3. EL NIÑO–SOUTHERN OSCILLATION IMPACTS ON AGRICULTURE AND THE NATIONAL ECONOMY

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A RANGE OF INTERVENTIONS HAVE BEEN IDENTIFIED THAT, IF implemented, could help mitigate the adverse effects of climate shocks, such as El Niño–Southern Oscillation (ENSO) events, on the Ethiopian economy and the food security of its population. As outlined in Chapter 2, these interventions include, among others, on-farm investments in technology and irrigation infrastructure, investments in roads and grain storage facilities to expand and stabilize food markets, and social transfers to provide households with a cushion against immediate crises and opportunities for longer-term recovery. However, resource constraints and competing interests mean that there are sometimes trade-offs associated with pursuing policies aimed at building resilience to climate shocks versus policies aimed at achieving other development objectives. Therefore, to motivate resilience-building policies, it is necessary to assess the costs of inaction; to measure policy effectiveness using recognized outcome indicators; and to identify synergies between, say, resilience and development interventions and objectives.

To this end, this chapter measures the consequences of severe climate shocks for Ethiopia's economy and its population. More specifically, the chapter provides new quantitative estimates of the impacts of the 2015/16 El Niño event on the agricultural sector and the national economy. The 2015/16 El Niño was selected as a representative El Niño event in the modeling framework because of its severe droughts and consequent economywide impacts. As discussed in Chapter 1, this is not the first study to evaluate climate shocks in Ethiopia. However, previous studies have typically focused on agriculture in isolation from the broader economy, or have measured the incremental costs from long-term climate change while overlooking the substantial economic costs caused by historical climate variability. These limitations make it more difficult to explain (1) how climate shocks that originate within agriculture can have economywide implications, (2) why action is needed today to build resilience to existing climate variability, and (3) that resilience-building interventions are often consistent with broader development goals.

The Gender, Climate Change, and Nutrition Integration Initiative (GCAN) framework introduced in Chapter 1 describes the many complex factors determining resilience to climate shocks. Within that framework, this chapter focuses on tracking the pathways between climate shocks and household welfare, and measures outcomes (well-being) at both national and household levels. ENSO is associated with extreme weather events throughout Africa South of the Sahara, but the economic impacts caused by these events are difficult to disentangle from those of other climate shocks, natural disasters, and economic cycles. This complicates the design of policies and response mechanisms that could help mitigate economic damages and welfare losses.

The ENSO cycle encompasses fluctuations in temperature between the ocean and atmosphere across the east-central Equatorial Pacific and consists of two opposite phases: El Niño and La Niña. El Niño and La Niña are the warm and cold phases of ENSO, respectively. Deviations from normal surface temperatures can have large-scale impacts, not only on ocean processes but also on global weather. El Niño and La Niña episodes occur every 2 to 7 years and typically last 9 to 12 months. ENSO's effect on weather patterns can be forecast, albeit with varying degrees of accuracy, and this makes it possible to design policies and prepare emergency responses in advance of extreme shocks.

ENSO's adverse effect on agriculture is most concerning, given the sector's linkages to national poverty and food security. Agriculture is an important economic sector in Ethiopia, providing over one-sixth of national employment and one-half of GDP. Most poor people live in rural areas and work in agriculture, and so are vulnerable to climate shocks. Moreover, climate shocks such as floods and droughts have had severe adverse impacts on the overall agriculture–food system (AFS) in Ethiopia. This includes farmers as well as workers in downstream sectors and consumers purchasing foods in local and national markets. ENSO's impacts on agriculture therefore have economywide implications. Whereas a growing body of empirical evidence measures the effects of climate change and variability on agricultural and national economies, few studies have focused on the measurement of economywide outcomes. Although there is an expanding literature on how natural disasters are managed in Ethiopia, quantitative evaluation of the policies and investments that could help avoid at least some of the damages caused by ENSO events is limited.

