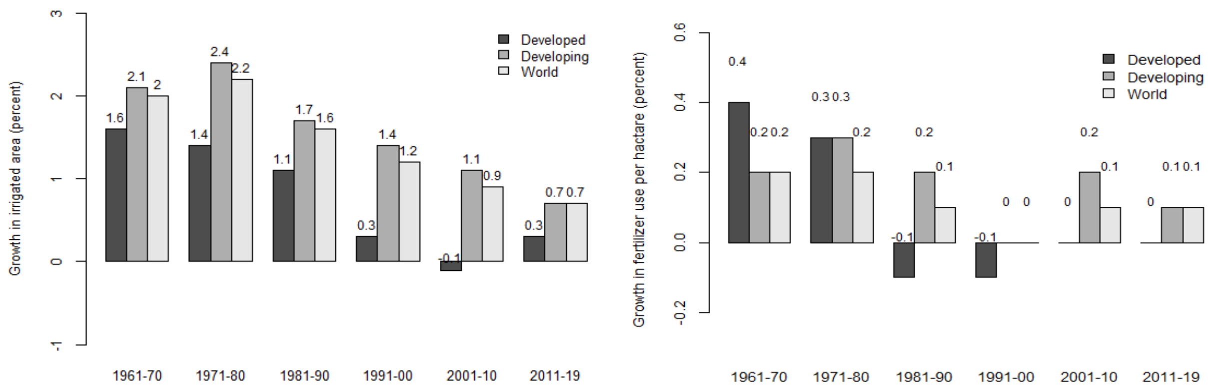


Source: Author's calculations. Data are from USDA, Economic Research Service (ERS) International Agricultural Productivity data product.

High TFP growth in developed and developing countries comes with less input growth. Among inputs, irrigation and fertilizer are seen as the key drivers of input-led growth, particularly in 1970s and 1980s. From the 1970s to 1990s, developing countries invested heavily in irrigation to ensure food security for growing populations.

High TFP growth in developed and developing countries comes with less input. Among the multi-inputs, irrigation and fertilizer uses are seen as the key drivers of input led growth, particularly in the 70s and 80s. With the invention of improved varieties of crops, intensity in fertilizer use receded since 80s (right panel in Figure 3). Green revolution has been coined with expansion of irrigation as the world saw huge growth in irrigated area for cultivation (left panel of Figure 3). From the 70s to 90s, the developing countries were seen to go for investing hugely in irrigation as the countries in this income group tried to ensure food security amid rising population. In the later periods, during the decades of 2000 and 2010, growth in irrigated area and fertilizer use declined.

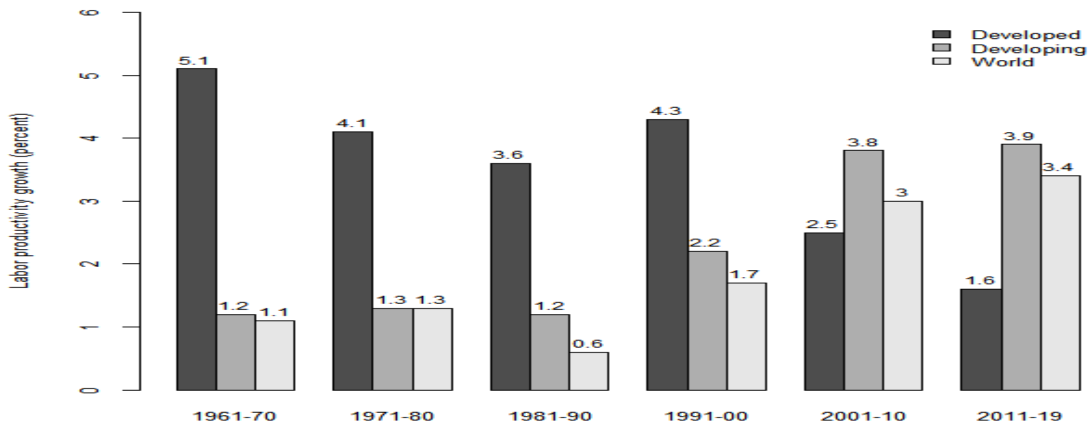
Figure 3: Growth in irrigated area and fertilizer use per hectare, 1961-2019



Source: Author's calculations. Data is from USDA, Economic Research Service (ERS) International Agricultural Productivity data product.

Shifting from multi-input productivity measure to single input allows researchers to investigate the depth of input intensification. In the graph below we plot average labor productivity by developed and developing region. Notably, developing regions have been able to ramp up labor productivity to the level obtained by the developed regions in 70s or 80s, as Figure 4 suggests. The world's average labor productivity (output volume per worker) growth shows between 2 to 3 percent during the 1990 to 2019 period. It is the developed region that shrank in output per worker from as high as 4.3 percent in the 90s to 3.9 percent in the last decade.

Figure 4: Labor productivity (output per worker) growth, by income group, 1961-2019



Source: Author's calculations. Data is from USDA, Economic Research Service (ERS) International Agricultural Productivity data product.

The world's agricultural productivity growth rate remains as high as 2.3 percent per year. There is growing evidence that the gap between developed and developing countries is shrinking. It is thus imperative to investigate the role of government policy supports in productivity. As climate change is already impacting agricultural activities in different countries, the farmers face growing uncertainty in production and price. Numerous studies are pointing to how best we repurpose agricultural support and where to invest more so that we achieve resilient and climate smart agriculture (Laborde et al, 2021; Gautam et al, 2022; FAO, UNDP & UNEP, 2021).

4. FARM SUPPORT IN AGRICULTURE

Farm support in agriculture also evolved over the past 50 years, from production-tied or commodity output-based support to payments based on unconstrained input use or payments based on factors of production as well as other subsidies decoupled from production. Among the various policy instruments, the most distorting ones are those that severely affect market prices, often imposed through trade and market interventions, such as import barriers (tariff and nontariff), export subsidies, and taxes. According to AgIncentives data (2021), a total of 58 countries[1] provided US$453 billion per year (net) during 2014 to 2018 in both positive and negative price supports and subsidies. In gross terms, the amount stands at nearly US$700 billion per year, of which 48 percent comprises price incentives, meaning it is a positive income transfer to farmers through distorted market prices. High-income or developed countries including the United States, the EU, Canada, and Australia together provided incentives amounting to US$95 billion per year, representing more than 40 percent of gross farm receipts. Negative price supports are common in low-income and lower-middle-income countries (Table 1) and in some upper-middle-income countries. Among middle-income countries, India is seen to suppress domestic prices heavily, providing around US$65 billion per year on average during 2014–2018. Trade policy in India seems to cater to consumers' needs, rather than producers', and thus can be considered taxation on farmers. On the other hand, China, an upper-middle-income country, has moved from negative price support to positive territory lately (Laborde et al., 2021).

[1] These countries together represented close to 90 percent of the global value of agricultural production in the period 2014–2018.

Table 1: Farm support in agriculture (US$ billion, average 2014–2018)

Region	Price disincentives	Price incentives	Output subsidies	Input subsidies	Subsidies based on factors of production	Other subsidies, decoupled from production
World	-118.5	329.2	10.5	91.0	73.1	67.7
High-income countries	-0.2	94.8	4.6	24.7	40.4	57.6
Low-income countries	-18.3	9.1	0.0	0.4	0.0	0.0
Lower-middle-income countries	-86.3	34.4	0.0	31.6	0.3	0.7
Upper-middle-income countries	-13.8	191.0	5.9	34.3	32.3	9.3
Brazil		1.6	0.3	2.9	0.2	
China		163.5	3.7	22.9	29.0	9.0
Europe		20.3	0.6	13.4	24.0	44.1
India	-64.8	7.2	0.1	28.9		0.9
United States		11.0	1.8	8.6	8.6	8.3

