Measuring the Impacts of Repurposing Agricultural Support for Global Agriculture

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by

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Short Abstract

Vast amounts of resources are spent on support to agriculture, with questionable results for agriculture, for national incomes, for nutrition and for the environment. Is it possible to repurpose some of this support in ways that will bring about better outcomes? This study uses detailed modeling of the links between support, emissions and other outcomes to examine several different potential approaches. Simply removing or rearranging support seems not to be sufficient. While removing subsidies can reduce emissions, these reductions are slight relative to current emission levels, while removing border measures may increase emissions by increasing global demand and reallocating production. More comprehensive reforms, such as allocating more resources to R&D that results in lower emissions and higher efficiency, could have much more favorable impacts. Approaches that use conditionality to move producers to lower-emission production approaches can also play a role, although, if these involve lower productivity, they may put greater pressure on land use change and its associated emissions.

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Impacts of Repurposing Agricultural Support for Global Agriculture

When considering reforms of agricultural support policies, it is vitally important to understand the complex and multifaceted links between the support provided and the outcomes achieved. This requires creating measurable outcomes and then exploring the relationships between the support instruments and the policy goals. Reducing emissions of greenhouse gases (GHG) is critical to environmental sustainability.[1] This is because agriculture is both an important contributor to global warming and strongly affected by the impacts of climate change and variability. But we cannot focus solely on the impacts of reforms on GHG emissions because policy makers are also deeply concerned about impacts on poverty, nutrition, and the natural environment. Thus, the question becomes whether we can identify policy reforms that help—or at least do not hinder—achievement of those goals as well as reductions in GHG emissions.

This study expands on previous work which examined the impacts of reforming agricultural support on emissions from agricultural production (Laborde et al. 2020, 2021). That study included only the agricultural support provided by 51 countries as measured by the OECD (2020) and looked only at the impacts of reforming agricultural support measures on GHG emissions from agricultural production. It did not consider impacts through agricultural land-use change.

Despite these limitations, that analysis provided important insights into the degree and channels of influence of agricultural support on production and GHG emissions. It also highlighted the differential impacts of support provided by subsidies on production and inputs and that provided in by market price support arising from trade measures. The study found that the current pattern of subsidies induces higher levels of global agricultural production and GHG emissions than in the absence of such support. With market price support from border measures, by contrast, the

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[1] Agriculture is also the lead contributor to biodiversity loss, through the conversion of natural habitats to agricultural land, and degradation of the natural resource base, including land and water. The analysis in this study, however, is focused on GHG emissions because incorporating the all the other dimensions explicitly is enormously complex, and remains a task for future research. Nevertheless, some of these externalities are implicitly subsumed in the estimation of GHG emissions (e.g., through GHG emissions associated with land use change, and emissions directly from soils, crop burning, fertilizer and other chemical uses, etc.) though the longer term and 'hidden costs' associated with these externalities, such as loss of ecosystem services, and their potential impacts on future productive potential, are not adequately accounted for. As such, the estimates of the economic impacts in this study may be considered as lower-bound estimates of the true cost associated with policies influencing the decisions of agricultural producers.

stimulus to global output (and emissions) provided by higher prices in protected markets is offset by a contraction in global demand resulting from higher consumer prices in those markets.

A further important insight from the previous study was that a global strategy for repurposing of agricultural support towards expenditures on R&D and other measures directly targeting productivity improvements and lower emission intensities has great potential for reducing global GHG emissions from agriculture. This potential remained despite a significant 'rebound effect' caused by higher productivity growth, with higher productivity lowering consumer prices, stimulating demand and increasing output. While this rebound effect was only partial (because demand elasticities for food are relatively low), it does limit the effectiveness of productivity growth in lowering global emissions from production. A key question is what further complementary measures could help contain the rebound effect. And perhaps most importantly, a key question is the extent to which these overall outcomes might change when also taking account the impacts on emissions from land-use change.

The present study expands the analysis in three important ways. First, it considers the effects of agricultural land-use change on GHG emissions in addition to emissions from agricultural production. Second, the analysis uses a larger group of countries for which consistent data are available, expanding the coverage from the 51 countries covered in the earlier analysis to 73 countries,[2] bringing coverage of global agricultural production close to 83 percent. Importantly, coverage now includes several low-income countries that are not included by the OECD in its latest update (OECD 2020). It should be noted, however, that – overall – the increased country coverage only modestly increases the earlier cited global cost of agricultural support, as the added lower-income countries have relatively smaller agricultural sectors and limited fiscal resources.[3] The third enhancement relative to the earlier work is to move to explore approaches for repurposing support for better environmental, economic, and social outcomes.

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[2] These data were collated from, in order of preference, the agricultural support measures incorporated in the Agricultural Incentives database (Tokgoz et al. 2017); data on agricultural distortions from Anderson et al (2009); and data on tariffs obtained from the Prerelease of the Version 11 GTAP database for 2017 which updates and extends Aguiar et al. (2019). In addition, we added measures of agricultural subsidies obtained from literature reviews of individual countries.

[3] For instance, the global transfer created by market-price support for agricultural producers provided through import restrictions increases by 4 percent with the inclusion of the additional 19 lower income countries. The transfers away from producers generated by (negative) market-price support through export restrictions increases by 20 percent, however, enhancing the representativeness of coverage of this type of measures

These extensions, and particularly the addition of emissions from land-use change, are hugely important. This is partly because, globally, gross GHG emissions associated with land use change[4] are in the same order of magnitude as those from agricultural production. It is also important to account for other potential negative externalities associated with land-use change, such as biodiversity loss (World Bank 2021). Accounting for land-use change is likely to influence the results in important ways. For instance, incentives to expand production may induce deforestation, increasing emissions from expansion of agricultural land use and reduction in sequestration capacity. This matters both for changes in support and when funds are repurposed from providing direct subsidies into supporting R&D that can both reduce emissions and increase productivity. In the earlier analysis, such R&D suffered from a rebound effect, where higher productivity lowered consumer prices and increased demand. The current and more robust analysis, with land-use change is incorporated, shows—inter alia—that the increase in productivity reduces the demand for land and the emissions associated with land-use change.

The first step for the present analysis was to enhance the global modeling framework to include the expanded database of agricultural support measures, update the baseline estimates of emissions from both agricultural production and land-use change, and include model specifications for the links between support measures, agricultural production, land-use change and GHG emissions. A second step was to perform policy experiments to study the impacts of existing support, by creating a counterfactual of what would be levels of production, emissions, incomes, prices, etc. in the absence of the different kinds of support. The third step was to perform experiments that examine changes in the use of support, including refocusing of subsidies away from products with high emission intensities, conditionality designed to reduce use of chemical fertilizers and pesticides, and greater investments in research and development (R&D) that both lower emissions and increase productivity.

The next section of the paper considers the analytical tools needed for this study, particularly the modeling framework, the emissions database, the measures of agricultural distortions and the household models used to assess impacts on poverty. Section 2 examines the results from a range of simulations, and Section 3 provides a short summary and conclusions.

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[4] ‘Gross’ in this context refers to emissions from land use change not accounting for change in GHG sequestration by soils and forests.

1. Analytical Tools

In this section, we describe, respectively, the development of the database on agricultural support; the enhanced database on emissions from agriculture and land use change; the modeling framework to capture the impacts of changes in incentives on emissions, poverty, and food security. We further explain how the global model framework is linked to a large set of household data and models needed to assess the impacts of agricultural policy reforms on poverty.

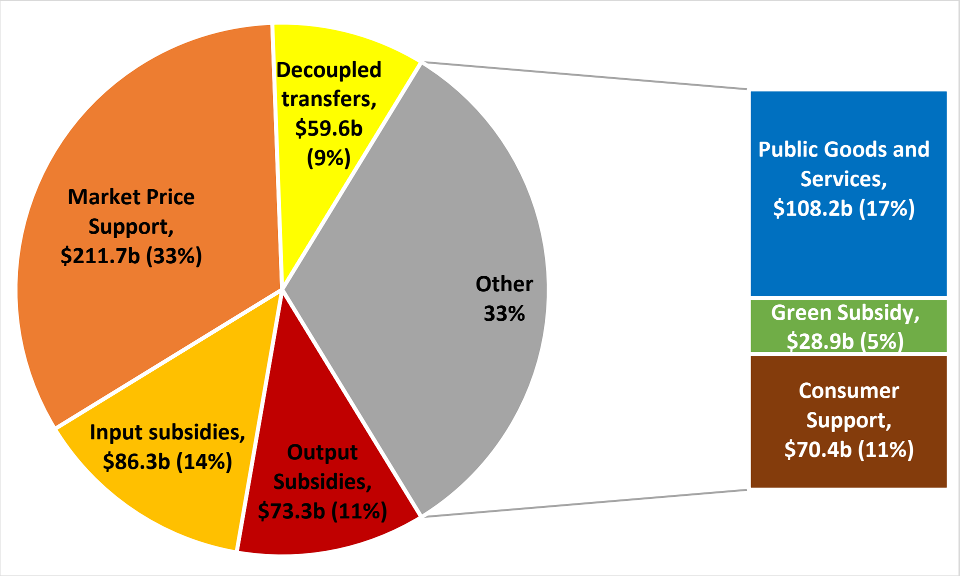
1.1 The Scale and Nature of Agricultural Producer Support

Total support to agriculture producers is provided through multiple channels. These include market price support (MPS), which is provided using many different instruments, including measures such as tariffs, licenses, tariff-rate-quotas, quotas, and trade bans. While in most countries this support is positive, some countries effectively (either implicitly or explicitly) tax producers, providing negative support using measures such as export taxes or restrictions on physical exports (including quotas or outright bans). The combined impacts of these measures are usually measured using comparisons between domestic and world prices of the same product. The OECD (2020) computes these measures for many countries regularly. These measures are complemented by data from the Inter-American Development Bank's Agrimonitor program and the FAO MAFAP's monitoring effort curated by IFPRI in the Ag-Incentives database for the International Organizations (IO) Consortium (www.ag-incentives.org). The database allows calculating the tariff equivalent, or nominal rate of protection (NRP), as a summary measure capturing all prevailing border measures, and the transfers to government associated with border interventions such as import tariffs and export taxes. The coverage of countries in the resulting database varies over time as some countries do not have data for all years since 2005. At its peak, the database includes 88 countries accounting for 88% of global agricultural production in 2012. The coverage declines to 73 countries in 2017, but still includes 83 percent of the value of world production and the pattern of protection remains consistent.

The agricultural support provided through budgetary transfers from governments (or public expenditures) to producers are regularly recorded as part of a more comprehensive measures of producer support called the Nominal Rate of Assistance (NRA). For modelling purposes, this type of support may be broadly categorized into subsidies to produce certain outputs, subsidies to inputs, or subsidies to factors. For this study, the database combines all the available measures of distortions in a way that allows the impacts of changes in these measures on output and production to be modeled.

The scale of total support provided to the agricultural sector is quite large. Restricting attention to 79 countries for which data are available for 2016-2018, the average annual support (as transfers from the government or from consumers through MPS) over these three years is estimated to be $638.3 billion (figure 1). This total includes the implicit taxation of producers through negative MPS, which on average between 2016-18 amounted to about $74.3 billion across 17 countries. In other words, the positive transfers for agriculture were $713 billion.

Figure 1: Total Annual Support to Agriculture provided by 79 Countries (2016-2018) (billions of current US$).



Source: Authors using data from IFPRI, OECD, FAO, IDB, and World Bank

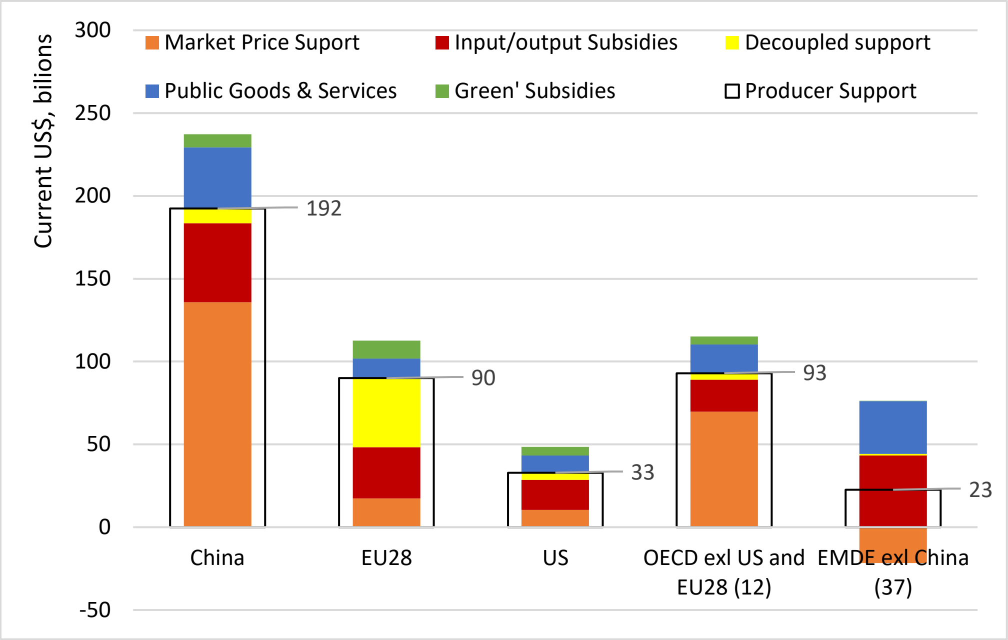
Of the total, about 11 percent is provided through measures to support poor consumers (e.g., as food stamps or public distribution systems). About 5 percent, or nearly $29 billion, is provided as ‘green subsidies’ or subsidies provided in support of environmental outcomes. This support is channeled through different instruments across countries – as input subsidies to promote less polluting inputs, or to encourage production of outputs with fewer negative externalities, or as payments for resource conservation or land set asides. Support through green subsidies has increased in recent years but remains limited in volume and in the number of countries providing such support.