ESTIMATING AGRICULTURAL AND ECONOMIC LOSSES

Methods for evaluating climate impacts

Numerous studies have evaluated climate impacts on developing economies (see Tol 2009 for an early review). Most studies still focus on agricultural impacts, because this is where damages to low-income countries are expected to be greatest and most immediate, and where there is the strongest evidence on the link between climate signals and outcomes. Agriculture-focused studies can be divided into two groups based on the methods they use. The first and larger group uses biophysical crop models to capture local agroecological conditions (for example, soil type and elevation), climate patterns (for example, rainfall, temperature, and solar radiation), and crop-specific plant physiology (see, for example, Parry et al. 2004). Changes in weather patterns, either historical or projected, are imposed on these crop models to estimate how crop yields are affected. An alternative approach uses statistical or econometric analysis (rather than process-based modeling) to estimate the historical relationship between weather patterns and crop production (Lobell et al. 2011). These ex post relationships are then used to project ex ante the impact of climate changes or shocks. Statistical approaches have the advantage of being empirically grounded, but they are limited by how well the historical record captures climate events of interest (that is, they are susceptible to conducting "out-of-sample" projections). Crop models, on the other hand, can be used to examine hypothetical climate scenarios, because they are less dependent on historical data, but they are generally more data demanding and more reliant on model assumptions. Given their respective limitations, our analysis uses both crop models and econometric analysis to estimate the impacts of severe climate shocks on Ethiopia's agriculture sector (see detailed discussion below). Combining these approaches also broadens our impact assessment to include both crops and livestock.

Biophysical analysis may be of limited use for decision-makers, who need to understand the economic and social impacts of climate changes. Most studies at the country level therefore combine biophysical and econometric models to link climate signals to economic outcomes. Again, the literature can be divided into two groups. The first group uses agriculture-sector models to capture how supply shocks caused by climate variability affect agricultural prices and demand (see, for example, Block et al. 2008; Nelson et al. 2009). These models track changes in demand and supply for detailed crops, livestock products, or both, and sometimes include subnational regions, although rarely at the same level of detail as crop models. The main shortcoming of these models, however, is that they do not capture spillovers or linkages between agriculture and the rest of the economy. These can be important effects, especially in low-income countries, where agriculture is a large part of the economy and where much of the nonagricultural sector is still agriculture related. A growing number of studies capture these spillovers by using economywide models, such as computable general equilibrium (CGE) models (Hertel et al. 2010; Yu et al. 2010). Like agriculture-focused models, these models capture the direct impacts of climate shocks on agricultural production, as well as the indirect effects on downstream sectors and nonfarm/urban households. Our analysis uses an economywide model because of its broader capture of the economy and food system.