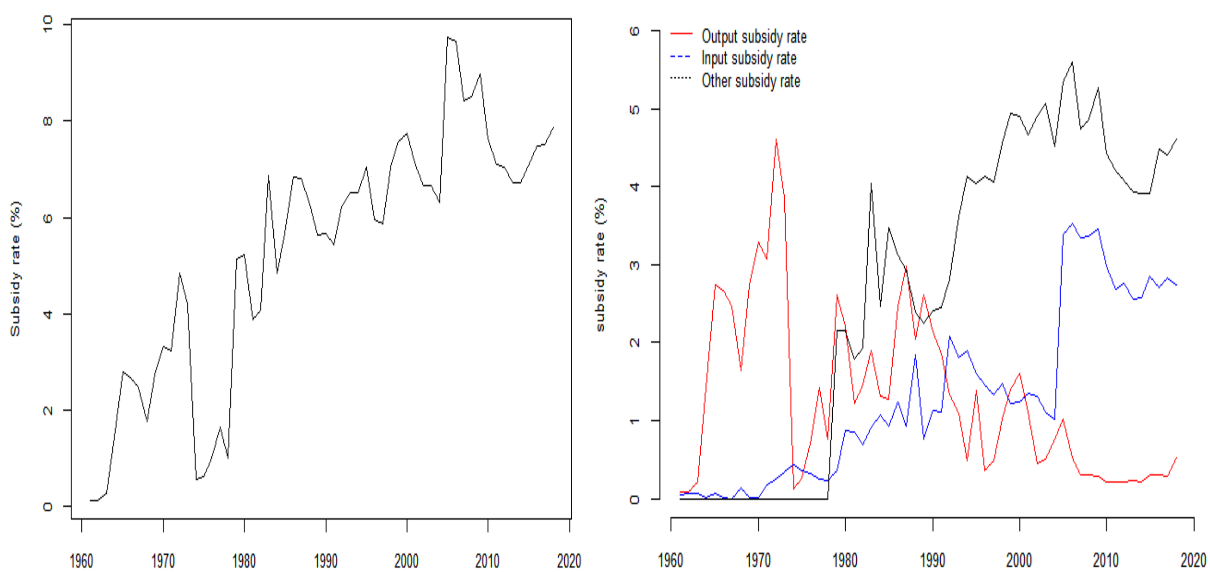
Source: Author's calculation. Data from Laborde and Mamun (2022).

More than one-third of the total support is provided through fiscal subsidies at the global level. Of the total subsidy amount of US$242 billion annually, 38 percent goes to input subsidies and another 30 percent to subsidies paid to farmers for factors of production (land, capital, and labor). Thus, payments for inputs and factors of production together account for 68 percent of subsidies, reflecting governments' efforts to keep the agriculture sector productive and ensure food security for all. Notably, high-income, and upper-middle-income countries jointly provide much of the support for inputs, often unconstrained. European countries, China, and India are among those that heavily subsidize inputs and factors. Output subsidies account for less than 5 percent and are provided mostly by high-income and upper-middle-income countries. Subsidies are also paid to farmers through decoupled mechanisms[2] Globally, about one-third of subsidies are decoupled. This reflects the reforms undertaken by some developed countries, including the United States and the EU, to shift away from payments tied to production, with the aim of reducing market distortions.

[2] Decoupled payments, often called direct payments, are transfers from taxpayers and are not related to current production, factor use, or prices. Eligibility criteria for receiving this type of payment are defined by a fixed, historical base period in agricultural activities.

Nominal rate of assistance (NRA) data reveal that the total subsidy rate gradually increased from less than 1 percent in the early 1960s to around 7–8 percent during the period 2010–2018 (Laborde and Mamun, 2022) (Figure 5). An early increase in investment in R&D in agriculture followed the Green Revolution in the 1960s and 1970s. The subsidy rate climbed to more than 5 percent of the total value of production in the 1980s, measured at the reference or undistorted price, and since then the rate has risen further, stabilizing at 7.5 percent in 2017–2018. Countries across the world, particularly high-income and middle-income countries, saw an expansion of agricultural activities with increased fiscal support in the 1980s, while production gains took off after the 1990s.

Figure 5: Total subsidy rate (%) and decomposition, 1961–2018



Source: Laborde and Mamun (2022).

During this 60-year period, the composition of subsidy programs changed substantially, with growth in input and other subsidies that include payment for factors of production as well as decoupled payments, while the output subsidy rate declined. The right panel of figure 5 decomposes this with three separate lines, for output, input, and other subsidies. The output subsidy rate was as high as 4.5 percent in 1970, and then declined steeply from the mid-1970s, though it experienced a few peaks in 1980 and the early

1990s. From 2000 onward, the output subsidy rate declined to less than 2 percent of the total value of production, and since 2010 has declined to less than 1 percent.

Since the beginning of the 1990s, subsidies of “other” types have increased significantly. The period is marked by massive reform or reorientation of farm support programs, mostly in developed countries, especially high-income ones. Along with other types of subsidies, governments’ use of input subsidies in both developed and developing countries increased sharply beginning in the mid-2000s (Figure 5).

The extent and nature of farm support is likely to affect production, but its impact depends on the specifics of the program, how it creates incentives for producers, and how farmers’ decisions reflect those incentives. Raising farm incomes, reducing vulnerabilities, and improving agriculture sector competitiveness are among the key objectives of all farm support programs (OECD, 2008).

Empirical evidence suggests that subsidies may spur productivity in agriculture when farmers face poor access to inputs (Hennessy, 1998; Ciaian and Swinnen, 2009; Garrone et al., 2019). Subsidies may also have an insurance effect when farmers incur production losses. Fuglie et al. (2021) discusses the role of policies—including investments in R&D, economic reforms, credit policies, investment in irrigation, and land policies—in agricultural productivity growth.

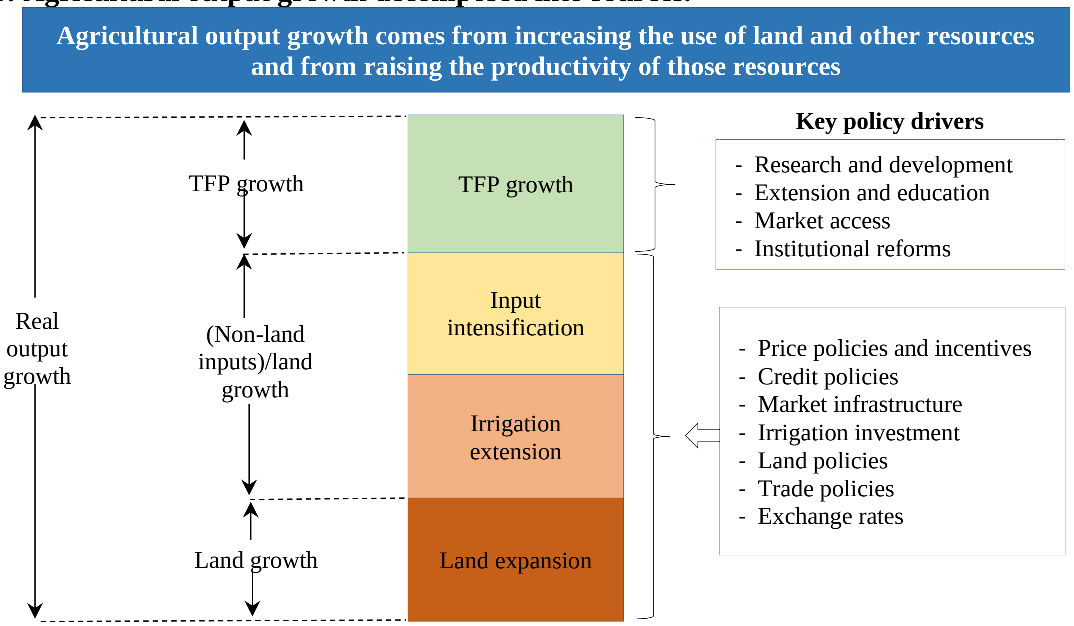
5. EMPIRICAL APPROACH

This study relies on two underlying theoretical and analytical frameworks – one on productivity in agriculture itself, and other on economic theory that describes growth accounting overall. In the agriculture productivity front I have reviewed the papers and the data source, primarily from USDA Economic Research Services (ERS). This section explains both analytical and theoretical framework in greater detail, along with estimation strategy.

5.1 Analytical Framework

Analytical framework on productivity in agriculture and their sources are nicely decomposed by USDA ERS (2021) in the following diagram, which helps understanding the potential contributions of different drivers in the growth process. It also gives a clear idea about the interplay between different components of growth – output growth, land growth, TFP growth and non-land inputs intensification. These are all measures of total productivity. On the other hand, output per agricultural worker or value addition per worker are partial measures of productivity. This section will discuss briefly both the strengths and shortcomings of each measure.

Figure 6: Agricultural output growth decomposed into sources.



TFP = Total factor productivity

Source: Adapted, from USDA, Economic Research Service, *International Agricultural Productivity* data product. Data and methods as of October 2021

As described in ERS (2021), the real output growth can be decomposed into three components – land growth, TFP growth, and growth in non-land inputs/land. This analytical framework points to, apart from research and development, and extension service, the role of policies, prices, credit facilitation, market infrastructure etc. in agricultural growth.

To have a broader understanding, and due to the scope of farm support programs[3], we aim to model output growth. On the other hand, in partial productivity analysis we bring in growth in output per worker. These measures capture the comparative performance of economies in the agriculture sector (Martin, 2001).