Public goods and services account for 17 percent of the total support. Within this, about 31 percent is for R&D, 42 percent for infrastructure (most popularly irrigation development), and remaining 27 percent for other public services. In other words, only about 5.3 percent of the total support provided for agriculture is devoted to R&D spending, which is identified as a core driver of productivity and a key instrument to address the challenge of resilience in the face of climate change.

In contrast, transfers to producers in forms that have the greatest tendency to distort markets, specifically market price support or support/subsidies linked to output and input use (OECD 2020) account for 81 percent of producer support (i.e., total support less expenditures on public goods and services and for consumer support). Green subsidies are 6 percent and the less distorting decoupled income transfers are 13 percent of producer support.

Behind these aggregate global numbers, the level and nature of support varies significantly across countries (Figure 2). Importantly, while market price support remains the dominant form of distortionary support for most countries. Several emerging and developing countries continue to implicitly tax their producers by keeping domestic prices for key commodities below the world market (or reference) prices. In most OECD countries, positive market price supports through trade measures remains the most popular form of support governments provide to producers. As a group, the emerging and developing countries provide the largest share of their direct public support for agricultural public goods and services. Green subsidies are emerging, but evidence shows that other than China, these are largely in the developed countries.

Figure 2: Nature and Level of Agricultural Support Across Countries

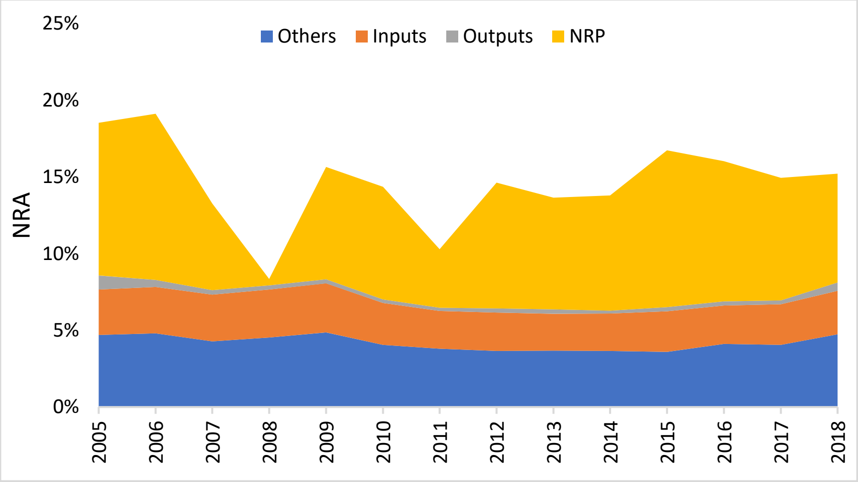


Source: Authors using data from IFPRI, OECD, FAO, IDB, and World Bank

Focusing more squarely on the elements of producer support that have the potential to alter the incentives that influence producer decisions, it is useful to assess them relative to the size of the agricultural sector, that is in terms of NRP and NRA. The trends in global agricultural producer support (using data for countries for which consistent time series are available) are presented in Figure 3. The figure shows the key measures of support – the NRP (i.e., the MPS provided by border measures), and the subsidies provided to output, inputs and other forms of support, including support decoupled from production. These measures are added up to arrive at the NRA, represented as a proportion of the value of the goods relative to external prices.

The NRA averaged 15.4 percent of gross farm receipts (GFR) for three years 2016-18. A key feature of Figure 3 is the predominance of the support provided by protection (captured by the NRP) relative to support provided in the form of public expenditures – through subsidies to output, inputs, or conditional on other variables. As noted above, support varies significantly across countries. To capture this, a breakdown of NRAs by country income levels is shown in Annex 1. The trends show the minimal support provided by low income countries while they tax to tax their farmers more in order to keep consumer prices in check. The level of publicly funded support also tends to be low (about 5 percent on average) across middle income countries, but at near 15 percent in high income countries.

Figure 3: Nominal Rate of Assistance, by Major Component (%)



Source: Authors' database of agricultural support.

Border protection measures accounted, on average, for roughly half the total assistance provided (8.1 percent of GFR on average between 2016-18). Of the subsidies provided directly by governments, most are not based on inputs or outputs to production, but on factor use, such as area planted or animal numbers (4.3 percent of GFR). While roughly 45 percent of this support is not linked to current production decisions (OECD 2020, p102), most of this nevertheless indirectly influences production through conditions such as restrictions on payments to active farmers (Abbott 2020; EU 2015) or through perceptions that payment bases are likely to be updated (Bhaskar and Beghin 2010). In order of magnitude of support, support coupled to input use (such as water, power, and fertilizer), comes next (about 2.7 percent of GFR). Direct subsidies coupled to output are smallest, averaging 0.4 percent of GFR.

A striking feature of the graph is the relative volatility of market price support, particularly in periods of high prices, such as 2008 and 2011, when many countries reduced their protection, or increased taxation on their farmers through export restrictions, seeking to reduce the impacts of the increases in world prices on their consumers. Unfortunately, this results in a serious collective action problem, with the resulting increases in demand for food exacerbating the increases in world prices (Anderson, Ivanic and Martin 2014). Another important feature of Figure 3 is the relative stability of global support patterns in periods of relatively stable prices, particularly the 2016-18 period used in this analysis.

The database used in this analysis provides estimates of the amount of support provided, not only for major producer countries, but also for many contexts important for poverty reduction and where agriculture is important to the national economy. Table 1 provides data on positive market price support in a range of economies and key regions during 2015-17 for products important both for the economy and for GHG emissions. Almost all the support shown in this table is provided by import protection, with just a few cases where protection was provided to export oriented industries through implicit export subsidies.

Table 1 highlights the relatively small differences in rates of protection between developed and developing countries, with the notable exception of rice, where the protection rate is nearly three times higher in developed countries. Another exception is wheat, which is an export crop for many developed countries inducing them to keep protection rates relatively low (12.6 percent), while developing countries maintain higher levels of protection (24.4 percent on average). Overall, while many developing countries have no protection for many commodities, they tend to apply relatively high rates when they do protect. The highest rate of protection, for instance, is provided to domestic milk production in the Dominican Republic (at 231 percent).

Table 1. Positive Protection Rate for Key Commodities by Region and Country, 2016-18 (%)

Region	**Beef**	**Milk**	**Pork/Poultry**	**Rice**	**Sugar**	**Wheat**
World	11.5	17.5	14.1	46.1	28.5	12.6
Developed	10.7	15.8	11.8	123.8	25.8	0.7
Developing	12.5	22.6	15.4	34.4	29.1	24.4
Africa	0.7	0.9	0.5	38.8	59.1	12.3
Asia	25.0	56.2	20.8	48.3	44.4	27.3
Latin America & Caribbean	0.9	6.6	3.6	38.9	9.7	2.0
Country						
Argentina	0.0	0.0	2.9			0.0
Australia	0.0	0.0	0.0	0.0	0.0	0.0
Benin				61.1		
Brazil	0.8	4.4	0.0	21.5	0.0	6.3
Burkina Faso				60.0		
Burundi				48.0		

Region	Beef	Milk	Pork/Poultry	Rice	Sugar	Wheat
Canada	0.0	66.9	0.9			0.0
Chile	0.0	0.0	0.0		3.5	0.0
China	15.5	72.0	16.9	31.3	103.1	55.0
Colombia	3.5	40.5	8.3	113.9	13.0	
Costa Rica	0.0	0.6	43.8	130.0	29.1	
Dominican Republic	29.4	230.8	45.1	58.9		
Ecuador	0.0	19.0	36.1	64.2		
El Salvador	14.4	22.4	148.2	22.4	40.8	
Ethiopia						15.7
European Union	27.0	0.1	9.0	23.9	3.1	0.8
Guatemala			67.9	6.2	81.5	
Honduras	26.1	22.1	28.9	7.2	27.5	
Iceland	37.2	92.7	210.2			
India			25.2		25.8	0.4
Israel	4.5	50.4	43.1			16.9
Japan	38.5	134.8	94.0	228.3	34.3	0.0
Kazakhstan	3.5	0.0	0.0			4.2
Kenya				30.6	80.8	18.3
Korea, Republic of	43.4	133.8	136.5	102.3		
Mali	13.9			34.7		
Mexico	0.0	0.2	0.3	0.0	42.5	0.0
Mozambique			9.8	4.3		
New Zealand	0.0	0.0	7.5			0.0
Nicaragua	0.0	0.0	83.3	75.2	0.0	
Norway	84.0	102.2	111.6			89.1
Paraguay	0.0	0.0	0.0	0.0		0.0
Philippines	10.0		37.3	136.6	59.7	
Russian Federation	22.1	38.8	11.5		46.3	0.2
Rwanda				80.7		104.6
Senegal				20.0		
South Africa	0.0	0.9	0.5		56.1	0.4
Switzerland	71.4	29.0	138.9		2.1	32.5
Turkey	120.3	0.5	39.4		2.8	0.0
Uganda				74.9	48.3	
Ukraine	0.0		4.5		2.7	0.0
United States of America	0.0	27.6	0.0	0.0	81.6	0.0
Uruguay	0.0	0.0	43.0	0.0		0.0
Viet Nam	21.2		0.0	9.2	98.6	

Source: Authors' calculations only for countries/commodities with positive protection.

Of the major world economies, China now provides substantial positive support to key agricultural products, a complete reversal from the overwhelming taxation of the sector in the 1980s and 1990s (Huang et al. 2009). The European Union, in contrast, currently provides relatively modest market price support on the key commodities in Table 1, while high rates of market price support in the USA are applied on milk and sugar. Japan continues to have relatively high protection on rice and milk. A set of relatively land-scarce high-income countries including Iceland, the Republic of Korea, Norway, and Switzerland also have high rates of protection. But high rates of protection are also seen in many developing countries, with rates above 100 percent on rice seen in Colombia, Costa Rica, and the Philippines.

Table 2. Negative Protection Rate for Key Commodities by Region and Country, 2016-18 (%)

Region	Beef	Milk	Pork/Poultry	Rice	Sugar	Wheat
World	-2.0	-12.1	-0.9	-8.4	-1.1	-1.0
Developed	0.0	0.0	0.0	0.0	0.0	-1.8
Developing	-6.0	-18.7	-3.1	-8.8	-1.3	-0.3
Africa	-2.6	-56.7		-42.4	-20.3	
Asia	-26.2	-20.7	-34.3	-7.4		-12.6
Latin America & Caribbean	-18.7	-31.8	-35.6		-3.0	-0.3
Country						
Argentina	-18.3	-33.5	-39.2			-0.3
Burundi				-0.1		
Dominican Republic	-12.4				-3.0	
Ghana				-63.1		
Guatemala	-22.2	-9.2				
Honduras			-2.2			
India	-26.2	-20.7		-6.2		
Kazakhstan				-52.4		-12.6
Kenya				-49.2		
Malawi					-20.3	
Mali	-2.6					
Mozambique				-25.8		
Russian Federation						-6.5
Rwanda		-56.7				
Tanzania				-37.4		
Uganda				-45.9		
Ukraine		-21.1				
Viet Nam			-34.3	-12.9		

Source: Authors' calculations only for commodities/commodities with negative protection.

A very different pattern is evident with the negative protection shown in Table 2. This is generally imposed through explicit or implicit taxation of exports, although occasionally it is the result of import subsidies used to keep domestic prices below world prices. Such "negative support" is almost non-existent in the developed countries and much less widely used in developing countries than positive import protection. Developing countries that do apply export taxes or import subsidies, however, tend to do so quite strongly, reflected in high average rates of between 22 percent and 35 percent for beef, milk, and poultry. One particularly important case is India where domestic prices for bovine meat and milk are substantially below world prices, with important implications for global production and consumption levels. Argentina is another important outlier, particularly at its income level, where domestic prices of beef, milk and pork are substantially below world prices.