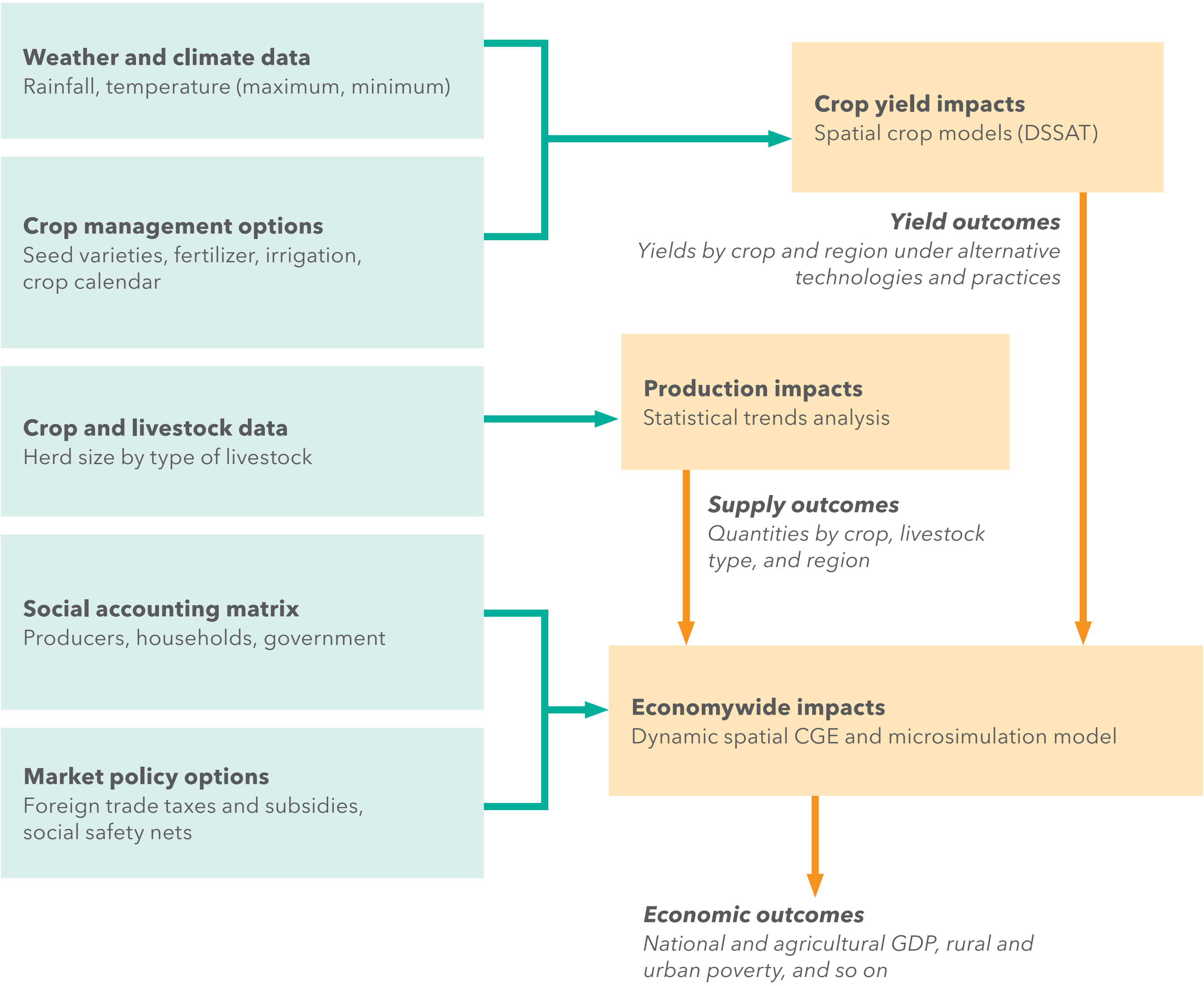
Ours is not the first study to combine crop and CGE models to assess the economic effects of climate change in low-income African countries. Most studies, however, focus on the incremental effects of long-term climate change on agriculture rather than on historical climate shocks (see, for example, Arndt et al. 2012; Calzadilla et al. 2013). More recent studies assess the effects of climate *uncertainty* using stochastic simulation techniques, but although these studies capture the effects of droughts and floods on the agriculture, transport, and energy sectors, they still do not separate historical climate variability from long-term climate change (Arndt et al. 2014; Arndt and Thurlow 2015). Few published studies focus on historical events. Pauw and colleagues (2011) combined statistical analysis and a CGE model to estimate the impact of droughts and floods on Malawi's economy, and Thurlow, Diao, and Zhu (2012) combined crop and CGE models to estimate the damages caused by historical droughts on the Zambian economy. These authors paid particular attention to the ENSO-related droughts of the early 1990s. We will use an approach similar to that of these studies in our integrated assessment of the 2015/2016 drought in Ethiopia.

Integrated analytical framework for Ethiopia

This report employs a framework that combines an analysis of ENSO impacts on crop and livestock agriculture, as well as the spillover impacts from agriculture to the rest of the economy (Figure 6). This integrated approach first examines historical climate data, including variability in rainfall and temperature. It focuses exclusively on the weather pattern that occurred during the latest severe El Niño event, in 2015/16, as a representation of ENSO-induced climate variability, because data are available to validate the estimated impacts. Short-term climate fluctuations during this event year are compared with "neutral" weather years that did not experience ENSO shocks, in order to isolate ENSO-related deviations in rainfall and temperature. Changes in weather variables during 2015/16's main crop-growing season (*meher*) are translated into crop productivity outcomes using a process-based model. More specifically, crop models in the Decision Support System for Agrotechnology Transfer (DSSAT) are used (Hoogenboom et al. 2017; Jones et al. 2003). DSSAT is widely used by agricultural researchers to understand crop production system dynamics and simulate different farm management and environmental changes in Ethiopia (for example, Araya et al. 2015; Kassie et al. 2014, 2015; Mohammed et al. 2017) and climate variability impacts associated with ENSO (for example, MacCarthy et al. 2017; Sarkar, Ortiz, and Balkcom 2017).