Overall output growth as a measure of total productivity is preferred to gross or real value addition (after subtracting value of intermediate inputs) per worker for several reasons including non-distortive or homogenous measure of real output growth across countries (USDA ERS 2021). For example, terms of

3 Farm support programs are channeled in different forms. Farmers receive deficiency payment as well as inputs at subsidized price. For input intensification there are programs to provide fertilizers, seeds, finance, pesticides, irrigation, extension services, risk management, mechanization, fuel, land management, insurance etc. Under payment for factors of production, producers get area-based payment that specific to certain products, for labor and capital etc.

trade in agriculture or exchange rate fluctuations can distort gross value added and hence may not reflect real output in agriculture. At the same time, gross output treats inputs as symmetrical with capital and labor inputs, and hence using value added measure may not be appropriate to model behavior of agricultural producers, as opposed to gross output (Fuglie et al, 2012).

5.2 Theoretical Model

This study follows the neoclassical growth framework applied in Rizov (2005) and Garrone et al. (2019). The growth theory that tests convergence among different economies—including between developed and developing countries—has drawn interest from economists since Solow's (1956) seminal paper on the growth equation, and the subsequent econometric works to allow an extended set of explanatory variables (Barro, 1991; Barro et al., 1991; Barro and Sala-i-Martin, 1995).

Convergence theory states that a negative relationship exists between the growth rate of productivity and the initial productivity level. Two types of convergence hypotheses are examined in much of the literature: absolute convergence and conditional convergence in growth. Absolute convergence, usually referred to as β-convergence, requires that countries have the same factors of production but different initial levels of productivity, and hence is restrictive. Conditional convergence allows for different stationarity conditions among economies but requires inclusion of additional explanatory variables. If the sign of the "lag of growth" variable (productivity in this study) is negative and one or more explanatory variables are found significant, then conditional convergence exists. Convergence is tested within an economy or across economies in terms of growth rate or income level (Islam, 2003).

As the convergence growth theory underpins the role of different structural variables in economies as well as the initial condition of productivity, this paper carefully reviews agricultural productivity in different countries or groups of countries (developed vs. developing), the trajectory of development, and the contributing factors.

As summarized in Section 3, developing countries' progress in agricultural productivity is no surprise, as the last 60 years saw significant government investment in R&D, extension services, and education.

Publicly funded domestic agricultural research institutes and universities focusing on agricultural disciplines contributed greatly to the development of many modern crop varieties. Advances were also made in the livestock sector. In addition, R&D spillovers from international agricultural research institutes, such as CGIAR (Consultative Group on International Agricultural Research), contributed to growth. The contribution of CGIAR research centers has been shown to be significant in agricultural TFP growth in Asia, Africa, and Latin America (Fuglie, 2018).

Technological advancement in agriculture was significant over the past 60 years and passed through similar stages of development in developed and developing countries (Gollin et al., 2021). Since the 1990s, developing countries surpassed their developed counterparts in terms of agricultural productivity growth. Both benefited from public research institutes as well as from international centers. Development of modern varieties of crops and livestock and adoption of input-saving technologies are prevalent across the world. As one of the key assumptions in the neoclassical growth model is homogeneity in technological progress among countries, the empirical findings discussed above and the trend in productivity growth suggest a suitable case for studying convergence.

5.3 Estimation Strategy

Following Rizov (2005) and Garrone et al. (2019), a conditional convergence model at the global level is used to estimate the relationship between agricultural output growth and farm support policies. The model is specified as follows:

$$\Delta y_{it} = \beta y_{it-1} + \theta S_{it-1} + \delta' X_{it-1} + \gamma_t + \mu_i + \varepsilon_{it} \qquad (1)$$

where $\Delta y_{it} \equiv \ln Y_{it} - \ln Y_{it-1}$ denotes country i's productivity growth between time t and t −1; y_{it-1} is the lagged log of agricultural output or output per worker; that is, the convergence term. Y_{it} can be output or yield or output per worker. The terms γ_t and μ_i represent year and country fixed effects that can capture unobserved impact of country and year specific characteristics. Introduction of fixed effects allow us to isolate the impact of explanatory variables from the year and country specific effects.

The variable of interest here is the agricultural subsidy rate, S_{it-1}. Subsidy rates can be broken down into inputs, outputs, and others or by nature of subsidy, such as coupled or decoupled. X_{it-1} is a vector of control variables that may also affect labor productivity, such as the logarithm of labor force growth, the logarithm of population density, the logarithm of gross capital formation as a share of GDP, and so on. The subsidy variables as well as other covariates enter the equation lagged by one year.

Econometric estimation in dynamic panel data requires satisfying various assumptions and conditions. In addition to the model requirements, subsidy policies and productivity growth data follow a distribution that merits special attention. Some subsidy policies are tied with past production; for example, payments decoupled from production are made to producers based on historical data on area or livestock numbers. In such a case, potential arises for endogeneity bias in the regression coefficients. Simple linear regression may not suffice for such a situation. Productivity levels can be dependent on their own past realizations and are likely to create another type of bias if not addressed properly. Therefore, a lag structure is suggested in the equation.

Endogeneity of subsidy payments to agricultural productivity may come from various sources. The econometric model proposed in this study includes the subsidy rate—that is, the value of support over the value of agricultural production. If the denominator goes down, meaning productivity slows, farmers will ask for more farm support from the government. Thus, the allocation of various types of subsidies, such as output subsidies or input payments, is likely to be dependent on past productivity. Hence, negative agricultural growth will lead to more support. Negative growth in agriculture can be attributed to bad weather, climate shock, increased input prices, and other factors.

On the other hand, domestic subsidy programs categorized as Green Box[4] support under the World Trade Organization (WTO) Agreement on Agriculture (AOA)—and often deemed to be decoupled payments—have a large share in total support that is tied to past production. The impact channels of this support

4 Green Box support, as labeled in the AOA by the WTO, specifies that these domestic subsidy programs should have “no or minimally trade and production distorting” effects. Thus, the subsidies should not involve transfers from consumers and must not have the effect of providing price support to producers.

include risk effects, land price effects, credit effects, labor participation effects, and expectation effects (UNCTAD, 2007; Mary, 2013; Breustedt and Habermann, 2011). Political economy factors also affect the level and allocation of resources. This is particularly relevant to protection in the agriculture sector when pressure intensifies from farmer groups for more budgetary disbursements because of land and credit constraints (Olper, 1998, 2007; Falkowski and Olper, 2014).

To address this potential endogeneity problem, the model is fitted with productivity and subsidy rates rather than absolute levels. Therefore, the subsidy rate is delinked from past productivity levels to a large extent. Moreover, the proposed system GMM (SYS-GMM) estimation approach is a suitable method to remove residual endogeneity biases in estimates.

Simultaneity bias also arises when a link exists between payments and production activities. Allocation of subsidies—particularly those tied with production (output, input, and payments for factors of production)—may depend on the past productivity of farms and regions (Garrone et al., 2019). These issues are particularly important for U.S. and EU farmers as their programs are designed in this way.

Many time series datasets include a large number of countries (N) but short time periods (T). In the subsidy data used for this study, the original data comprise 62 countries over 60 years, but the coverage is not homogenous across all countries. Data for the whole period is only available for 42 countries. However, in the convergence equation proposed above, instrumental variables (IV) must be introduced as covariates. One instrumental variable is employment in the agriculture sector, for which the available data from the International Labour Organization (ILO) go back as far as 1991. Therefore, the dataset used is restricted to the period 1991–2018.

Standard OLS and fixed effect (FE) methods of estimation generally suffer from biases because they do not account for endogeneity and the lag effect. Omitted variable problems can potentially cause estimator bias in regression. To avoid OLS estimators, there is an FE estimation method that overcomes the issue that arises when the dependent variable y_{it-1} is correlated with the fixed effects in the error term, ε_{it}, often termed as "dynamic panel bias" (Nickell, 1981). However, for unbalanced panel data, the GMM approach is more appropriate.

To deal with the above issues in data and potential biases, a GMM estimation approach is used, as originally proposed by Arellano and Bond (1991) and Blundell and Bond (1998). GMM estimators are popular in various data situations, particularly when the following apply: (1) panels are “small T and large N”; (2) the dependent variable is dynamic, meaning the current period observation is dependent on own past realizations; (3) explanatory variables are not purely exogenous, possibly correlated with past and current realizations of error; (4) there exists fixed individual effects; and (5) heteroscedasticity and autocorrelation within individuals are observed but not across. Two GMM estimators are commonly found in the literature: difference GMM and SYS-GMM.

Blundel and Bond (1998) propose the introduction of additional instruments and assume first differences of instruments are uncorrelated with the fixed effects. This approach leads to use of the SYS-GMM. With this method, instruments y_{it-1} and any other endogenous variables are uncorrelated with the error term. Since productivity growth, not the level, is used here, the process aligns better with the idea that the relationship between growth and subsidies is not affected by endogeneity bias. Therefore, SYS-GMM fits well with the underlying data-generating process for this study.