Table 3.a. Distribution of Subsidies by Product, Instrument and Country Grouping, 2016-18

	High-Income countries				***Low- and Middle-Income countries***				
Sector	**Output subsidies**	**Input subsidies**	**Factor subsidies**	***Sub-Total***	**Output subsidies**	**Input subsidies**	**Factor subsidies**	***Sub-Total***	**World Total**
Cattle	0.1	1.3	4.1	*5.5*	0.1	1.2	1.1	*2.4*	**7.9**
Dairy	0.4	1.2	4.4	*6.0*	0.2	1.3	0.5	*2*	**8.0**
Poultry and Pigs	0.3	1.8	5.1	*7.2*	0.2	2.0	2.3	*4.5*	**11.7**
Livestock subtotal	0.8	4.3	13.6	*18.7*	0.5	4.5	3.9	*8.9*	**27.6**
Fibers	0.1	0.1	0.6	*0.8*	6.1	0.9	1.2	*8.2*	**9.0**
Maize	0.4	0.9	2.8	*4.1*	0.1	2.1	7.2	*9.4*	**13.5**
Oilseeds	2.4	0.7	1.8	*4.9*	0.1	1.8	3.6	*5.5*	**10.4**
Other crops	0.0	0.9	3.5	*4.4*	0.3	3.3	1.1	*4.7*	**9.1**
Rice	0.1	0.1	0.8	*1.0*	0.1	3.7	2.1	*5.9*	**6.9**
Sugar crops	0.3	0.2	0.5	*1*	0.1	0.8	0.2	*1.1*	**2.1**
*Vegetables * Fruits*	0.0	2.1	5.5	*7.6*	0.5	4.8	2.5	*7.8*	**15.4**
Wheat	0.8	0.4	1.9	*3.1*	0.2	1.6	1.1	*2.9*	**6.0**
Crops subtotal	4.1	5.4	17.4	*26.9*	7.5	19.0	19	*45.5*	**72.4**
All products	4.9	9.7	31.0	*45.6*	8.0	23.5	22.9	*54.4*	**100.0**

Table 3.b. Rate of Subsidies by Instrument, Sector and Country Grouping, 2016-18

	High-Income countries				***Low- and Middle-Income countries***			
Sector	**Output subsidies**	**Input subsidies**	**Factor subsidies**	**Total**	**Output subsidies**	**Input subsidies**	**Factor subsidies**	**Total**
Cattle	0.3	1.8	4.5	6.6	0.4	1.2	1.7	3.3
Dairy	0.7	2.2	5.7	8.6	0.7	1.5	1.0	3.2
Poultry and Pigs	0.3	1.7	4.2	6.2	0.7	1.2	1.9	3.8
Fibers	2.1	2.5	8.0	12.6	34.6	3.2	3.3	41.1
Maize	0.8	2.6	4.2	7.6	0.5	1.8	5.1	7.4
Oilseeds	7.7	2.4	4.7	14.8	0.4	1.7	3.0	5.1
Other crops	0.0	2.7	12.4	15.1	1.5	3.1	1.5	6.1
Rice	0.1	1.3	9.3	10.7	0.7	3.2	2.4	6.3
Sugar crops	6.0	1.8	4.3	12.1	0.4	2.5	0.9	3.8
Vegetables & Fruits	0.0	2.0	5.4	7.4	1.0	2.0	1.5	4.5
Wheat	5.0	2.3	6.0	13.3	0.9	3.2	2.6	6.7

Source: Authors' calculations.

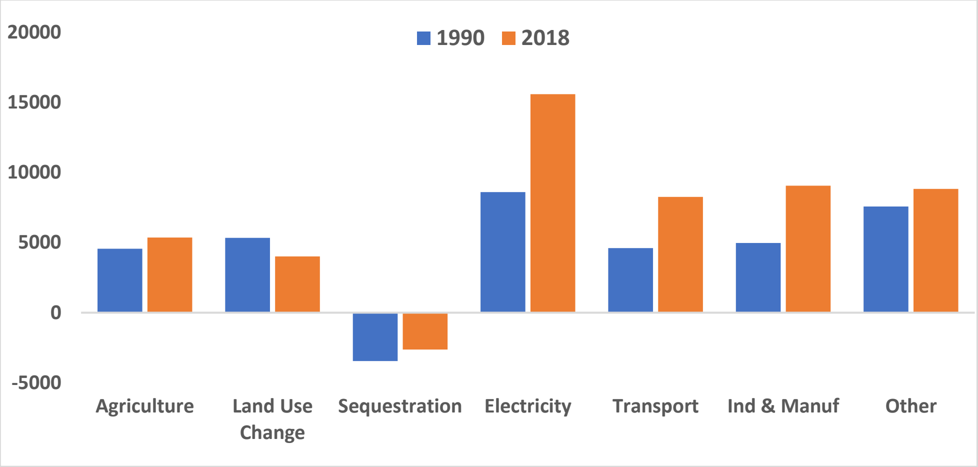
From earlier analysis (Laborde et al. 2020), it is known that subsidies tend to have a significant influence on GHG emissions, partly because they increase output without the offsetting impact on global demand associated with market price support, and partly because part of this support is in the form of subsidies on inputs such as chemical fertilizer or pesticides, which directly affect emissions.

1.2 The Database for Emissions

GHG emissions from agricultural production and land use change remain an important component of total emissions. Figure 4 shows key components of global GHG emissions in megatons of CO_2 equivalent for 1990 and 2018. The increase in emissions from agriculture was 17% during that period. By contrast, gross emissions from land use change declined by 25 percent because of a reduction in the rate of deforestation and a reassessment of organic soils emissions. The quantity of CO_2 sequestered by forests declined by 24 percent, partly because of the decline in overall forest cover and forest health. But the changes in emissions associated with agriculture were small relative to the changes observed for other sectors, especially energy/electricity (81 percent), transport (79 percent) and industry (82 percent).

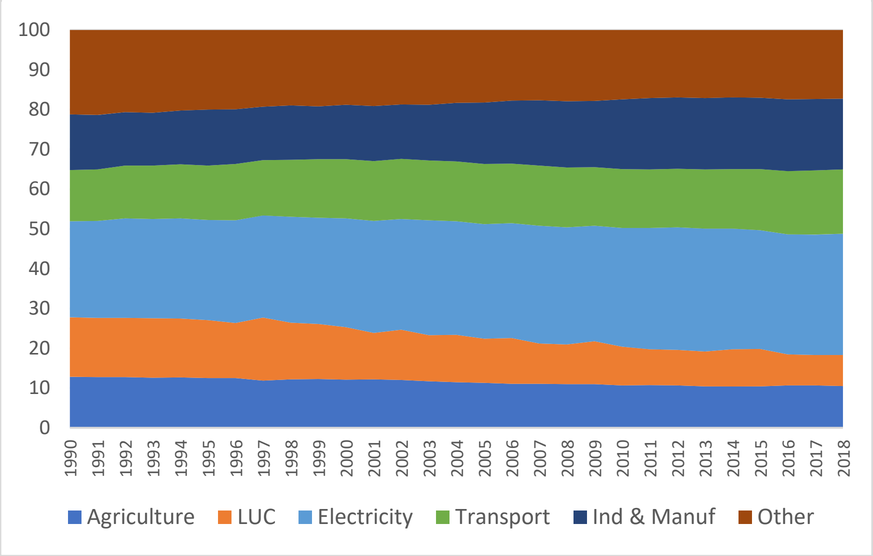
Figure 5 shows that the share of agriculture and land use change in gross emissions (excluding sequestration) fell from 28 percent in 1990 to 18.3 percent in 2018. This leaves the share of agriculture and land use change in gross emissions roughly on par with the shares for transport, industry, and other, which includes fugitive emission from energy production and waste. Despite the decline in the sector's share, achieving global climate goals will clearly not be possible without major efforts to reduce emissions from agricultural production and related land-use change.

Figure 4: Changes in Levels of GHG Emissions by Main Economic Sector (megatons of CO_2 equivalent).



Source: FAOSTAT for agricultural and land-use change emissions (faostat.org extracted 17 April 2021). Other categories of emissions from Climate Watch data (www.climatewatchdata.org extracted 17 April 2021).

Figure 5: Shares in Global Gross Emissions of GHG by Main Economic Sector (%)



Source: FAOSTAT for agricultural and land-use change emissions (faostat.org extracted 17 April 2021). Other categories of emissions from Climate Watch data (www.climatewatchdata.org extracted 17 April 2021)

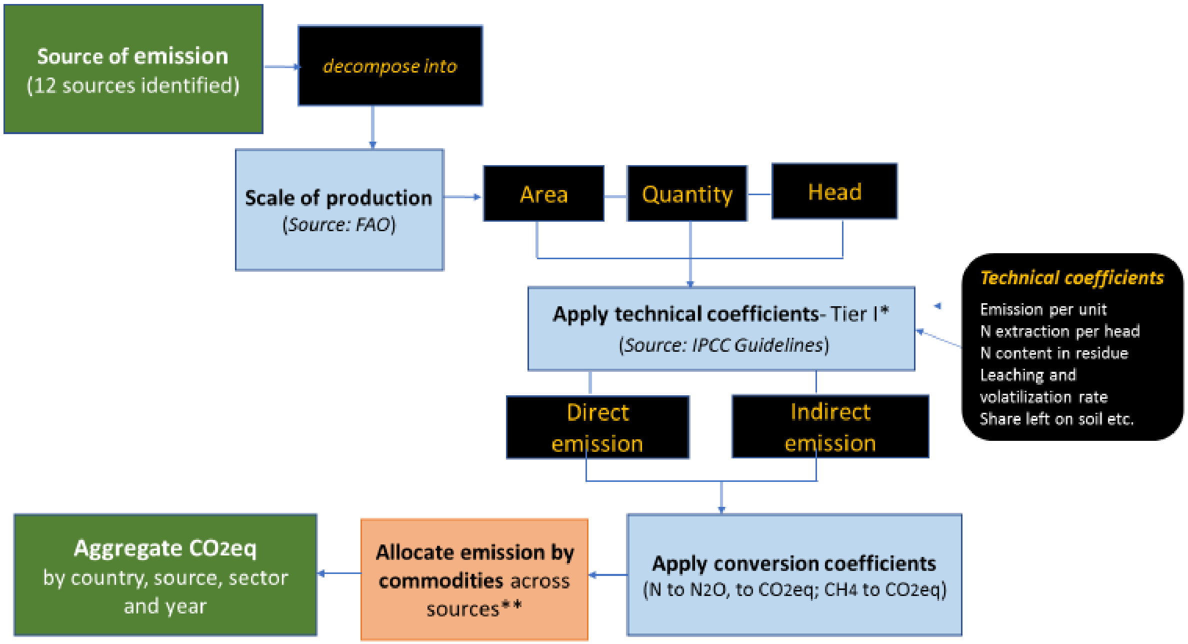
For this study, detailed databases of emissions in agricultural production and from land use change were created. FAOSTAT presents vectors of data on emissions by type and by commodity for each country, but a full matrix of emissions by type, commodity, and source is needed to consider changes in emissions by type in production of each commodity, such as reductions in emissions from enteric fermentation in beef production. Wherever possible, a full matrix is derived by reverse engineering the FAO emission data to ensure that the total matched the FAOSTAT estimates. Where this was not possible, as in the case of emissions from pesticides, a similar IPCC Tier 1 methodology was used to generate comparable estimates.

Emission sources are identified using eleven FAOSTAT-based categories plus emissions from agricultural pesticides. The first step was to define the activity levels associated with commodity outputs, such as the area used for rice cultivation. The second was to calculate the emission coefficients (EC) for CH_4, CO_2 and N_2O by activity level using, wherever possible, the FAOSTAT database. Finally, emissions of N_2O and CH_4 were converted to CO_2 equivalents using 310 and 21 for N_2O and CH_4 respectively.

In many cases, the FAOSTAT emission database provided implied emission factors by activity and emission source, such as the area harvested in rice cultivation and the nitrogen content of manure. In some cases, it provides the base activity data, such as areas of organic soil cultivation and the number of head of livestock for enteric fermentation and manure management. In other cases, such as burning crop residues, only data on biomass burned are provided, rather than data on the crops burned. In such cases, base activity data are imported from the FAOSTAT crop and livestock production database for the crops whose residues are frequently burned—maize, rice, sugar cane and wheat.

For synthetic nitrogen fertilizer, the activity data (i.e., agricultural use of nitrogen) is missing. Fertilizer use data are obtained from two sources – FAOSTAT and the International Fertilizer Association (www.ifastat.org). FAOSTAT gives the total fertilizer volume for many countries, while the IFA's Fertilizer Use by Crop data provide the nutrient content of fertilizer by crop for 54 countries. Fertilizer use data from FAOSTAT were scaled to match IFA numbers for all countries and this was done by mapping the characteristics of IFA countries to the countries listed in FAOSTAT. Finally, emissions are estimated by multiplying fertilizer volume by the emission coefficients given in FAOSTAT database. For the final version of the database, the base activity (or index) data are retained to estimate the average amount of emissions per index type (land, animals, output, fertilizer, and energy). The process for creating of this new database is presented schematically in Figure 6.

Figure 6: Creation of Database of GHG Emissions from Agriculture by Source, Location, Commodity, Production Stage and Technology



Source: Laborde et al 2021.
Notes: * Tier I: Default emission factors from IPCC guidelines (2006); ** Using disaggregation space and linkage matrix

The allocation of emissions from enteric fermentation and manure management between the joint products of meat and milk (and wool in the case of sheep) from buffaloes, camels, cattle, goats and sheep is in line with the value of their products. The resulting livestock numbers were then linked to emissions using data from the FAOSTAT emissions database. In the final step emissions data are produced by country, emission source and commodity. Data on emissions by commodity and source are presented in Table 4.

Table 4. Shares of Emissions from Agricultural Production by Commodity and Source, 2017 (%)

	Rice	***Other cereals***	***Milk***	***Ruminant meat***	***Pig, poultry meat and eggs***	***Total***
Burning of crop residues	0.2	0.5	0.0	0.0	0.0	0.7
Crop residues	1.3	3.2	0.0	0.0	0.0	4.5
Enteric fermentation	0.0	0.0	28.0	21.2	0.5	49.7
Manure management	0.0	0.0	2.2	1.9	3.4	7.5
Manure left on pasture	0.0	0.0	6.4	10.0	1.2	17.7
Manure applied to soils	0.0	0.0	1.1	1.0	2.0	4.1
Pesticides	0.0	0.3	0.0	0.3	0.0	0.6
Rice cultivation	10.7	0.0	0.0	0.0	0.0	10.7
Synthetic fertilizers	0.3	1.9	0.0	2.2	0.0	4.5
Total	12.5	5.9	37.6	36.8	7.1	100.0

Source: FAOSTAT

Table 4 highlights the extraordinary importance of emissions from milk and ruminant meat in overall emissions. Enteric fermentation associated with production of these commodities accounts for almost half of total emissions, while manure from production of these two commodities accounts for close to another 22.6 percent. The only other agricultural commodity with an important impact on emissions is rice, with 11 percent from cultivation and use of chemical fertilizers.

Another potentially important distinction is between the emission intensities of products both across products and between countries. At the world level, the emission intensity of bovine meat is roughly 40 times that of chicken and close to 20 times that for pork. The emission intensity for rice is more than four times that for other cereals. There are also sharp differences between countries and regions, with the emission intensity for beef much lower in the United States than in countries like Australia that are more focused on grass-fed production methods, while emission intensities are particularly high in India (Table 5). For both milk and bovine meat, the emission intensities in the industrial countries are much lower than in developing countries.

Table 5. Emission Intensities for Key Products and Regions, 2017 (Kg CO_2 Eq/Kg of Product)

Country/Region	***Cereals excl. rice***	***Eggs***	***Bovine meat***	***Chicken***	***Pig meat***	***Milk***	***Rice***
Australia	0.2	0.4	24.5	0.2	2.5	0.6	0.7
Brazil	0.2	0.8	34.6	0.3	2.4	1.1	0.5
European Union	0.2	0.7	15.5	0.3	1.5	0.5	3.1
India	0.3	0.5	108.3	0.4	5.0	1.0	0.7
United States	0.2	0.5	11.9	0.3	2.0	0.4	1.1
Developed	0.2	0.6	15.0	0.3	1.7	0.5	1.1
Developing	0.2	0.7	31.8	0.7	1.4	1.3	0.9
World	0.2	0.6	25.5	0.6	1.5	0.9	0.9

Source: FAOSTAT.

Emissions from land use and land-use change were estimated beginning with an inventory of land in each region mapped to the category "Cropland, Pasture, Forest and Other". The stocks of carbon associated with land use and land-use change were then tracked using procedures consistent with FAOSTAT and IPCC (2003). Carbon stock accumulation in cropland, grassland and sequestration in forests were tracked, as well as conversion between cropland and forests.

1.3 The Modeling Framework

IFPRI's global computable general equilibrium (CGE) model, MIRAGRODEP, provides the core of the modeling framework. It is an extension of the widely used MIRAGE multi-sector, recursive dynamic CGE model of the global economy[0] (Decreux and Valin 2007) that allows for a detailed and consistent representation of the economic and trade relations between countries.

In each country, a representative consumer maximizes a CES-LES (Constant Elasticity of Substitution-Linear Expenditure System) utility function subject to an endogenous budget constraint to generate the allocation of expenditures across goods. This functional form replaces the Cobb-Douglas structure of the Stone-Geary function (that is, LES) with a CES structure that retains the ability of the LES system to incorporate different income elasticities of demand (Stone 1954), with those for food typically lower than those for manufactured goods and services. The demand system is calibrated on the income and price elasticities estimated by Muhammad et al. (2017). Once total consumption of each good has been determined, the origin of the goods consumed is determined by another CES nested structure, following the Armington assumption of imperfect substitutability between imported and domestic products.

On the production side, demands for intermediate goods are determined through a Leontief production function that specifies intermediate input demands in fixed proportions to output. Total value added is determined through a CES function of unskilled labor and a composite factor of skilled labor and capital. This specification assumes a lower degree of substitutability between the last two production factors. In agriculture and mining, production also depends on land and natural resources.

The underlying database used for the analysis is Pre-release 1 of the GTAP v11 database for 2017 (www.gtap.org). This database includes 141 regions/countries and 65 products. It includes updated Social Accounting Matrices for all individually specified countries and updated estimates of agricultural support measures based on measures of average domestic support provided by OECD adjusted to include the impacts on bilateral protection rates of major trade preferences. A realistic baseline is constructed aligned with the United Nations' demographic projections and updated IMF economic growth estimates to bring the base year values (2017) to those of the actual years of simulation (2021-25) and on to the comparisons between reference and simulated outcomes in 2040.

The data on agricultural support were adjusted in line with the measures discussed in the article for agricultural border measures and subsidies that influence output or input decisions (coupled subsidies). The model was augmented with a post-solution module based on the new emission database presented above which links GHG emissions to outputs and inputs of agricultural activities within the model. These linkages are presented schematically in Figure 7. The combined model was then used to assess the impacts of policy reform on emissions of CH_4, CO_2 and N_2O, and these results combined to generate changes in emissions in CO_2 equivalents.

The macroeconomic assumptions used for the analysis were designed to be relatively "neutral" to avoid situations where macroeconomic adjustments such as real exchange rate changes outweigh the impacts of interest, and to allow focusing on the impacts of agricultural support policies on emissions. These assumptions were:

(i) the analysis is based on macroeconomic projections to 2040 implemented annually in a recursive-dynamic model;

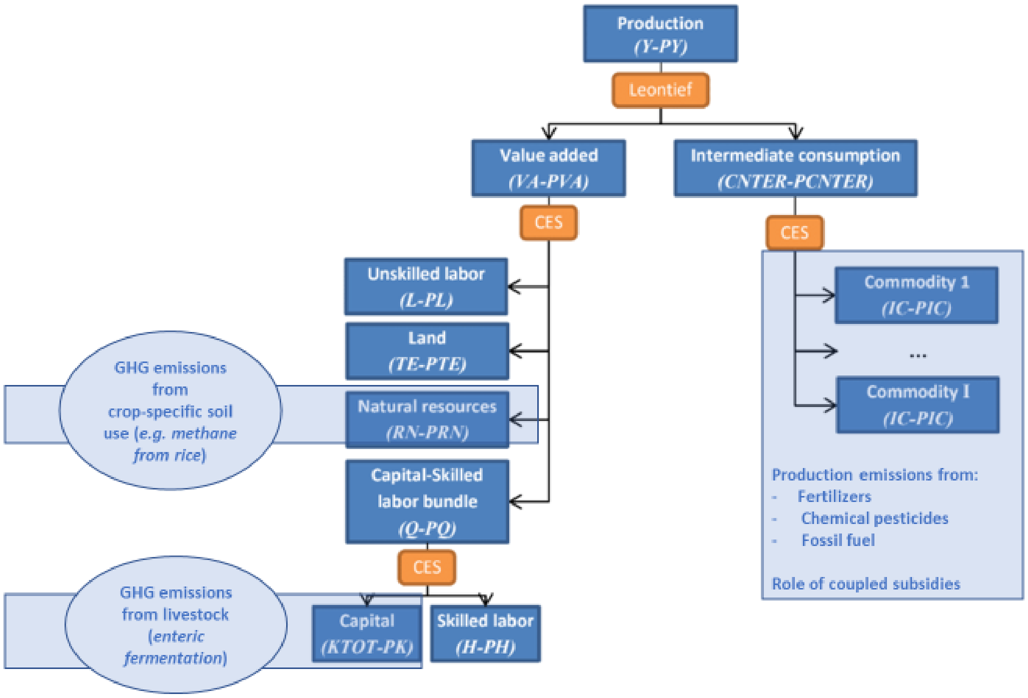
(ii) Investment is savings driven and the real exchange rate adjusts to keep the current account constant relative to national GDP,

(iii) aggregate real public expenditures are kept constant, and a consumption tax is adjusted to keep the government budget balance fixed as a share of GDP;

(iv) land use change varies across agro-ecological zones as defined for each region specified in the model and follows the procedure outlined in Hertel et al. (2009) where land is reallocated in response to changes in returns;

(v) total employment as a share of the active population is constant. The active population is defined by the 15 to 60 year old group in the UNDESA projections.

Figure 7: Linking Emissions to Production in MIRAGRODEP



Source: Laborde et al. (2021).

The modeling approach for land builds on the AEZ approach of Hertel et al (2009). Competition for land between forestry and agricultural uses within 16 agro-ecological zones is represented using a constant elasticity of transformation (CET) specification. Land is also reallocated between agricultural activities in response to changes in relative prices. Emissions from land use and land use change arise from conversion of land between forestry and agricultural uses, from transitions between grassland and cropland, from cultivation of organic soils, and from CO_2 sequestration. The model considers only land use and land use change created by changes in agricultural incentives and thus generates estimates of emissions from conversion of forest to agricultural land smaller than the gross estimates of land conversion away from forestry reported by FAO.

The poverty analyses reported in the paper were conducted using the POVANA household modeling framework documented in Laborde, Martin and Vos (2020). To make this relevant to the 2020-2040 projection period for this study, household incomes within the model were projected forward in line with trend economic growth in each country. This reduced the poverty rate in the benchmark to 3.5 percent at the traditional World Bank extreme poverty line value of $1.90 and to 10 percent at the $3.20 poverty line (both poverty lines are expressed per person per day and in purchasing power parity dollars).

2. Simulating Policy Options

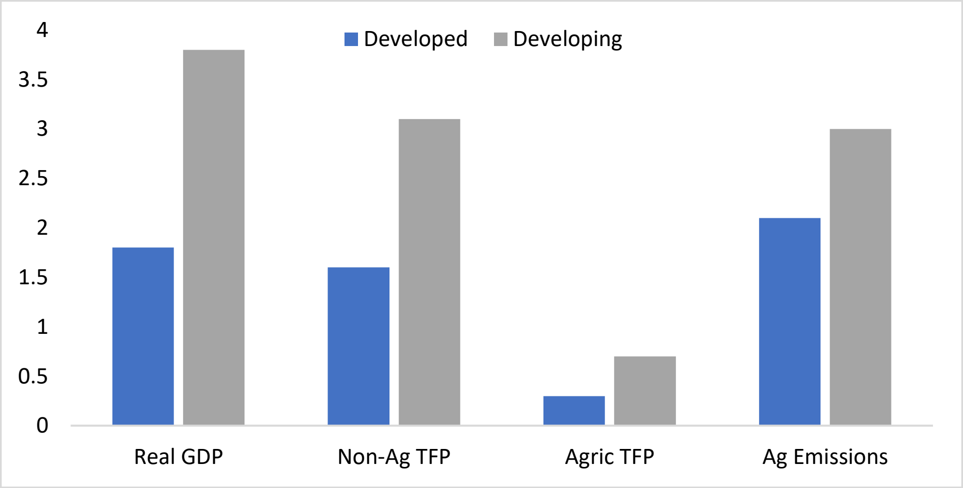
The agricultural policy reforms are assumed to be gradually (linearly) phased in between 2021 and 2025, against the backdrop of global economy-wide projections from 2020 to 2040. This allows the analysis to take into account the anticipated substantial changes in the structure of the world economy and particularly the large projected increase in the share of developing economies over the period. Simulating relative to this dynamic benchmark also allows the effects of changes in policies to cumulate over time. In the baseline scenario, the rates of protection and assistance provided by import and export barriers and subsidies were held constant. All scenarios yield simulated projections of impacts over the period 2020-2040.

One important caveat to note is that the simulations do not currently incorporate any impact of future climate change on agricultural productivity (or TFP). The historical impacts are already reflected in the current TFP assumptions (based on historical outcomes). But as Ortiz-Bobea et al (2021) point out, these impacts are accelerating and with continued unsustainable emissions, the reduction in TFP may be expected to be even larger. Future work will incorporate these into the modelling framework. For this study, some insights can be gained from the modelling scenarios that do incorporate productivity changes discussed below, which all eventually point to an even greater urgency of reducing GHG emissions.

2.1 Understanding baseline trends

As noted, impacts of policy changes are estimated as deviations from the baseline projection. It is therefore important to also have a good understanding of the baseline trends and the underlying assumptions. To focus on the core issues at hand – the impact of policy reforms – and avoid what are likely, in retrospect, to be extraordinary and uncertain adjustments to the baseline because of COVID-19 shocks, the last pre-COVID set of economic forecasts from the World Economic Outlook are used—those from October 2019 (IMF 2019). These provide historical data up to 2018, and then forecasts to 2024. The GDP forecasts to 2024 were used to capture adjustment dynamics in that time period. The final year growth rates are then used to provide a benchmark growth rate for subsequent years. In line with the trends of recent decades and most long-term projections for the world economy, the average rate of income growth in developing countries is assumed to be higher than in developed countries during 2021-2040, as are the rates of growth for population, agricultural total factor productivity and agricultural emissions (see Figure 8).