This study uses a two-step SYS-GMM estimator. The first step is “partialling” the individual dummies out of other explanatory variables; the second step is running the final regression with the residuals received from the first step. Partialling refers to the use of a mean-deviation transformation for each variable in the first step.

6. DATA

Two datasets are primarily used: one for subsidy rates by type and the other for agricultural productivity, as described next.

6.1 Subsidy Data

Subsidy data are sourced from Laborde and Mamun (2022), who compiled a long time series on NRA for 42 countries and regions (EU as one region) stretching from 1961 to 2018. Key components include the output subsidy rate, the input subsidy rate, other subsidies, and the nominal rate of protection (NRP). This dataset is rich as it combines two different datasets with distinct coverage but similar measures.

Of the two data series used to produce this long series, the World Bank's research project Distortions to Agricultural Incentives (DAI) covers the longest period, dating back as far as 1955. DAI data introduced a comprehensive set of policy indicators, such as the NRA, the relative rate of assistance (RRA), and others. This work is based on the methodology developed by Anderson et al. (2008) and the DAI database, as of the latest release in 2011, which covers 82 countries and runs to 2011. In addition, AgIncentives, a consortium of several multilateral organizations—including OECD, FAO (Monitoring and Analysing Food and Agricultural Policies/MAFAP), the International Food Policy Research Institute, the Inter-American Development Bank, and the World Bank—publishes data on NRP and NRA that predate 2005. The final dataset for regression estimation includes 42 countries and covers the period 1991–2018. The time period is curtailed from 1961 to 1991 as data on important control variables, such as employment growth in agriculture, are not available prior to 1991. Table A3 presents the list of countries and their time coverage.

6.2 Agricultural Productivity Data

The USDA's Economic Research Service (ERS) provides an excellent dataset on international agricultural productivity (IAP)—including annual indices for agricultural TFP, outputs, and inputs for individual countries, major global regions, and countries grouped by income level—from 1961 to 2019.

The agricultural output data consists of quantities harvested for 200 commodities (162 crops, 30 animal products, and 8 aquaculture products). The crop and animal output data come from FAOSTAT, which has published estimates of annual production by country since 1961. Aquaculture products are from FAO's FISHSTAT. These 200 farm outputs are aggregated using global average prices for 2014–2016 (in purchasing power parity dollars) to provide a measure of the gross value of agricultural output.

This measure of agricultural output differs from commonly used agricultural value added or agricultural GDP reported in national accounts in two ways: in the use of current national prices to aggregate commodities and in subtracting the value of intermediate inputs. For international comparisons of the real volume and growth of agricultural output over time, the measure—using global average prices for 2014–2016—avoids distortions caused by exchange rates and terms of trade. On these grounds, labor productivity as measured by output per worker is considered to run the conditional convergence model.

6.3 Instrumental Variables

Five instrumental variables, as suggested by the literature on conditional convergence models, are considered in the estimation: GDP growth; population density; employment growth in agriculture; the grassland ratio; and domestic investment as a share of GDP. Among these variables, all but the grassland ratio are sourced from the World Bank's World Development Indicators (WDI) database. The relevant literature that studies conditional convergence models in agricultural productivity includes Garrone et al. (2019), Rizov (2005), and Cuerva (2012).

In line with Garrone et al. (2019), population density, measured as total population per km^2, is used to indicate market conditions such as the level of activity in product and factor markets. The grassland ratio is computed as the ratio of land used for pastures over total agricultural land, using agricultural land data from FAOSTAT. It inversely indicates the farm and production structure in each country as it reflects the use of agricultural land for production.

Factor markets are important for agricultural growth. Employment growth in agriculture is used as a control variable as it implies different conditions in different economies (Gardner, 2005). As in other growth literature, employment growth is adjusted by the common exogenous rate of technical change and the common depreciation rate (Caselli et al., 1996; Islam, 2003; Mankiw et al., 1992). The sum of these rates is reported as 0.05 in Mankiw et al. (1992).

GDP growth is the indicator of a country's economic conditions and development. Overall economic growth is indicative of the performances of respective economies, and the growth pattern varies between developed and developing countries. Agricultural growth in many developing countries accompanies high overall economic growth. Notable cases include China, India, Indonesia, Viet Nam, and Brazil. Therefore, GDP growth should be considered as an instrumental variable in the model.

Though Garrone et al. (2019) considers the share of large farms as a control variable, it is not included in this study, mainly because the data were not available. Finally, domestic investment, which represents gross fixed capital formation, is taken from WDI data. This indicator measures investment in infrastructure in a country, including land improvements, plants, machinery, roads, and so on. The size of domestic investment should drive a country's economic growth by inducing fixed capital in the rural areas and can catalyze agricultural transformation.

The instrumental variables proposed in this study are the structural ones generally found in the conditional convergence growth literature for agriculture. The model is run with overall economic growth to explicitly show that agricultural growth is part of the growth process at the macro level. The model is controlled with market for agriculture (population density), labor force in the production function (employment growth in agriculture), land used in agriculture (which indicates agriculture production structure, as proxied by the grassland ratio), and capital intensity in the economy, assuming that investment affects the agriculture sector as well (gross capital formation or domestic investment). Since this study intends to test conditional convergence in agricultural productivity and since the countries or economies studied here are not identical in size or structure, economic integration, or growth, selection of the control variables covers an exhaustive set of conditions that exist in different economies: product and factor markets, market conditions, labor force, land, and investment. Agricultural productivity can be broadly conditioned by this set of indicators.

7. RESULTS

The econometric estimation results reported here are from Table 2 and Table 3, starting with output growth as regressed on the model variable. Each table presents five SYS-GMM models, one fixed effect (FE) model, and one OLS model. Different combinations of subsidy-related variables appear in different SYS-GMM models separately, to test which farm support policies and their combinations are associated with productivity, positively or negatively.

Specification of the five different SYS-GMM models includes: (1) the input subsidy rate only; (2) the output subsidy rate only; (3) the total subsidy rate; (4) output, input, and other subsidies; and (5) coupled and decoupled subsidies.[5] In each table these explanatory variables and their combinations appear from columns (3) to (7). Columns (1) and (2) show results for the OLS model and the FE model, respectively. All independent variables, including explanatory and control variables, appear with a one-period lag in each model. Standard tests for consistency of the SYS-GMM estimators and validity of instruments are reported at the bottom of each table. Arrelano-Bond tests for AR(1) and AR(2) test for the presence or absence of serial correlation of order one and higher. The Hansen-Sargan test for overidentification is also reported in the tables. In all tables, only non-robust standard errors are reported, as the two-step GMM estimation already produces robust standard errors in the first step.[6]

All GMM models include a dependent variable with a lag of order 2 in the control variables set, as the initial AR(1) and AR(2) Arrelano-Bond tests of autocorrelation yield low p-values, suggesting that the error terms are serially correlated of order 1. Therefore, agricultural output (in level) is added with a two-period lag and higher in the instrument set (Roodman, 2009). In the initial Arrelano-Bond test results, a second-order lag improves the dynamic model setup significantly, as the p-values for the AR(2) test in most models appear higher than 0.05, in which case the null hypothesis of the absence of a second-order serial correlation is not rejected.

[5] Coupled and decoupled subsidies add up to the total subsidy as do output, input, and “other” subsidies together.

[6] Roodman (2009) states that robust standard errors are likely to ensure the Windmeijer finite sample correction, as non-robust standard errors are often biased in small samples. However, as this study is done at global level, with a large number of countries, and the data cover around 90 percent of agricultural production, reporting non-robust standard errors is sufficient.

AR(1) and AR(2) test results indicate the absence of higher-order serial correlation, meaning that a one-period lag is appropriate in the model. However, the p-values of the Hansen-Sargan test for all SYS-GMM models in Table 2 (more than 0.05) suggest acceptance of the null hypothesis of joint validity of instruments. This may be a situation of weak exogenous instruments in modeling output growth. However, there is risk in relying blindly on the Hansen-Sargan test, as Roodman (2009) points to the weakness of this test when applying more moment conditions.

A negative sign on output (in level) in the one-period lag implies conditional convergence in output growth. The speed of convergence (in column (6)) is only 0.1 percent (absolute value of coefficient of agriculture output in t-1 times 100). The convergence values for models (4), (5), and (7) are high, ranging from 4–6 percent. The FE model estimates of the β coefficient are higher (in absolute terms) than those observed in the GMM models, indicating that the GMM estimates have a downward bias. The OLS estimate does not show convergence, as the sign is positive in this case.

To check the robustness of the regression results for output growth, three additional SYS-GMM models are estimated (Table A1). The first of these models (column (1) in Table A1) considers only the convergence term (y_{t-1}) as instrument. In the second model (column (2)), both the convergence term and subsidies are instrumented but no external or exogenous indicators appear as instruments. The final model considers only subsidy variables with a lag of two and three periods (t-2, t-3) as instruments, dropping the convergence term and exogenous variables as instruments. All three models reveal no convergence in productivity growth (a positively signed coefficient on the convergence term is revealed). This means past output level and subsidy rates are not sufficient to achieve convergence in growth. Convergence in agriculture is thus conditional on important economic and demographic factors, the ones considered in this study. The coefficient signs of the policy variables vary greatly across the models.

The coefficients of the policy variables reveal that only output subsidies, when modeled along with other types of subsidies (column (6) in Table 2), have a positive and statistically significant impact on productivity (p-values less than 0.05). The input subsidy also has a positive regression coefficient, but it lacks statistical significance. Among the subsidy instruments, “other” subsidies, which are mostly decoupled, show a negative coefficient. The FE and OLS models do not produce any statistically significant coefficient for any subsidy instrument (columns (1) and (2)). If subsidies are grouped by (de)coupled nature and placed as regressors, only coupled subsidies show a positive impact on output growth, while the coefficient for decoupled subsidies is negative and statistically insignificant at any level.

Among the control variables, agricultural employment growth positively impacts growth, as indicated by the coefficients across all models. Similar positive coefficients are found for population density and the grassland ratio. GDP growth and domestic investment are found to be negatively associated with output growth. The SYS-GMM models in columns (4), (5), and (7) produce significant coefficients for most of the control variables. However, when all subsidy instruments are introduced in the model (column (6)), only employment growth is significant (p-value less than 0.001).

Table 2: Convergence regression for agricultural output growth

Dependent variable: Output growth	**(1) OLS**	**(2) FE**	**(3) SYS-GMM**	**(4) SYS-GMM**	**(5) SYS-GMM**	**(6) SYS-GMM**	**(7) SYS-GMM**
Total subsidy (t-1)					0.038 (0.059)		
Coupled subsidy (t-1)							0.028 (0.065)
Decoupled subsidy (t-1)							-0.031 (0.063)
Output subsidy (t-1)	0.010 (0.043)	0.030 (0.114)		0.058 (0.123)		0.196* (0.096)	
Input subsidy (t-1)	0.084 (0.103)	-0.072 (0.144)	0.558 (0.397)			0.264 (0.401)	
"Other" subsidy (t-1)	0.008 (0.017)	0.041 (0.062)				-0.023 (0.049)	
Agr. output (t-1)	0.001 (0.001)	-0.118*** (0.019)	-0.001 (0.006)	-0.041* (0.016)	-0.054** (0.020)	-0.001 (0.008)	-0.056** (0.02)
GDP growth (t-1)	0.091 (0.065)	0.056 (0.073)	-0.109 (0.146)	-0.024 (0.135)	-0.127 (0.156)	-0.057 (0.136)	-0.142 (0.161)
Population density (t-1)	-0.003 (0.002)	-0.028 (0.035)	-0.009 (0.029)	0.116* (0.049)	0.139* (0.062)	0.020 (0.028)	0.146* (0.062)
Grassland ratio (t-1)	-0.002 (0.009)	-0.387*** (0.104)	0.023** (0.007)	0.666** (0.214)	0.965*** (0.282)	0.044 (0.078)	0.984** (0.305)
Employment growth (t-1)	0.019** (0.006)	0.02** (0.007)	0.238. (0.141)	0.031*** (0.006)	0.033*** (0.008)	0.026*** (0.007)	0.034*** (0.008)
Domestic invest. (t-1)	0.022 (0.031)	0.077. (0.046)	-0.015 (0.138)	-0.292. (0.161)	-0.443* (0.188)	-0.105 (0.121)	-0.474* (0.195)
N	1018	1018	1983	1983	1983	1983	1983
R^2	0.045	0.065					
Adjusted R^2	0.012	-0.007					
Number of instruments			38	38	38	38	38
Hansen-Sargan J-stat p-value			0.092	0.127	0.686	0.174	0.835
AR(1) p-value			0.000	0.000	0.000	0.000	0.000
AR(2) p-value			0.055	0.057	0.067	0.051	0.068

Note: OLS regression includes time dummies; FE regression includes region and time fixed effects; SYS-GMM regressions include time fixed effects, and subsidy payments, employment growth, and GDP growth are treated as endogenous, while population density and the grassland ratio are exogenous. AR(*n*) is the Arellano and Bond test for autocorrelation of first and higher order, respectively; the Hansen-Sargan test ("J test") is the test for overidentification or joint validity of instruments. Standard errors based on Z-statistics are reported in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Convergence in labor productivity, which is a partial measure of agriculture productivity, is tested as well. Single-factor productivity measures give an indication of economic performance that compares production with the amount of labor hours worked. A multitude of factors and forces can impact labor productivity over time, including technological advances, improved worker skills, better farm practices, economies of scale, and increased use of nonlabor inputs. Fiscal support can trigger this last influencing factor when farmers can opt for input intensification.

Labor productivity here indicates what the agriculture sector generates per effective worker. The residual from regressing labor productivity on the coupled subsidy is used as the measure of labor productivity, as this process nets out the payment from output value. As specified in equation (1), Table 3 presents the econometric estimation of the models following SYS-GMM, OLS, and FE estimation techniques. The Sargan test in all models reported in Table 3 shows p-values less than 0.05, except the models in columns (5) and (7). This is a situation where not all control variables are strictly exogenous. AR(1) and AR(2) test results show the absence of a higher-order serial correlation.

The results indicate conditional convergence in labor productivity, as the sign of the coefficient of lagged labor productivity is negative in all specifications, with statistical significance at the 10 percent level. The speed of convergence ranges from 1.3 percent to 1.8 percent. The FE model (column (2)) indicates statistical significance and high convergence (the coefficient value is -0.123). The coefficient signs follow the same pattern between FE and SYS-GMM models (column (2) and column (6)), though the coefficient values differ in magnitude.

As with agriculture output growth, three additional SYS-GMM models are estimated (Table A2), with the same set of instruments as described for Table A1. In this case too, no conditional convergence is achieved in labor productivity (that is, a positive coefficient on convergence term). The findings are consistent with those revealed for output growth (Table A1).

Table 3: Convergence regression for output per worker at global level

Dependent variable: Δ **Agr. output per worker**	**(1) OLS**	**(2) FE**	**(3) SYS-GMM**	**(4) SYS-GMM**	**(5) SYS-GMM**	**(6) SYS-GMM**	**(7) SYS-GMM**
Total subsidy (t-1)					-0.042 (0.122)		
Coupled subsidy (t-1)							0.001 (0.102)
Decoupled subsidy (t-1)							0.010 (0.176)
Output subsidy (t-1)	0.051 (0.048)	-0.046 (0.134)		-0.119 (0.117)		0.048 (0.138)	
Input subsidy (t-1)	0.137 (0.117)	0.255 (0.171)	1.228*** (0.342)			0.947** (0.304)	
"Other" subsidy (t-1)	0.001 (0.022)	0.113 (0.073)				0.051 (0.156)	
Agr. out. per worker (t-1)	-0.002 (0.002)	-0.123*** (0.015)	-0.015+ (0.009)	-0.017 (0.011)	-0.015 (0.013)	-0.018+ (0.01)	-0.013 (0.013)
GDP growth (t-1)	0.102 (0.079)	0.072 (0.086)	-0.175 (0.183)	-0.228 (0.162)	-0.30+ (0.168)	-0.287+ (0.171)	-0.304+ (0.166)
Population density (t-1)	-0.002 (0.003)	-0.106* (0.042)	-0.005 (0.021)	-0.001 (0.013)	-0.013 (0.031)	0.024+ (0.015)	-0.013 (0.032)
Grassland ratio (t-1)	0.002 (0.011)	-0.008 (0.122)	0.416** (0.136)	0.446*** (0.125)	0.549** (0.192)	0.236** (0.077)	0.538** (0.186)
Employment growth (t-1)	0.011 (0.007)	0.014+ (0.008)	0.024* (0.01)	0.025*** (0.007)	0.027** (0.009)	0.027** (0.008)	0.027** (0.009)
Domestic invest. (t-1)	-0.038 (0.036)	-0.041 (0.053)	-0.11 (0.169)	-0.102 (0.168)	-0.138 (0.179)	-0.053 (0.162)	-0.104 (0.178)
N	1018	1018	1983	1983	1983	1983	1983
R^2	0.049	0.079					
Adjusted R^2	0.017	0.005					
Number of instruments			38	38	38	38	38
Hansen-Sargan J-stat p-value			0.014	0.041	0.057	0.017	0.073
AR(1) p-value			0.000	0.000	0.000	0.000	0.000
AR(2) p-value			0.061	0.057	0.062	0.062	0.062

Note: OLS regression includes time dummies; FE regression includes region and time fixed effects; SYS-GMM regressions include time fixed effects, and subsidy payments, employment growth, and GDP growth are treated as endogenous, while population density and the grassland ratio are exogenous. AR(*n*) is the Arellano and Bond test for autocorrelation of first and higher order, respectively; the Hansen-Sargan test ("J test") is the test for overidentification or joint validity of instruments. Standard errors based on Z-statistics are reported in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

As with agricultural output growth, the input subsidy is positively associated with labor productivity too, and the coefficient (0.947) is statistically significant (column (6) in Table 3). This significant and high coefficient value is also shown in column (3) when only the input subsidy is added, dropping the other two subsidy instruments. If the productivity measure captures technology (TFP) and input intensification together, labor productivity rises, and input subsidies play a larger role in raising productivity per worker, as signified by the large positive coefficients on the subsidy instrument in the GMM model (columns (3) and (6) in Table 3). Output subsidy and "other" subsidies yield relatively low coefficient values (column (6)).