Figure 1: Baseline Projections of Key Economic and Environmental Drivers, 2017-40 (average annual growth rates in percent).



Source: Authors' baseline scenario.

Important features of Figure 8 are the substantial differences in the rates of GDP growth between developed and developing countries. Another important difference is the much higher projected growth rate of total factor productivity in developing countries for both agriculture and non-agriculture, a projection consistent with continuing income convergence (Martin 2019; Startz 2020). Agricultural total factor productivity (TFP) was adjusted relative to non-agricultural TFP taking into account information on rates of yield growth, the desirability of avoiding excessive changes in real agricultural prices during the projection baseline and the adverse impacts of climate change on yield growth going forward (Schlenker 2021; Ortiz-Bobea 2021).

2.2 Analyzing the impact of reforming current support measures

As previously noted, the options for policy reform under consideration were implemented progressively between 2020 and 2025, with the 2025 policy stance held constant as the models are projected forward. Most of the reported impacts are given as deviations from the benchmark outcome in 2040.The analysis will focus here in first instance on repurposing of domestic support measures, as these rest on re-allocable fiscal resources with a determined budget, and findings from earlier work found that this type of support tends to have a greater impact on global GHG emissions than market access barriers (Laborde et al. 2021).

The first eight simulation experiments reported in Table 6 aim to assess the impact of eliminating all coupled domestic subsidies simultaneously by all countries on global GHG emissions, farm incomes, poverty and other economic and social outcomes While achieving such a global consensus may be difficult in practice, this set of experiments is useful for understanding the influence of the current forms of support on the outcomes of interest. The first experiment assumes all support provided through coupled subsidies is eliminated. The next six experiments eliminate different components of the coupled support differentiated by form of payment, whether to crops or livestock, or to developed countries only. The final experiment adds the support provided to farmers through trade barriers such as tariffs or quotas.

Considering first the impact on GHG emissions, eliminating subsidies reduces total emissions, in large part because it reduces farm output. This effect is greater for subsidies than for market price support because the incentive to increase output created by the subsidy is not offset by a reduction in demand for farm products in supporting countries. As a result, agricultural employment, agricultural land use and agricultural output volumes would all decline with removal of subsidies. The net result in terms of the reduction in output at the global level is modest, but this global outcome masks significant underlying shifts in production across countries to continue to meet the growing global demand, which remains largely unaltered. Under this scenario, global GHG emissions from production would fall by 0.6 percent of the 2040 projected baseline level of agricultural and land use emissions. This decline is complemented by a decline of 0.9 percent of emissions resulting from land use change. The overall reduction in global GHG emissions is 1.5 percent, nontrivial, but an order of magnitude short of the reductions needed to stabilize the climate. This net result also hides the significant differences in the effects of subsidies on crop and livestock emissions, as discussed below on the context of removing specific components of subsidies.

An important finding from other simulated impacts of removing domestic support is that the reduction in emissions entails important tradeoffs. These include a decline in real farm income per worker of 4.5 percent and an increase in world agricultural prices of 2.9 percent as world markets adjust to the reduction in global supply. The price increases further reduce consumption of nutrient-dense food products such as dairy products and vegetables and fruit, while bringing about a large drop in sugar consumption. The average cost of a basket of food items consistent with what is considered a healthy diet would rise, while the impact on global poverty is very small.

The impacts of the elimination of specific components of coupled subsidies—to outputs, inputs and factors—presented in the next three columns of Table 6 follow a similar pattern to that of taking away overall domestic support, though unsurprisingly the impacts are smaller in these cases because of their more limited coverage.

The impacts of removing support to crops and livestock subsectors separately, in columns 5 and 6 of Table 6 demonstrate the complexity of interpreting global aggregates. The findings also indicate the need for a more carefully considered and nuanced strategy to approach the repurposing of current agricultural support. Eliminating all support to crops reduces emissions the most, by almost 2 percent of the baseline 2040 projection of total agricultural emissions. But this is a substantial 31 percent reduction in the incremental emissions from crops between 2020 and 2040 under the baseline scenario. This is a sizeable impact considering production falls by only 1.3 percent.

Removing subsidies to the livestock sector, on the other hand, gives surprisingly different results. Given the overwhelming importance of livestock—and particularly ruminants—in overall emissions from production agriculture, abolition of subsidies to livestock production might be expected to strongly reduce global GHG emissions, but this does not appear to be the case. One reason for this result is that substantial support to crops goes to products like maize that are used for livestock feed. Another key reason is that large amounts of emissions from livestock are generated in countries with low levels of farm subsidies: either advanced economies, like Australia and New Zealand, or developing countries with large, and low productivity, herds (e.g., Ethiopia and India). While emissions from production decline, emissions from land-use change increase slightly for a marginal increase in emissions. In this scenario, per capita dairy consumption worldwide would fall by 0.7 percent, but it would also decrease in developing countries where the average level of dairy consumption is considered below requirements for nutrition-adequate diets.

The impacts of elimination of agricultural subsidies in developed countries reflect the major structural change in the world economy in recent years, the rise in the importance of developing countries relative to developed (Martin 2019). Elimination of the subsidies in high-income countries has only a third to a half of the impact on most variables of removing them globally. In this scenario, the amount of land used for agriculture declines. Emissions from land-use change decline with it; an effect compounded by a switch in usage from cropland to pastures.

The final column of Table 6 shows the impacts of a scenario in which all trade barriers are eliminated in addition to all coupled domestic support. A naïve view might be that, because this is such a large share of total support, its elimination would significantly reduce both global agricultural output and GHG emissions. However, this ignores the important distinction between domestic support and trade measures: trade protection raises consumer prices which in turn depresses demand for agricultural products. Hence, the removal of these trade barriers, which are substantial in many countries as noted in Table 1, amounts to a removal of a heavy tax on consumers, unleashing a surge in demand for the protected products.

At the same time, the elimination of domestic support puts added pressure on farm incomes in countries where both distortions exist. On net, the removal of trade barriers offsets some (but only slightly) of the decline in global production volumes for crops and livestock observed in the scenario reported in the first column. The combination of removing trade barriers (rise in demand) and eliminating domestic support (decline in output) results in a net the increase in world prices of agricultural products which is larger than in the scenario which only abolishes the coupled domestic support. The dynamics at the farmgate are much more complex and context specific (depending on the mix of policies in effect at this time) and require more detailed analysis at the individual country specific level which is beyond the scope of this global study. The net result at the global aggregate level is that with greater integration of domestic prices with world market prices, the change in global farm incomes per worker (-3.54 percent) is smaller under this scenario than with the abolition of subsidies alone (-4.51%). Removing both trade barriers and coupled subsidies mitigates the impact on global GHG emissions as compared with the scenario in which only coupled subsidies are removed. This finding is consistent with the more muted decline in global agricultural output. As prices fall in formerly protected markets, consumers demand more of these products after removal of the trade barriers, contributing to higher output and emissions.

Stepping back and summarizing the overall results (including the results in rows not discussed in detail above) in Table 6 provides some important additional perspectives. All the simulations indicate an increase national real income, suggesting overall economic efficiency gains from removing subsidies and support. The highest and substantial economic gains come from the removal of both trader barriers and domestic support (9 percent), followed by removing domestic support alone (5 percent. By contrast, the (negative) changes in farm income per worker are sometimes much larger, with abolition of all domestic support reducing real farm income per worker the most, by under 5percent. The impacts of abolishing subsets of domestic support are smaller, with support to crops having a much larger impact than livestock. A somewhat surprising finding is that the reduction in global average net farm income is similar when both trade measures and domestic support are abolished as when only domestic support is abolished. As discussed above, this reflects complex dynamics on both demand and supply sides for agricultural products. More concretely, this finding rests on two factors—one is the presence of substantial amounts of negative market price support in a few but major producing and consuming countries, and the other is the significant influence of trade protection by some countries on world prices, and hence the prices received by producers in unprotected countries.

The percentage changes in poverty in the second block of results show small increases in poverty associated with elimination of domestic subsidies, and particularly input subsidies. It is important to remember that these results refer to percentage changes from the projected base poverty rates of 3.3 percent at $1.90 PPP per person per day or 10 percent at $3.20 PPP per person per day. This means that the largest entry, of 0.07 percent, in the poverty rate for 2040 implies a rise in the relative poverty rate of 0.0023 percentage points. These very small impacts occur despite the fall in the rates of the consumption taxes needed to finance agricultural subsidies under the scenario assumptions.

The impacts on diets in the third block of the table are important in that they indicate tradeoffs between economic, environmental and nutritional outcomes. The results reflect a range of outcomes. Increases in consumption of dairy products in developing countries likely contribute to better nutritional outcomes given the high nutrient density of dairy products. Likewise, in most of the simulations, sugar consumption per person declines, which would further contribute to better diets. By contrast, in the scenario abolishing all support (including trade barriers), sugar prices fall and demand increases, which would worsen the quality of diets. In all scenarios, however, the average cost of the food basket aligned with healthy diets (Hirvonen 2019) increases. As a result, the share of the global population unable to afford healthy diets increases in all cases.

Turning to the results for climate-relevant impacts, the elimination of support reduces energy use in agriculture. However, the marginal impact of adding market price support (in column 8) to the abolition of domestic support (in column 1) is a small increase in energy use. Turning to emissions from agricultural production, abolition of subsidies reduces emissions from agricultural production. This is partly because subsidies create an incentive for agricultural production that is not offset by reductions in consumption demand. The reductions in emissions from production are, however, relatively small as a share of total emissions from agriculture and land use (ALU) with a reduction of 0.6 percent for elimination of all subsidies. Adding MPS in column 8 yields a smaller reduction in emissions than for full abolition of subsidies in column 1. This increase in emissions reflects both an increase in demand in the countries that now apply protection, and a shift toward production in countries with higher emission intensities than in the protecting countries.

Another perspective on the results for removing different types of agricultural support is provided by the model results examining the impacts of each policy on key variables, such as real farm income for some key economies. The results for the scenario in which global subsidies are abolished are presented in Table 7 for the world, developed and developing countries as groups, and for some selected large agricultural countries individually, including Brazil, China, the EU, India, and the USA. The global average gain in economic welfare, reflected in the increase in aggregate national income (of 0.05 percent) is distributed very unevenly across countries and regions. As mentioned, the losses in farm income per capita would average about 4.5 percent for the world in this scenario, but farmers in developed countries, and specifically the EU (-24 percent) and the US (-9 percent) would be affected much more than the BRICs or the developing world,. Only for major agricultural exporting countries, such as Brazil, that are also light subsidizers, are there net gains to the agricultural sector, with the gains to the sector from higher world prices large enough to overcome the losses due to elimination of own support. Shifts in production across countries are also reflected in farm employment, which declines in the countries where agriculture is expected to contract and increases in exporters (such as Brazil).

Table 6. Global impacts of removing components of agricultural support (% change in each indicator by 2040 with respect to baseline)

	All domestic support	**Output subsidy**	**Input subsidy**	**Factor payment**	**Crops only**	**Livestock only**	**Developed only**	**Trade Barriers & Dom. Support**
Macroeconomic								
National Real Income	0.05	0.01	0.01	0.02	0.03	0.01	0.02	0.09
Farm Sector								
Real Farm Income per Worker	-4.51	-0.66	-0.59	-3.37	-3.76	-0.78	-2.43	-3.54
World Prices	2.93	0.74	1.05	1.12	2.66	0.30	1.63	4.38
Production Volume - Crops	-1.31	-0.40	-0.57	-0.35	-1.30	-0.02	-0.35	-1.23
Production Volume - Livestock	-0.49	0.01	-0.28	-0.22	0.12	-0.61	-0.32	-0.35
Social								
Farm Employment	-0.53	-0.15	-0.60	0.22	-0.49	-0.03	0.29	-1.51
2040 Poverty Rate at $1.90 Poverty Line	0.01	0.00	0.01	-0.01	0.01	0.00	-0.01	-0.02
2040 Poverty Rate at $3.20 Poverty Line	0.05	-0.01	0.07	-0.02	0.05	0.00	-0.03	0.05
Nutrition/Diets								
Dairy Cons Per Capita	-0.42	-0.04	-0.24	-0.14	0.23	-0.66	-0.25	0.55
Fats Cons Per Capita	-0.94	-0.54	-0.01	-0.40	-0.95	0.01	-0.91	-2.68
Sugar Cons Per Capita	-1.24	-0.17	-0.97	-0.09	-1.29	0.04	-0.39	4.91
Veg & Fruit Cons Per Capita	-0.48	0.04	-0.31	-0.21	-0.50	0.02	-0.21	0.02
Healthy Diet Food Prices	1.70	0.08	0.83	0.79	1.40	0.33	0.89	1.15
Climate								
Energy in Agriculture - MToE	-1.04	-0.18	-0.55	-0.32	-0.75	-0.29	-0.35	-0.91
Emissions from Production, % of ALU	-0.59	-0.03	-0.47	-0.09	-0.40	-0.20	-0.11	-0.20
Emissions from Land-Use Ch., % of ALU	-0.89	-0.33	-0.28	-0.31	-1.55	0.24	-0.39	-0.35
Total Emissions - % of ALU	-1.48	-0.36	-0.75	-0.41	-1.95	0.04	-0.50	-0.55
Nature								
Agricultural Land	-0.06	0.00	-0.08	0.04	0.09	-0.17	0.01	-0.02
Cropland	-0.19	-0.06	-0.04	-0.10	-0.38	0.12	-0.10	-0.08
Pasture	0.01	0.03	-0.11	0.10	0.32	-0.32	0.07	0.01

Note: ALU refers to emissions from Agricultural Production and Land Use. MToE refers to million tonnes of oil equivalent energy use.