Production structure (grassland ratio) and employment growth both have an enabling influence on increasing labor productivity. The positive coefficient sign on the grassland ratio indicates that a high-intensity production structure (use of more agricultural land) reduces labor productivity, and the converse is true when the sector uses less land (a high grassland ratio). On the other hand, domestic investment (a proxy for rural infrastructure or capital investment) is found to be negatively associated with labor, a result that contradicts the hypothesis of investment's positive role in productivity growth. Population density shows a positive impact on labor productivity.

The findings from modeling labor productivity suggest that input subsidies have a significant role in enhancing farm output by providing access to improved technologies and services, better inputs, and farm practices than on labor productivity. The findings are consistent with the existing literature that argues for addressing constraints or lack of access to credit and technologies (Hennessy, 1998; Ciaian and Swinnen, 2009; Rizov, 2005; Garrone et al., 2019). Other empirical studies reveal that farmers tend to pursue input intensification when provided with subsidies for farm inputs such as fertilizer, seeds, and irrigation (Zhu and Oude Lansink, 2010; Kazukauskas, Newman, and Sauer, 2014; Mary, 2013: Garrone et al., 2019).

Though this study is mainly focused on studying agricultural productivity-subsidy link, an attempt has been made to investigate the role of price incentives as well. SYS-GMM models have been fitted for both productivity measures – output growth, and labor productivity. In this case, price incentives, measured by Nominal Rate of Protection (NRP), appears with other subsidy variables in the regression equation. The idea is to test if various forms of farm supports including price support do impact productivity. The results table given in annex (Table A.3) reveal no statistically significant relationship between NRP and output growth or NRP and labor productivity (growth agriculture output per worker). This implies that price protection given to the agriculture sector has no relation to productivity increase. They can only influence the production decision of the farmers.

The empirical relationship between farm subsidies and agricultural productivity investigated in this study emphasizes the importance of addressing farm constraints, as argued in the literature section (Ciaian and Swinnen, 2009). Conditional convergence growth models with explanatory variables in one period lag and using SYS-GMM estimation approach allow assessments of productivity growth with theoretical soundness (Ciaian and Swinnen, 2009; Rizov, 2005; Garrone et al, 2019). SYS-GMM estimation approach is widely used to account for unobserved country and time effects. The study uses instrumental variables in the estimation to control potential endogeneity bias. Moreover, I have performed robustness check by estimating additional models with and without convergence terms and external control variables. Strong positive and statistically significant coefficient of input subsidies observed in the model of labor productivity growth give evidence that farm subsidies in different forms, such as fertilizer and seed distribution at subsidized price, government funded irrigation programs, access to finance, risk insurance etc. play important role in productivity improvement. Production linked subsidies are also found to be positive and significant in agricultural output growth, though not significant in labor productivity. Overall, the results presented for different productivity measures reveal the presence of β-convergence in the agriculture sector. The negative coefficients on productivity measures (one-period lag) in all specifications and their statistical significance indicate conditional convergence in the sector globally. Subsidies play an important role in this convergence process, though impact varies by the type of subsidy instrument and by productivity measure. Input subsidies have a strong impact on labor productivity but less so on agricultural output growth. Without a TFP effect, input subsidies play little or no role in increasing productivity. Output subsidies, mostly implemented in developed countries, have a positive impact on output growth but a negative impact on labor productivity. Decoupled payments and payments related to factors of production, clubbed as “other” subsidies, have a positive effect on labor productivity growth.

8. CONCLUSION

Agricultural support has evolved over the past half century from price-distorting measures to direct income support to producers who face production shortfalls due to the sector's stochastic nature. Support also goes to subsidize farmers to buy inputs, and governments facilitate financing for farmers and provide insurance facilities. Reforms in subsidy policies took place over the last three decades, particularly for coupled subsidies. All of these policies may exert influence on production decisions that are less input intensive but more productive. This study examines what happens to production efficiency when farmers receive subsidies in various forms.

The result from the econometric estimation is that production-linked subsidies have a positive impact on output growth, consistent with results from the FE model. Output subsidies have a positive but lower influence on labor productivity. Though the choice of productivity measures matters when doing comparative analysis, this econometric estimation suggests that output subsidies are of less significance in raising labor productivity.

The most notable result from the convergence model studied here is that input subsidies have a large and statistically significant labor productivity-enhancing effect. This implies the effect of input intensification and technology where input subsidies play a significant role. It also shows the impact on economies' performance in terms of rising labor productivity in the agriculture sector. Major developing countries such as China, India, and Indonesia provide a huge amount (US$66 billion per year, out of US$91 billion globally) of input subsidies for buying fertilizers, pesticides, seeds, et cetera. Notably, agricultural productivity growth in these developing countries has reached a level that outpaces that observed in developed countries (Figures 1). Farm policy that subsidizes quality inputs accelerates the growth process in agriculture, as evidenced in many of these developing countries over the past few decades. High payoffs from quality inputs contribute greatly to sustaining agricultural growth (Gardner, 2005).

Findings also show that decoupled subsidies or those that pay for factors of production have a positive impact on labor productivity. However, these same subsidies are negatively associated with output growth. Both Rizov, Pokrivcak, and Ciaian (2013) and Garrone et al. (2019) show a positive impact of decoupled subsidies on EU farms. While decoupled subsidy policies are largely practiced by developed countries, China is the largest economy among developing countries that pays farmers largely in the form of decoupled subsidies (Table 1).

This study finds that subsidy policies have a heterogeneous impact on various measures of productivity. This heterogeneity is also revealed by prior studies (Cuerva, 2012; Garrone et al., 2019). The incidence of agricultural support policies needs to be examined in context as the details emerge on their role in efficiency gains. Careful review and repurposing of certain policy instruments is of high importance given that the sector is facing the threat of global climate change and price uncertainty (Laborde et al., 2021; Gautam et al., 2022). Policy messaging toward a uniform approach is critical in this regard. This study advances understanding of the effectiveness of various policy instruments, and thus can contribute to efficient policy design and implementation.

Findings from the study on subsidy and productivity relationship merits about discussion future implications of farm support policies, particularly for developing countries. Though total subsidy rates are found to be rising, the composition of different types of subsidies vary between developed and developing countries (Table 1 and Figure 5). While the high-income countries reformed farm policies and moved towards decoupled subsidies and the subsidies based on factors of production, developing countries spend significant amount for input subsidies. The importance of input subsidies cannot be overlooked as long as the farmers face constraints in accessing improved agricultural inputs. Developing countries, particularly the low-income countries, should pay attention to design appropriate input subsidy policies. As we face growing uncertainty of climate, the subsidy programs must emphasize that the farmers will require risk insurance against any crop failure.

On the other hand, it is important to state that the spending on R&D and rural infrastructure can only accelerate the pace of agricultural growth. Another implication of this study is that the subsidies of 'other' types that includes decoupled payment and payments for factors of production need to be reviewed carefully, as there is subdued significance of this type of subsidies observed in this study. Instead, the resources can be repurposed to climate resilient agricultural technologies.

One important government-run program is spending on R&D for genetic innovation, disease control, and pest management. Fiscal support is also given to extension services and rural infrastructure. Fiscal support for R&D, extension services are critical for raising TFP in the sector. An integrated framework for analyzing public R&D spending and extension services, subsidies, price supports, and their role in agricultural productivity is highly relevant. Evaluation of all these farm supports may establish the effectiveness and importance of each policy. Therefore, further research is needed to address these aspects when considering reform in farm support policies.