Table 7. Results by country group and selected countries for scenario of abolition of all subsidies
(% change by 2040 in each indicator with respect to baseline)

	World	Developed	Developing	Brazil	China	EU	India	USA
Macroeconomic								
National Real Income	0.05	0.05	0.04	0.26	0.03	0.11	0.03	0.02
Farm Sector								
Real Farm Income per Worker	-4.51	-11.36	-2.70	0.76	-5.03	-23.07	-2.37	-9.36
World Prices	2.93	2.93	2.93	2.93	2.93	2.93	2.93	2.93
Production Volume - Crops	-1.31	-2.56	-1.02	0.66	-1.83	-3.97	-3.06	-5.06
Production Volume - Livestock	-0.49	-1.10	-0.07	0.81	0.19	-3.00	-0.82	0.15
Social								
Farm Employment	-0.53	0.25	-0.60	1.04	-1.07	-1.01	-2.62	-1.69
2040 Poverty at $1.90	0.01	0.01	0.01	-0.03		0.00	0.06	
2040 Poverty at $3.20	0.05	-0.01	0.06	-0.06		0.00	0.29	
Nutrition/Diets								
Dairy Cons Per Capita	-0.42	-0.49	-0.37	-0.17	-0.06	-0.60	-0.35	-0.13
Fats Cons Per Capita	-0.94	-1.16	-0.87	-0.98	-1.42	-0.98	0.64	-1.70
Sugar Cons Per Capita	-1.24	-0.93	-1.46	0.33	-0.49	-0.07	-3.98	0.15
Veg & Fruits Cons Per Capita	-0.48	-0.54	-0.45	-0.64	-0.33	-0.58	-1.23	-0.73
Healthy Diet Food Prices	1.70	2.17	1.44	1.37	1.09	3.19	1.91	2.40
Climate								
Energy in Agriculture - MToE	-1.04	-1.43	-0.83	0.83	-0.60	-3.07	-2.08	-1.55
Emissions from Production, % of ALU	-0.59	-1.52	-0.38	0.74	-0.30	-6.29	-1.21	-2.42
Emissions from Land-Use Ch., % of ALU	-0.89	-4.52	-0.07	-0.29	5.67	6.83	-0.02	-29.73
Total Emissions - % of ALU	-1.48	-6.04	-0.44	0.45	5.37	0.53	-1.23	-32.15
Nature								
Agricultural Land	-0.06	-0.15	-0.01	-0.03	0.85	-1.28	-0.01	-0.15
Cropland	-0.19	-0.50	-0.06	0.01	0.32	1.39	-0.01	-2.44
Pasture	0.01	0.01	0.01	-0.05	1.05	-6.50	0.00	1.42

In terms of diets, consumption of dairy products, fats, and vegetables and fruits would decline in all countries but India. The cost of a healthy diet increases in all countries but particularly in Europe. Emissions fall in most countries, and particularly in the USA, where the decline of 32% is primarily driven by reductions in emissions from land use and land use change. As might be expected, emissions rise slightly in Brazil. More surprisingly, emissions rise in China and the EU, in both cases driven by increases in emissions associated with land use change relative to the baseline. In each of the countries considered, except for China, land use declines slightly, while it rises by 0.85 percent in China, where more land is needed to meet food demand in the absence of subsidies on production.

In summary, the simulations with changes at the global level yield some sobering results. With sustained growth in demand (as population and incomes continue to grow), simply removing all agricultural support will not yield substantial gains in global GHG emissions. This is because while significant shifts in production will occur across countries, in the aggregate there will be only a modest decline in output. These results, as well as the divergent impacts on farmer incomes, poverty, and nutrition indicate that naïve policy options like simply removing all subsidies and border distortions entail real tradeoffs which make such actions extremely challenging politically, and likely infeasible. These findings suggest a need to explore options for repurposing current policies and support in search of the much-wanted ‘win-win’ options.

2.3 Repurposing Agricultural Policies and Support for Better Outomes

Given the tradeoffs, and the associated political economy dilemmas involved in reducing or reshaping support, and its apparent limited effectiveness in substantially reducing emission, this section explores some potential options for repurposing current support rather than simply “doing away” with potentially economically distortionary policies and support measures. This is important, because in pursuit of global goals, an internationally concerted and broadly accepted agenda of policy reforms is needed to contribute towards those objectives.

Three broad categories of repurposing scenarios are examined that aim to maintain the support currently provided to agriculture but to redirect it in alternative ways. The analytical framework used in this study allows analyzing the impact of policy repurposing options on the triple goals of reduce GHG emissions, gains in farm efficiency and income, and hence poverty, and nutritional outcomes. The three policy reform options considered are:

(i) *Repurposing* subsidies within the current subsidy budget – first to a uniform distribution of support and then away from carbon-intensive products (i.e., repurposing towards relatively climate-smart products).

(ii) Explicitly making subsidies *conditional* on switching to production processes that are less polluting with currently available technologies, and

(iii) Repurposing a portion of public expenditures spent on coupled subsidies to spending on development and adoption of *new technologies that reduce emissions and increase productivity*.

The first two simulations consider moving from the current highly differentiated set of subsidy rates across outputs, inputs, and factors in two less distortionary directions. The first simulation moves to a *uniform rate* across all agricultural products, removing the bias differentiated rates create across specific products, while the second moves to a uniform subsidy rate on non-emission intensive products (e.g., not meat, dairy products, or rice) to encourage less emission intensive or more climate-smart production choices. Both simulations are based on uniform subsidy rates that require the same spending in 2020 as the current pattern of subsidies. By removing distortions in favor of some and against other products, these simulations also mimic the conversion of coupled subsidies to decouple subsidies (i.e., direct income transfers not tied to specific commodities or inputs).

Conditional payments involve conditioning support on farmers' willingness to provide environmental services. There is strong evidence that, in countries where there is substantial support to farmers, cross-compliance conditions can increase adoption of sustainable agricultural practices (Piñeiro et al. 2020). These policies frequently involve reductions in the use of chemical inputs such as fertilizers and pesticides and, sometimes, more comprehensive moves to organic agriculture that involve reductions in emissions.

An example of this approach in industrial countries is the use of enhanced conditionality in the European Union's future CAP proposal (European Commission 2020a). This seeks to achieve reductions in emissions associated with reductions in specific inputs, while compensating farmers for providing environmental services by adopting technologies that they otherwise might not adopt or that might be less productive than the technologies they currently apply. The conditionality elements of the EU's farm-to-fork proposal (European Commission 2020b), include that farmers should strive for reducing pesticide use by 50 percent, chemical fertilizer use by 20 percent, and antimicrobials by 50 percent, while increasing the share of organically farmed output to 25 percent. The reduced use of chemical inputs is pursued because of local externalities (risks to land degradation, water quality, public health), as well as because of global externalities (GHG emissions) associated with their use. The move to organic agriculture is equally driven by such motivations through the shift to alternative technologies and practices have beneficial for improving soil quality.

The conditionality scenario as presented is expected to have two potentially offsetting impacts on GHG emissions. On the one hand, the targeted reductions in chemical input use will reduce emissions, while, on the other hand, the expected productivity losses associated with a switch to organic farming could increase GHG emissions as additional land is brought under cultivation to maintain the same level of production (and not accounting for potential increase in the sequestration capacity of improved soil quality). The direct impacts of reducing polluting inputs can be tracked relatively easily since they are tracked in the emissions modeling framework used in this study. The impacts of reductions in productivity are much more wide ranging, involving changes in the allocation of land and change in product mix, but can also be tracked. The available literature points to indicative values for the productivity impacts of moving to organic agriculture. A survey by Ponisio et al. (2014) estimates this at -19.2%, while the survey by Seurfert, Ramankutty and Foley (2014) puts it between -13% and -34%. If the productivity of organic agriculture were around 20 percent less than that of non-organic, then the 25% production requirement would translate into a productivity reduction of 5% for agriculture as a whole.

A quite different approach to reducing emissions by inducing farmers to change production methods is frequently seen in developing countries. The climate smart agriculture (CSA) approach (Bell et al. 2018) seeks to achieve three objectives: (i) improvements in productivity, (ii) increases in resilience and (iii) mitigation of climate change by reducing emissions. Another approach with potentially important implications for emissions and for agricultural productivity is the agroecology, which (HLPE 2019) sees as a polar opposite of approaches to sustainable intensification like CSA that seek to raise land productivity as a way to achieve sustainable intensification. De Pinto et al. (2020) use crop modelling techniques to show that widespread adoption of CSA could in fact increase agricultural productivity. Bezner Kerr et al. (2021) survey the literature on agroecological approaches and conclude that its adoption has typically improved food security and nutrition, in part by raising sustainable productivity levels. Where these approaches are effective in raising productivity and lowering GHG emissions, it is clear that they are highly desirable and their consequences for GHG can be analyzed in terms of both their direct impact on emissions, and through the changes in economics structure brought about by adoption of higher-productivity techniques.

A key challenge—addressed in the paper by Bell et al.—is to identify approaches that are not currently used that will contribute more strongly to the objectives of CSA and/or agroecology. If this lack of adoption is due to a lack of information, or high capital costs, then approaches that alleviate the associated market failures are better than those blunt instruments that induce compliance by, for example, conditioning support on adoption of new technologies or simply by regulatory fiat.

Even if policy makers and policy advocates feel confident that adoption of a particular technology will reduce costs, raise productivity and increase resilience, there remains some uncertainty about the productivity impact of that technology in any specific environment. Given this, any policy that encourages or requires adoption of a technology that is believed to be better in the three dimensions of CSA must recognize the risk that this technology has, in fact, lower private productivity than the technologies that producers would otherwise choose. Where the lack of adoption turns out to be due to over-optimism about their impacts on productivity, then the analysis must take into account the impacts of the lower productivity on food prices and real incomes.

A key question for policy makers seeking to induce higher adoption of technologies with lower emission intensities—both in poor and in rich countries—is when the environmental benefits might potentially outweigh the private costs of a technology with lower productivity in terms of private inputs and outputs. This question has been addressed for individual countries (see, for example, Smith et al 2019), but not, to the best of the authors' knowledge, at a global scale.

The final set of scenarios increases in productivity and reductions in emission intensities. These policies are considered separately from conditionality-based policies because it is assumed that new technologies that improve productivity and/or resilience will be adopted voluntarily—or that policies to disseminate information about improved technologies are in place. The challenge in achieving such outcomes is creating technologies not currently available that will achieve these outcomes. To turn this from an aspiration to an outcome requires investments in R&D that will develop such new technologies.

This analysis uses the same 30 percent reduction in emissions and increase in productivity following the example of emission reductions and productivity gains in cattle considered by Mernit (2018) and analyzed in Laborde et al. (2020). More recent evidence suggests that the reductions in emissions as well as reductions in costs associated with some innovations may even be higher than this figure (Kinley et al. 2020). Chang et al (2021) highlight substantial reductions in emission intensities associated with livestock production in the past two decades and conclude that improvements in livestock production efficiency for achieving emission reductions show much more promise than efforts to change consumer demand patterns. Another motivation for using a 30 percent increase in productivity is an examination of the implications of allocating one percent of agricultural value of production to research and development. The indicative Benefit-Cost ratio of 10 suggested by Alston, Pardey and Rao (2020), with a 50-year distributed-lag response to investments in R&D is consistent with a sustained increase in productivity of just over 30%.

The specific repurposing simulations used are as listed in Table 8 with short explanations.