REFERENCES

Alston, J. M., and James, J. S. (2002). "The Incidence of Agricultural Policy." In B. L. Gardner and G. C. Rausser (Eds.), *Handbook of Agricultural Economics* (pp. 1689–1749), North-Holland: Elsevier.

Anderson, K., Kurzweil, M., Martin, W., Sandri, D., & Valenzuela, E. (2008). *Methodology for measuring distortions to agricultural incentives* (No. 48326). Washington, DC: World Bank.

Arellano, M., and Bond, S. (1991). "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations." *Review of Economic Studies*, *58*(2), 277–297.

Barro, R. J. (1991). "Economic Growth in a Cross Section of Countries." *Quarterly Journal of Economics*, 106(2), 407–443.

Barro, R. J., and Sala-i-Martin, X. (1995). *Economic Growth*. New York, NY: McGraw-Hill.

Barro, R. J., Sala-i-Martin, X., Blanchard, O. J., and Hall, R. E. (1991). "Convergence Across States and Regions." *Brookings Papers on Economic Activity*, *22*(1), 107–182.

Blancard, S., Boussemart, J. P., Briec,W., and Kerstens, K. (2006). "Short and Long-Run Credit Constraints in French Agriculture: A Directional Distance Function Framework Using Expenditure-Constrained Profit Functions." *American Journal of Agricultural Economics*, *88*(2), 351–364.

Blundell, R., and Bond, S. (1998). "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models." *Journal of Econometrics*, *87*(1), 115–143.

Breustedt, G., and Habermann, H. (2011). "The Incidence of EU Per-Hectare Payments on Farmland Rental Rates: A Spatial Econometric Analysis of German Farm-Level Data." *Journal of Agricultural Economics*, 62(1), 225–243.

Caselli, F., Esquivel, G., and Lefort, F. (1996). "Reopening the Convergence Debate: A New Look at Cross-Country Growth Empirics." *Journal Of Economic Growth*, *1*(3), 363–389.

Ciaian, P., and Kancs, D. A. (2012). "The Capitalization of Area Payments into Farmland Rents: Micro Evidence from the New EU Member States." *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie*, *60*(4), 517–540.

Ciaian, P., and Swinnen, J. (2009). "Credit Market Imperfections and the Distribution of Policy Rents." *American Journal of Agricultural Economics*, *91*(4), 1124–1139.

Cuerva, M. C. (2011). "Dynamics of European Agricultural Productivity: An Analysis of Regional Convergence." *Review of Agricultural and Environmental Studies,* 92 (3), 237–258.

Cuerva, M. C. (2012). "Determinants of Labor Productivity Convergence in the European Agricultural Sector." *Agrociencia*, *46*(6), 621–635.

Falkowski, J., and Olper, A. (2014). "Political Competition and Policy Choice: The Evidence from Agricultural Protection." *Agricultural Economics*, 45, 143–158.

FAO, IFAD, UNICEF, WFP and WHO. 2022. *The State of Food Security and Nutrition in the World 2022. Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable*. Rome, FAO. https://doi.org/10.4060/cc0639en

FAO, UNDP and UNEP. (2021). A multi-billion-dollar opportunity – Repurposing agricultural support to transform food systems. Rome, FAO. https://doi.org/10.4060/cb6562en

Fuglie, K. (2018). "R&D Capital, R&D Spillovers, and Productivity Growth in World Agriculture." *Applied Economic Perspectives and Policy,* 40(3), 421–444.

Fuglie, K., S. Wang, and V. Ball, eds. (2012). *Productivity Growth in Agriculture: An International Perspective*, Wallingford, UK: CAB International.

Fuglie, K., Jelliffe, J., and Morgan, S. (2021). "Slowing Productivity Reduces Growth in Global Agricultural Output." *Farm Economy*, United States Department of Agriculture, Economic Research Service. Ga

Gautam, M., Laborde, D., Mamun, A., Martin, W., Pineiro, V. and Vos, R. (2022). *Repurposing Agricultural Policies and Support: Options to Transform Agriculture and Food Systems to Better Serve the Health of People, Economies, and the Planet.* Washington, DC, World Bank and IFPRI. https://openknowledge.worldbank.org/handle/10986/36875

Garrone, M., Emmers, D., Lee, H., Olper, A., and Swinnen, J. (2019). "Subsidies and Agricultural Productivity in the EU." *Agricultural Economics,* 50, 803–817.

Gardner, B. L. (2005). "Causes of rural economic development." *Agricultural Economics,* 32 (2005): 21-41.

Gollin, D., Hansen, C. and Wingender, A. (2021). "Two Blades of Grass: The Impact of the Green Revolution." *Journal of Political Economy,* 129 (8), 2344–2384.

Hennessy, D. A. (1998). "The Production Effects of Agricultural Income Support Policies Under Uncertainty." *American Journal of Agricultural Economics*, *80*(1), 46–57.

Islam, N. (2003). "What Have We Learnt from the Convergence Debate?" *Journal of Economic Surveys*, *17*(3), 309–362.

Kazukauskas, A., Newman, C., and Sauer, J. (2014). "The Impact of Decoupled Subsidies on Productivity in Agriculture: A Cross-Country Analysis Using Microdata." *Agricultural Economics*, *45*(3), 327–336.

Kumbhakar, S.C., and Lien, G. (2010). "Impact of Subsidies on Farm Productivity and Efficiency." *The economic impact of public support to agriculture: An international perspective*. 109-124

Laborde, D., and Mamun, A. (2022). "Global Database on Nominal Rate of Assistance in Agriculture: 1961–2018." Washington, DC, IFPRI.

Laborde, D., Mamun, A., Martin, W., Pineiro, V., and Vos, R. (2021). "Agricultural Subsidies and Global Greenhouse Gas Emissions." *Nature Communications*, 12, 2601.

Latruffe, L., and Desjeux, Y. (2016). "Common Agricultural Policy Support, Technical Efficiency and Productivity Change in French Agriculture." *Review of Agricultural, Food and Environmental Studies*, *97*(1), 15–28.

Leibenstein, H. (1966). "Allocative Efficiency Vs. "X-Efficiency." *American Economic Review*, *56*(3), 392–415.

Mankiw, G., Romer, D., and Weil, D. (1992). "A Contribution to the Empirics of Economic Growth." *Quarterly Journal of Economics*, 107, 407–437.

Martin, W. 2019. "Economic Growth, Convergence and Agricultural Economics." *Agricultural Economics* 50 (S1): 7–27.

Mary, S. (2013). "Assessing the Impacts of Pillar 1 and 2 Subsidies on TFP in French Crop Farms." *Journal of Agricultural Economics*, *64*(1), 133–144.

Minviel, J. J., and Latruffe, L. (2017). "Effect of Public Subsidies on Farm Technical Efficiency: A Meta-Analysis of Empirical Results." *Applied Economics*, *49*(2), 213–226.

Nickell, S. (1981). "Biases in Dynamic Models with Fixed Effects." *Econometrica*, *49*(6), 1417–1426.

OECD. (2008). *Agricultural Policy Design and Implementation: A Synthesis*. Paris, France: OECD.

UNCTAD. (2007). *Green Box Subsidies: A Theoretical and Empirical Assessment*. UCTAD India Team, India.

Olper, A. (1998). "Political Economy Determinants of Agricultural Protection Levels in EU Member States: An Empirical Investigation." *European Review of Agricultural Economics*, 25, 463–487.

Olper, A. (2007). "Land Inequality, Government Ideology and Agricultural Protection." *Food Policy*, 32, 67–83.

Rizov, M. (2005). "Does Individualization Help Productivity of Transition Agriculture?" *Agricultural Economics*, 33(2), 215–227.

Rizov, M., Pokrivcak, J., and Ciaian, P. (2013). "CAP Subsidies and Productivity of the EU Farms." *Journal of Agricultural Economics*, 64(3), 537–557.

Roche, M. J., and McQuinn, K. (2004). "Riskier Product Portfolio Under Decoupled Payments." *European Review of Agricultural Economics*, 31(2), 111–123.

Roodman, D. M. (2009). "A Note on the Theme of Too Many Instruments." *Oxford Bulletin of Economics and Statistics*, 71, 135–158.

Haque, S., Foster, K. A., Keeney, R., Boys, K. A., & Narayanan, B. G. (2019). "Output and input bias effects of US direct payments." Agricultural Economics, 50(2), 229-236.

Solow, R. M. (1956). "A Contribution to the Theory of Economic Growth." *Quarterly Journal of Economics*, 70(1), 65–94.

USDA Economic Research Service. (2021). *International Agricultural Productivity* data product.

US Department of Agriculture (2022). https://www.ers.usda.gov/data-products/international-agricultural-productivity/ (accessed 10 May 2022).), Economic Research Service. International Agricultural Productivity.

Zhu, X., and Milán Demeter, R. (2012). “Technical Efficiency and Productivity Differentials of Dairy Farms in Three EU Countries: The Role of CAP Subsidies.” *Agricultural Economics Review,* 13(1), 66– 92.

Zhu, X., and Oude Lansink, A. (2010). “Impact of CAP Subsidies on Technical Efficiency of Crop Farms in Germany, the Netherlands and Sweden.” *Journal of Agricultural Economics*, 61(3), 545–564.

APPENDIX

Table A.1: Convergence regression of productivity growth based on different instruments

Explanatory variables	**(1) SYS-GMM[1]**	**(2) SYS-GMM[2]**	**(3) SYS-GMM[3]**
Output subsidy (t-1)	0.075**	-0.174	0.243***
	(0.025)	(0.259)	(0.049)
Input subsidy (t-1)	-0.051	-0.169	-0.213^{+}
	(0.076)	(0.28)	(0.128)
"Other" subsidy (t-1)	-0.001	-0.001	-0.087**
	(0.015)	(0.113)	(0.034)
Agr. output (t-1)	0.005**	0.007***	0.003***
	(0.002)	(0.002)	(0.001)
GDP growth (t-1)	-0.003	-0.01***	-0.005**
	(0.002)	(0.003)	(0.002)
Population density (t-1)	0.09^{+}	0.004	0.044
	(0.05)	(0.112)	(0.068)
Grassland ratio (t-1)	-0.000	-0.011	-0.01^{+}
	(0.007)	(0.015)	(0.006)
Employment growth (t-1)	0.023**	0.019*	0.008^{+}
	(0.008)	(0.008)	(0.004)
Domestic invest. (t-1)	0.011	0.041	0.048*
	(0.023)	(0.031)	(0.019)
N	1983	1983	1983
Number of instruments	18	18	18
Hansen-Sargan J-stat p-value	0.093	0.061	0.050
AR(1) p-value	0.000	0.000	0.000
AR(2) p-value	0.042	0.042	0.041

Note: SYS-GMM regressions include time fixed effects, and subsidy payments, employment growth, and GDP growth are treated as endogenous, while population density and the grassland ratio are exogenous. AR(*n*) is the Arellano and Bond test for autocorrelation of first and higher order, respectively; the Hansen-Sargan test ("J test") is the test for overidentification or joint validity of instruments. Standard errors based on Z-statistics are reported in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

1: SYS-GMM is estimated with instrumenting convergence term only (Agri. output (t-1))

2: SYS-GMM is estimated with instrumenting convergence term and subsidies (Agri. output (t-1), Output subsidy (t-1), Input subsidy (t-1), "Other" subsidy (t-1))

3: SYS-GMM is estimated with instrumenting subsidies only (Output subsidy (t-2), Input subsidy (t-2), "Other" subsidy (t-2), Output subsidy (t-3), Input subsidy (t-3), "Other" subsidy (t-3))

Table A.2: Convergence regression of labor productivity based on different instruments

Explanatory variables	**(1) SYS-GMM[1]**	**(2) SYS-GMM[2]**	**(3) SYS-GMM[3]**
Output subsidy (t-1)	0.062***	0.019	0.349***
	(0.016)	(0.24)	(0.086)
Input subsidy (t-1)	0.08^{+}	0.393	0.297
	(0.046)	(0.321)	(0.238)
"Other" subsidy (t-1)	-0.026	-0.236	-0.216***
	(0.018)	(0.162)	(0.045)
Agr. out. per worker (t-1)	0.007^{+}	0.008*	0.003*
	(0.004)	(0.004)	(0.001)
GDP growth (t-1)	-0.000	-0.004	0.001
	(0.002)	(0.005)	(0.003)
Population density (t-1)	0.232***	0.084	0.095*
	(0.045)	(0.111)	(0.045)
Grassland ratio (t-1)	-0.007	-0.018	-0.004
	(0.008)	(0.022)	(0.011)
Employment growth (t-1)	0.018	0.017	0.007
	(0.012)	(0.013)	(0.007)
Domestic invest. (t-1)	-0.048*	0.008	-0.040
	(0.023)	(0.037)	(0.024)
N	1983	1983	1983
Number of instruments	18	18	18
Hansen-Sargan J-stat p-value	0.034	0.009	0.007
AR(1) p-value	0.000	0.000	0.000
AR(2) p-value	0.039	0.034	0.046

Note: SYS-GMM regressions include time fixed effects, and subsidy payments, employment growth, and GDP growth are treated as endogenous, while population density and the grassland ratio are exogenous. AR(*n*) is the Arellano and Bond test for autocorrelation of first and higher order, respectively; the Hansen-Sargan test ("J test") is the test for overidentification or joint validity of instruments. Standard errors based on Z-statistics are reported in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
1: SYS-GMM is estimated with instrumenting convergence term only (Agr. out. per worker (t-1))
2: SYS-GMM is estimated with instrumenting convergence term and subsidies (Agr. out. per worker (t-1), Output subsidy (t-1), Input subsidy (t-1), "Other" subsidy (t-1))
3: SYS-GMM is estimated with instrumenting subsidies only (Output subsidy (t-2), Input subsidy (t-2), "Other" subsidy (t-2), Output subsidy (t-3), Input subsidy (t-3), "Other" subsidy (t-3))

Table A.3: Impact of price incentives on agricultural productivity

Dependent variable:	**Output growth**	**Δ Agr. output per worker**
	(1) **SYS-GMM**	**(2)** **SYS-GMM**
Nominal rate of protection (t-1)	-0.023. (0.013)	0.026 (0.024)
Output subsidy (t-1)	0.251*** (0.07)	0.116 (0.161)
Input subsidy (t-1)	0.32 (0.391)	0.757* (0.316)
'Other' subsidy (t-1)	0.028 (0.054)	0.09 (0.125)
Agr. Output (t-1)	-0.001 (0.005)	
Agr. output per worker (t-1)		-0.024** (0.009)
GDP growth (t-1)	-0.046 (0.126)	-0.342* (0.154)
Population density (t-1)	0.03. (0.017)	0.042** (0.014)
Grassland ratio (t-1)	0.022 (0.056)	0.222* (0.087)
Employment growth (t-1)	0.029*** (0.006)	0.028*** (0.008)
Domestic invest. (t-1)	-0.121 (0.119)	-0.064 (0.15)
N	1983	1983
Number of instruments	38	38
Sargan J-stat p-value	0.145	0.025
AR(1) p-value	0.000	0.000
AR(2) p-value	0.053	0.067

Note: OLS regression includes time dummies; FE regression includes region and time fixed effects; SYS-GMM regressions include time fixed effects, and subsidy payments, employment growth, and GDP growth are treated as endogenous, while population density and the grassland ratio are exogenous. AR(n) is the Arellano and Bond test for autocorrelation of first and higher order, respectively; the Hansen-Sargan test ("J test") is the test for overidentification or joint validity of instruments. Standard errors based on Z-statistics are reported in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.4: Country and data coverage

Country	Period
Argentina	1991–2018
Australia	1991–2018
Benin	1991–2018
Brazil	1991–2018
Burkina Faso	1991–2018
Canada	1991–2018
Chile	1991–2018
China	1991–2018
Colombia	1991–2018
Dominican Republic	1991–2017
Ecuador	1991–2016
Ethiopia	1991–2018
European Union[1]	1991–2018
Ghana	1991–2018
Iceland	1991–2018
India	1991–2018
Indonesia	1991–2015
Israel	1995–2018
Japan	1991–2018
Kazakhstan	1995–2018
Kenya	1991–2018
Korea, Republic of	1991–2018
Mali	1991–2018
Mexico	1991–2018
Mozambique	1991–2018
New Zealand	1991–2018
Nicaragua	1991–2017
Nigeria	1991–2015
Norway	1991–2018
Pakistan	1991–2013
Philippines	1991–2018
Russian Federation	1992–2018
Senegal	1991–2018
South Africa	1991–2018
Sri Lanka	1991–2014
Switzerland	1991–2018
Tanzania, United Republic of	1991–2018
Turkey	1991–2018
Uganda	1991–2018
Ukraine	1992–2018
United States of America	1991–2018
Viet Nam	1991–2018

Note: [1]The European Union is represented as one region.

ALL IFPRI DISCUSSION PAPERS

All discussion papers are available **here**

They can be downloaded free of charge.

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
www.ifpri.org

IFPRI HEADQUARTERS

1201 Eye Street, NW
Washington, DC 20005 USA
Tel.: +1-202-862-5600
Fax: +1-202-862-5606
Email: ifpri@cgiar.org