Table 8. Repurposing Scenarios Considered

	Label	**Region**	**Change in Instrument**	**Emission Coefficient**
1	Uniform Subsidy	World	To weighted average	None
2	Uniform on Non-CO_2 intensive goods	World	To weighted average for non-CO_2 intensive products, 0 otherwise	None
3	Constrained Conditionality	World	Agricultural TFP= -10%	-10%
4	Constrained Conditionality	Developed	Agricultural TFP= -10%	-10%
5	Constrained Conditionality	Developing	Agricultural TFP =-10%	-10%
6	Productivity	World	Agricultural TFP =+30%	-30%
7	Productivity with higher elasticity	World	Agricultural TFP =+30%	-30%
8	Productivity	World	Agricultural TFP =+30% 1% of Ag GDP is spend on R&D	-30%
9	Productivity	Developed	Agricultural TFP =+30% 1% of Ag GDP is spend on R&D	-30%

		Label	**Region**	**Change in Instrument**	**Emission Coefficient**
10		Productivity	Developing	Agricultural TFP =+30% 1% of Ag GDP is spend on R&D	-30%
11		Productivity & Subsidy Removal	World	Agricultural TFP =+30% 1% of Ag GDP is spend on R&D + All coupled subsidies removed	-30%

The results of these eleven repurposing experiments are presented in Table 9. The first two experiments address the question of whether it is the pattern of current subsidies or their level that most affects their impacts on economic, social and environmental outcomes. Changing from the current disparate pattern of subsidies to a uniform output subsidy with the same budget cost has generally modest impacts. Surprisingly, real national income falls, albeit very slightly, a second-best welfare result associated with the continuing distortions in border measures. Farm income per worker falls, while production shifts towards livestock, suggesting that livestock are, on average, less subsidized than crops—a not surprising result considering much of the support to crops is provided through input support that is crop specific, even if not commodity specific. This, in turn reduces prices of dairy products and raises their consumption levels. Overall, farm employment rises, and the cost of healthy diets falls (albeit slightly). Emissions from agricultural production rise by 0.5%, but this increase is more than offset by a decline of 1.1% in land use emissions.

The second simulation involves withdrawing support from the most emission-intensive agricultural commodities—livestock production and rice—and reallocating the available funding to all other agricultural commodities, which are mostly crops with much lower emission intensities. This scenario would reduce average real farm income only slightly and reduces world prices by around 2 percent as production of the highly traded grains and other non-livestock commodities expands. Consumption of dairy products and fats would decline while that of vegetable consumption would slightly increase. However, the biggest dietary impact by far would be a 14 percent increase in consumption of sugar, as increased support for production interacts with relatively low demand elasticities. The cost of a healthy diet dominated by non-livestock products falls by almost 2 percent. Perhaps surprisingly, global GHG emissions would increase slightly in this scenario, as the decline in emissions caused by lower agricultural production would be outweighed increased emissions from land-use change. This experiment suggests that superficially appealing ideas like shifting subsidies away from emission-intensive commodities may have surprisingly complex results and may not necessarily help reducing overall emissions.

The "constrained" conditionality experiment in the third column of Table 9 has some interesting and surprising results. National real income would decline by -0.8 percent because this experiment involves a decline in productivity in an important sector. Production falls sharply, with crop production falling over 6 percent and livestock production by nearly 5 percent. The decline in output raises world food prices by a substantial 12.7 percent. This increase in prices offsets the fall in production, contributing to an increase of nearly 2 percent in real farm income per worker. Farm employment and agricultural land use would increase as resources are drawn into the sector to offset the decline in productivity, slowing structural transformation. The simulated increase in farm income associated with a global reduction in agricultural productivity might seem surprising but is a consequence of the relatively low price elasticities of demand for agricultural products; that is, food prices rise more than proportionately with the decline in output.

It is important to remember that these results relate to the move to a presumed lower productivity technology by all countries. Moving to a lower productivity technology in an individual country would have exactly the opposite effect on farm income, reducing the volume of output for sale without a strong compensating increase in prices. This is an example of Cochrane's technology treadmill in agriculture (Cochrane 1958). As with Cochrane's treadmill analogy, a country that chooses a lower productivity technology while the rest of the world turns to higher productivity options is doubly likely to lose.

Table 9. Global Impacts of Repurposing Simulations (% change in each indicator with respect to baseline)

	Uniform	***1 for non CO2***	***Conditionality***	***3 only for Developed***	***3 only for Developing***	***Productivity***	***6 with high labor elasticity***	***Pub funded Productivity***	***8 only for Developed***	***8 only for Developing***	***9 with subsidy removal***
	1	**2**	**3**	**4**	**6**	**6**	**7**	**8**	**9**	**10**	**11**
Macroeconomic											
National Real Income	-0.01	-0.03	-0.81	-0.16	-0.63	1.71	1.75	1.57	0.33	1.31	1.61
Farm Sector											
Real Farm Inc per Worker	-2.28	-1.16	2.02	1.20	0.81	-4.54	-3.44	-4.79	-2.77	-2.22	-8.39
World Prices	-0.63	-2.03	12.71	4.47	7.41	-23.21	-22.27	-23.24	-10.72	-16.12	-20.85
Prodn Volume - Crops	-0.05	1.41	-6.28	-1.12	-5.19	18.02	17.22	17.95	2.99	14.80	16.06
Prodn Volume - Livestock	2.40	-0.69	-4.66	-1.49	-3.19	12.19	11.64	12.14	3.66	8.41	11.47
Social											
Farm Employment	0.25	0.18	4.65	0.98	3.53	-9.79	-11.39	-9.83	-2.49	-7.99	-10.50
2040 Poverty at $1.90	-0.01	-0.01	0.58	0.00	0.57	-1.02	-1.02	-0.99	-0.02	-1.01	-1.00
2040 Poverty at $3.20	-0.06	-0.06	0.58	-0.01	0.58	-1.05	-1.05	-1.02	0.04	-1.07	-0.97
Nutrition/Diets											
Dairy Cons Per Capita	3.20	-0.74	-6.37	-2.02	-4.32	17.15	16.49	17.07	5.14	12.14	16.41
Fats Cons Per Capita	-0.65	-0.18	-3.91	-1.00	-2.86	9.82	9.53	9.77	2.77	7.42	8.65
Sugar Cons Per Capita	3.58	13.57	-10.20	-3.90	-6.27	29.37	28.04	29.32	11.28	18.33	27.53
Veg/Fruit Cons Per Cap	0.09	1.14	-4.40	-1.05	-3.34	12.79	12.17	12.73	2.87	9.98	11.95
Healthy Diet Cost	-0.49	-1.98	10.01	3.39	6.21	-19.06	-18.13	-19.12	-7.60	-13.34	-17.63
Climate											
Agric Energy- MToE	0.98	0.72	-4.34	-1.33	-2.92	11.96	11.48	11.90	3.81	8.72	10.47
Emissions-Prodn	0.49	-0.05	-19.17	-3.42	-15.49	-23.48	-23.74	-23.55	-6.72	-17.41	-24.14
Emissions - Land Use	-1.14	0.31	4.59	1.42	3.11	-15.09	-14.51	-15.22	-4.79	-10.47	-16.31
Del Emiss- % of base	-0.65	0.26	-14.58	-1.99	-12.38	-38.57	-38.25	-38.77	-11.50	-27.88	-40.45
Nature											
Agricultural Land	0.02	0.00	0.62	0.27	0.35	-2.04	-1.99	-2.05	-0.80	-1.21	-2.15
Cropland	-0.22	0.03	0.45	0.10	0.34	-1.49	-1.42	-1.50	-0.44	-1.09	-1.72
Pasture	0.13	-0.02	0.70	0.35	0.35	-2.31	-2.27	-2.33	-0.98	-1.27	-2.36
Forest Habitat	0.04	-0.03	-0.23	-0.08	-0.15	0.39	0.39	0.40	0.15	0.32	0.40

The decline in productivity would cause per capita consumption of dairy products to fall by 6.4 percent, while vegetables and fruit consumption declines by over 4 percent, reflective of the simulated 10% increase in the cost of the healthy-diet food basket. The environmental benefits of putting environmental conditionality on support is evident with emissions from agricultural production falling by 19 percent, driven by the decline in emissions per unit of output and the substantial falls in output brought about by the decline in productivity only partly offset by the increase in prices. The reduction in emissions from production is only partially offset by an increase of almost 5 percent in emissions from land-use change as the sector would draw in more land in an attempt to offset the adverse impact on productivity.

The “constrained” conditionality experiments for developed and developing countries in the next two columns have substantially smaller impacts than for conditionality at the global level. Weighting the percentage changes in real farm income for each country group by its income share would suggest a much smaller increase in real farm income than is actually seen with global implementation. This difference arises because, when the two are introduced together, their effects through world prices cumulate helping increase key impacts such as the rise in real farm income and the pressure to use more land in agriculture. An important difference is the impact of conditionality on poverty in developing countries. Poverty rises much more when the “constrained” conditionality is used in developing countries than in rich countries because so the vast majority of poor people in developing countries are farmers.

The “constrained” conditionality scenarios, as just discussed, are potentially very interesting thought experiments to foster the policy dialogue. The reduction in emissions turns out to be more or less proportional to the reduction in agricultural productivity. This finding highlights the importance of certain linkages that are often overlooked. First, the productivity loss would lead to higher agricultural prices benefitting farm income, assuming effective enforcement of the conditionality. Second, increasing prices lead to a drop in demand and eventually production, and, hence, lower emissions. Third, the decline in productivity induces farmers to expand land use for agriculture, which in turn leads to higher emissions. If the productivity loss is large enough, the increase in emissions from land-use change could outweigh the reduction in emissions from production. Thus, it becomes particularly important to scrutinize proposals for conditionality very carefully for their impacts on productivity. Assumptions that any productivity losses would be small, or that productivity would actually increase need to be rigorously validated.

The last six columns of Table 9 refer to alternative scenarios for enacting stimulus to achieving a 30 percent increase in agricultural productivity. Broadly, the assumptions underlying the productivity ‘shocks’ are: as “manna from heaven” (or a completely exogenous and cost-less benefit) in the first case, or through publicly funding of investments in improved technologies and incentives to their adoption by farmers (in the remaining 5 cases). The final column refers to the case in which productivity increases and existing coupled subsidies are removed, with resources equivalent to 1 percent of the NRA repurposed from subsidies to finance R&D and the remainder used as direct and decoupled payments to farmers (at least till the benefits of R&D start to pay off).

The broad impacts for four of the six cases—whenever the productivity gain occurs in developing countries—are evident from the “productivity” column. Aggregate (world) national income would rise by around 1.7 percent, roughly in line with the 30 percent increase in productivity and the share of agriculture in the world economy of around 5%. The large productivity shock at the global level, drives prices down sharply by 23 percent as production of crop and livestock products rises by 18 percent and 12 percent, respectively. This result is the same as for a closed economy as a sharp increase in global output depresses prices as production cannot be “exported” out. The net result of higher output and a relatively even larger fall in prices is that real farm income per worker falls by 5 percent. Productivity increase also encourages structural transformation, with farm employment falling by close to 10 percent and land use by around 2 percent.

The declines in farm employment with the productivity increase are a key corollary of transformation, as resources needed to meet demand for food decline sharply. If unskilled farm and non-farm labor were identical and perfectly substitutable, labor would seamlessly move out of agriculture and returns in both sectors to be equalized. However, farm and non-farm labor are imperfect substitutes in labor markets, as are incorporated in the model as such. The imperfect substitution is in large part because educational opportunities for rural youth tend to be much more limited than for urban youth, and specialized agricultural skills may not be of use in employment outside agriculture. To account for these differences, the transformation of rural labor into urban labor assumes a constant elasticity of transformation function (Powell and Gruen 1968) with an elasticity of transformation of 0.9. This is below the value 1.32 used by Ianchovichina and Martin (2004) the value of 2.2 estimated by Sicular and Zhao (2004, p257) for China and the 3.7 estimated by Wang and Matthews (2011) using later data for China.

Productivity driven growth also delivers large poverty and nutrition benefits. Poverty declines substantially in all of the productivity increase cases, except for a marginal increase in poverty at $3.20 PPP per person per day in the case where the innovation is adopted only in the developed countries These poverty reductions occur because, as observed in Ivanic and Martin (2018), the declines in food prices tend to benefit poor net buyers of food—including many poor farmers. The composition of food consumption would shift substantially, as the consumption of dairy products would increase by 17 percent and that of vegetables and fruit by 13 percent. Overall, the cost of a healthy diet would fall by a large 19 percent, expected to drive a large increase in the consumption of nutrient-dense foods. At the same time, prices of unhealthy foods, like sugar, also falls, explaining the increase of almost 30 percent in sugar consumption

Productivity increases deliver huge gains in GHG emissions, appreciably more than in any of the earlier experiments. Emissions from production fall by 24 percent, as efficiency gains reduce input use significantly. In addition, land moves out of agriculture as less of it is needed with productivity growth, resulting in reductions in emissions from land use by 15 percent. The combined impact on emissions from agriculture is substantial at 38.6 percent. This means that the simulated productivity growth would bring emissions from agriculture in 2040 to below the 2020 levels.

The second productivity-based experiment relaxes the elasticity of labor transformation, meaning that it assumes labor becomes more ‘fungible’ across sectors. This is done by assuming an elasticity of transformation of 2, that is slightly more than twice the initial value of 0.9, bringing it closer to the estimate by Sicular and Zhao (2004) and still below the estimate of 3.7 by Wang and Matthews (2011). If this could be achieved (perhaps in the short run through vocational or skills training and in the medium to longer-term through educational programs), it would allow more labor to transition out of agriculture (more rapid structural transformation), reducing the loss in income per worker for those remaining engaged in agriculture. The impacts on most other outcomes are almost identical to the previous productivity simulation.

The two columns in which either only developed or only developing countries adopt improved technologies have smaller impacts than when all countries do it on a concerted basis. However, in contrast with approaches using existing technology—such as regulatory or priced-base measures such as use of a carbon tax—where unilateral action is undermined to some degree by “leakage” to non-adopting countries, the sum of the gains from individual adoption are greater than the gains from full adoption. This is because a country that adopts productivity-enhancing practices gains market share from those who do not. This reduction in the importance of the free-rider problem is a hugely important advantage of approaches based on inducing technological improvements over those that require collective action.

The results that agricultural incomes rise when productivity declines and decline when productivity rises may seem counter-intuitive at first. But these outcomes are a natural consequence of the low income and price elasticities of demand for food and the global nature of the experiments reported in Table 9. But these results raise an important question first highlighted by Matsuyama (1992). Will increases (reductions) in productivity in agriculture increase (reduce) agricultural output and employment in individual countries introducing policies with that effect? Matsuyama regarded the increase in agricultural employment and output resulting from higher agricultural productivity as a potential concern, although this outcome was only a consequence of assuming agricultural productivity to be stagnant when all the evidence (see, for example, Martin and Mitra 1992) suggests it has been more rapid than non-agricultural productivity in the post-Green Revolution period.

Table 10 shows the simulated impacts of a form of conditionality that reduces agricultural productivity and emissions by 10 percent in each of seven focus countries. Most, but not all, of the findings are consistent across countries. Real national income falls in line with the decline in farm productivity, with the size of the decline much larger in low income countries like Ethiopia and much smaller in rich economies like the United States and the EU. Agricultural production volumes decline; food prices decline, stimulating increases in food consumption; poverty rises; and energy use in agriculture declines. One might have expected more or less uniform declines in real farm incomes following the reductions in agricultural output. However, the simulation results indicate that real farm incomes per worker would in all countries, except the EU. Production falls sharply, as before, and being large agricultural economies, this pushes up global prices. But the rise in global prices is insufficient to compensate for falling production, and increased employment (as productivity decline result in land expansion and rise in farm employment) lead to a fall in farm incomes per capita. Emissions from agricultural production would decline, offset marginally by emissions from increased land use and land-use change.

Table 10: Impacts of Country-specific Repurposing Scenarios: Constrained conditionality policy reform in individual countries (% change in each indicator by 2040 with respect to baseline)

	Brazil	China	Ethiopia	India	Indonesia	EU	United States
Macroeconomic							
National Real Income	-1.0	-1.1	-3.1	-1.1	-1.0	-0.2	-0.2
Farm Sector							
Real Farm Income per Worker	-1.8	-0.2	-2.4	-0.5	-0.7	1.0	-0.9
World Prices	0.9	1.6	0.1	0.7	0.1	1.2	1.5
Production Volume - Crops	-11.5	-8.7	-8.8	-9.5	-8.8	-11.2	-11.4
Production Volume - Livestock	-8.6	-6.9	-6.8	-7.7	-8.1	-6.0	-5.9
Social							
Farm Employment	-1.3	2.2	2.0	1.6	1.4		
2040 Poverty at $1.90	0.1		0.9	0.1	0.2		
2040 Poverty at $3.20	0.2	0.0	1.1	0.4	1.2		
Nutrition/Diets							
Dairy Cons Per Capita	-5.4	-5.1	-7.3	-7.7	-4.1	-3.4	-3.2
Fats Cons Per Capita	-1.1	-3.4	0.4	1.1	-3.4	-0.8	-1.2
Sugar Cons Per Capita	-8.0	-7.2	-10.5	-6.8	-6.8	-7.1	-6.0
Veg & Fruits Cons Per Capita	-3.6	-4.3	-2.6	-3.7	-1.8	-1.3	-1.6
Healthy Diet Food Prices	4.6	7.5	6.0	5.2	5.1	4.6	4.4
Climate							
Energy in Agriculture - MToE	-9.6	-7.1	-6.9	-8.2	-8.5	-7.3	-7.4
Emissions-Prodn, % of ALU	-28.9	-41.4	-16.5	-17.1	-6.5	-34.3	-34.6
Emissions - Land Use, % of ALU	5.6	2.4	-0.1	0.0	-1.3	-1.1	0.2
Del Emissions - % of ALU	-23.3	-39.0	-16.6	-17.1	-7.8	-35.5	-34.4
Nature							
Agricultural Land	0.7	0.4	0.1	0.0	-0.4	0.4	0.6
Cropland	-0.1	0.1	-0.1	0.0	-0.3	-0.3	-0.4
Pasture	0.9	0.5	0.3	0.4	-0.6	1.7	1.3

Table 11: Impacts of Country-Specific Repurposing Scenarios: Policy support repurposed to Promote Productivity-enhancing and Emission-reducing farm practices and technologies in individual countries (% change in each indicator by 2040 with respect to baseline)

	Brazil	**China**	**Ethiopia**	**India**	**Indonesia**	**EU**	**United States**
Macroeconomic							
National Real Income	2.5	2.5	7.5	2.5	2.3	0.5	0.4
Farm Sector							
Real Farm Income per Worker	4.8	-0.3	6.7	1.2	1.6	-1.2	3.0
World Prices	-2.7	-4.0	-0.2	-2.3	-0.4	-3.4	-4.1
Production Volume - Crops	34.9	25.2	26.7	29.1	25.9	32.7	34.0
Production Volume - Livestock	28.8	18.0	22.8	23.5	23.4	16.7	17.2
Social							
Farm Employment	4.1	-5.6	-3.7	-3.0	-3.1		
2040 Poverty at $1.90	-0.2		-0.7	0.0	-0.3		
2040 Poverty at $3.20	-0.2	0.0	-3.0	-0.7	-0.8		
Nutrition/Diets							
Dairy Cons Per Capita	14.7	14.5	23.1	22.1	11.5	8.4	7.7
Fats Cons Per Capita	3.6	10.4	-0.5	-3.6	9.6	2.3	3.2
Sugar Cons Per Capita	23.8	21.3	35.7	20.0	21.8	19.7	16.4
Veg & Fruits Cons Per Capita	9.4	12.5	8.7	11.4	5.4	3.5	4.1
Healthy Diet Food Prices	-9.9	-16.8	-12.9	-12.3	-12.9	-10.4	-9.8
Climate							
Energy in Agriculture - MToE	30.2	19.4	21.9	24.9	24.3	20.6	21.9
Emissions-Prodn, % of ALU	-17.4	-44.7	-13.3	-14.6	-7.7	-33.3	-32.0
Emissions - Land Use, % of ALU	-11.1	-8.6	-0.5	-0.3	2.8	-7.1	-10.8
Del Emissions - % of ALU	-28.5	-53.3	-13.9	-15.0	-4.9	-40.4	-42.9
Nature							
Agricultural Land	-1.2	-1.6	-0.5	-0.2	0.7	-1.6	-1.8
Cropland	-0.1	-0.3	-0.5	-0.1	0.8	-0.1	0.5
Pasture	-1.6	-2.0	-0.6	-0.8	0.3	-4.5	-3.4

The results in Table 11 for the country specific productivity increase and emission reduction scenarios also provide consistent results for many experiments. As with the productivity experiments in Table 9, national real income rises in all countries; world prices decline; agricultural production volumes increase very substantially, especially for crops; food prices decline and food consumption rises; poverty declines everywhere that measurable poverty remains in 2040, with a particularly large fall in Ethiopia; overall emissions decline but by very different amounts per country; and agricultural land use declines in every country except Indonesia. All of these outcomes are consistent with individual countries having an incentive to adopt productivity and emission-reducing innovations with these features.

There are, however, some key results that might be a bit surprising at first sight. The increases in output are substantial (ranging from 25.2-34.9 percent for crops and 13.7-28.8 percent for livestock). However, for a 30 percent increase in productivity, at constant prices, such an increase in productivity might be expected to raise production even more – both by increasing output for any given use of resources, and by attracting additional resources induced by the greater profitability of the activity (Martin and Alston 1997). Falling output prices (as large producers they do influence world prices) explain part of the subdued output response. Effects of this type are not an artefact of modeling framework used in this analysis, and are also seen in other studies, such as Gollin, Hansen and Wingender (2021, Appendix Figure A6). Their event study analysis finds that agricultural productivity increases in individual countries increase output but reduce agricultural land use and employment of labor—strongly suggesting the presence of a substantial decline in product prices.

Finally, in addition to the positive and desirable outcomes, on important shift seen in country specific productivity scenarios is the impact on real farmer incomes per worker. As indicated, when productivity rises in unison across all countries, it results in excess supply, pushing prices down and reducing farmer returns to productivity growth. With country specific productivity increases, as shown in Table 11, real farmer incomes per capita rise for most countries – except for China and the EU. For all countries, world prices decline by much less than in Table 9 (global productivity growth). In Brazil, Ethiopia, India, and Indonesia, the favorable impact of the output increases more than offsets the more modest decline in prices and real farm incomes rise. For China and the EU, and the US, price decline is larger. The net result is that real farm incomes per worker fall slightly in China and EU, but the US is able to maintain a positive impact on farm incomes per worker. Agricultural land use declines in all of the covered countries except Indonesia. The impacts on global emissions differ substantially across countries. The decline in emissions from production is particularly large in China, the EU and the United States, and the share resulting from land use change is particularly large in Brazil.

3. Conclusions

The results of this study provide new perspectives on policy questions regarding repurposing of current agricultural support measures. Clearly, there is vast scope for improving on current agricultural support measures, particularly for achieving the SDG-related goals of reducing poverty, improving resilience and increasing sustainability. However, it is very important to be very strategic about the type of reforms to be pursued if those goals are to be achieved. Even if it were politically feasible, the findings suggest that while a simple abolition of current subsidies would have significant impacts at the individual country and even at the sector level (specifically in the crops sector), aggregate impacts on global GHG emissions will fall far short of what is needed to appreciably curb agriculture's contribution to climate change. There are several reasons for this—most notably that the support rates have been determined by political-economy grounds not obviously related to the environmental impacts of support, but also that some support is provided by countries with relatively low emissions per unit of output. Another reason is that with sustained and growing demand for agricultural products, there would be shifts in the structure of production across countries but the overall effect the level of production will be relatively small.

Abolition of border measures would actually increase emissions very slightly. This is because the dominant positive support measures combine support to output with a disincentive to consumption. If current protection were simply removed, the results suggest that the stimulus to global demand would slightly outweigh the loss of incentive to output in protected markets, raising the incentive to produce emission-intensive goods.

The findings also highlight clear tradeoffs among environmental, economic, nutrition and social objectives associated with simple options associated with removing subsidies. In scenarios associated with removing support, GHG emissions fall but these reductions come at the cost of falling farmer incomes (which are substantially in countries with high levels of support); and food prices and the cost of health diets rise as output falls, likely to worsen food insecurity and nutrition outcomes in poor countries.

Turning next to the options for repurposing rather than removing support to agriculture, the results again caution against seemingly straightforward solutions. Simple rearrangements of current subsidies tend to have quite limited effects on emissions, while generating quite substantial reductions in income in some key countries. In particular, replacing the current highly variable set of subsidies with a uniform set would have very little impact on emissions. Transferring all subsidies to low-emission cropping activities would, paradoxically, actually increase emissions from global land use change.

The results so far point to the need for not just a reduction in the distortions to agricultural incentives created by current policies but a more comprehensive repurposing to adopt approaches that focus more specifically on reducing emissions per unit of output. Measures that tie support to environmental conditionality are quite effective in reducing significantly higher levels of emissions, but they also come at a substantial cost in terms of private productivity that drives the needed reductions in emissions from agriculture, but the balance between the reduction in emissions and the loss in productivity, especially in developing countries is a major challenge. This tradeoff is captured in the increase in poverty associated with this policy as declines in productivity impact the poor (typically farmers) developing countries more.

The repurposing option that emerges as a clear win-win is repurposing a relatively small share (approximated in this study as 1%) of the current support (averaging about 7-8 percent of gross agricultural revenues across countries) that is funded from public expenditures towards productivity enhancing innovations. The results present a compelling case for investing in developing and disseminating production technologies that both increase productivity and reduce emissions. Such technologies appear to have the potential to sharply reduce global emissions, increase resilience, reduce poverty, significantly reduce the cost of healthy diets, and reduce land needed for agriculture. From the macro-economic perspective, this repurposing also has the strongest positive impact on real national income and structural transformation (i.e., reduction in agricultural employment as labor transitions to other sectors of the economy). Policies that lead to development of new technologies with higher private productivity also have the advantage of not requiring concerted action. Countries that choose to adopt more productive and lower emission technologies tend to gain market share, avoiding the problems of leakage that plague approaches based on use of current technologies.

None of these results should be construed as implying that current agricultural support measures should not be carefully scrutinized. Current support to agriculture distributes much of its benefits to the relatively well off and generates substantial inefficiency and inequity by excluding efficient producers from developing countries. Such policies need continuing scrutiny and criticism. However, what seems to be needed to make the needed break from the current sub-optimal situation is a shift to policies that directly contribute to achieving the Sustainable Development Goals and particularly contribute to strong, ongoing reductions in global GHG emissions.

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