The spatial crop models in the integrated analytical framework (Figure 6) estimate ENSO-affected seasonal yield deviations of major crops in a grid-based spatial analysis framework. Daily historical weather data are spatially interpolated from weather station data, linked with the corresponding ENSO phase, and then used as inputs to the crop models that estimate yield changes for two key crops: maize and wheat. The crop models also estimate how yield responses differ when using improved or traditional seed varieties, with and without chemical fertilizer, and with and without irrigation infrastructure. Crop-specific yield deviations are estimated for 5 arc-minute x 5 arc-minute (about 10 km x 10 km) grids

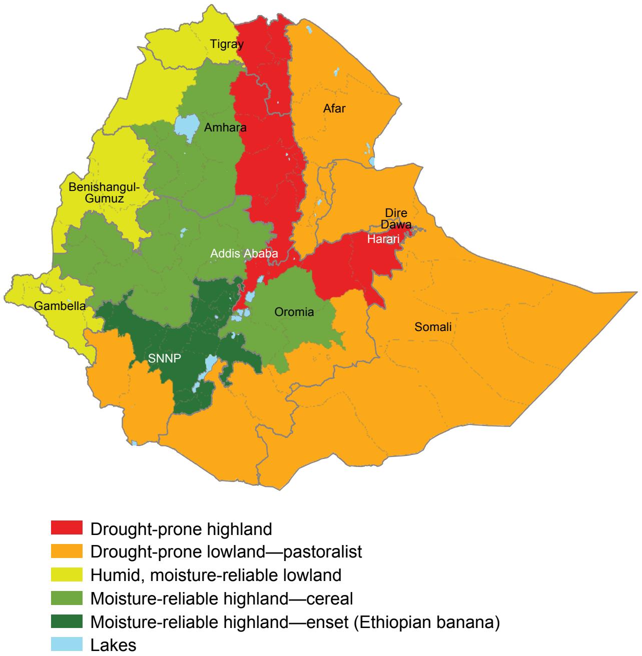
FIGURE 6 INTEGRATED ANALYTICAL FRAMEWORK



Source: Authors.

Note: CGE = computable general equilibrium; DSSAT = Decision Support System for Agrotechnology Transfer; GDP = gross domestic product.

FIGURE 7 ETHIOPIA'S FIVE AGROCLIMATIC REGIONS



Source: Schmidt and Thomas (2017).

covering the cropland extent of the entire country. Finally, gridded results are aggregated into major subnational regions using cropland use patterns (Figure 7). The crop modeling provides insights into the potential effectiveness of adopting improved farming technologies and practices in offsetting the productivity impacts caused by ENSO.

This process-based crop modeling is complemented with statistical analysis of secondary crop and livestock production data for major subnational regions. The impact of the representative 2015/16 El Niño event on crop and livestock production is estimated. For the former, the focus is exclusively on the *meher* cropping season. Like the crop modeling, the statistical analysis distinguishes between Ethiopia's five subnational agroclimatic regions. However, it examines a wider range of crops, namely teff, barley, wheat, maize, and other cereals (that is, rice and oats), as well as noncereal grains. Impacts on other crops are derived from historical correlation of production patterns. Finally, and most important, the statistical analysis considers changes in production quantities, not just yields. In other words, it includes the effect of ENSO on harvested land area, thereby capturing the fact that farmers may abandon fields due to complete crop failure.

The estimated impacts of ENSO events on crop and livestock production are then imposed on a dynamic CGE model. This class of model captures all producers and consumers in an economy, including the government, as well as interactions with the rest of the world (for example, imports and exports). All sectors and households are disaggregated across major subnational regions. Region- and crop-specific productivity shocks thus translate into changes in agricultural and national GDP, employment, and prices. The model reacts to crop- and sector-specific productivity changes by reallocating resources and products between sectors and households to minimize overall losses to the economy (that is, it takes autonomous adaptation into account). The CGE model is also linked to a survey-based microsimulation module that tracks changes in national and subnational poverty rates. Ethiopia's version of the CGE model developed by the International Food Policy Research Institute (IFPRI) has been used to examine a range of development policy issues, including providing background information to the country's Growth and Transformation Plan II, and is an ideal tool for assessing the economywide impacts of large shocks to the agriculture sector.

This integrated approach to measuring the economywide impacts of climate shocks is similar to that often used for long-term climate change impact studies. The DSSAT and CGE models represent some of the most sophisticated tools available for such analysis, and the high-resolution spatial databases used in both types of models are quite unique, for both Ethiopia and developing countries in general. The framework allows not only for isolation of the expected impacts of ENSO events, but also for experiments with alternative policy responses. Whereas the crop models focus on changes in on-farm technologies and practices, the CGE model focuses on market policies and safety nets.

It estimates how these would have mitigated the economic damages caused by a severe ENSO event, such as the 2015/16 El Niño.

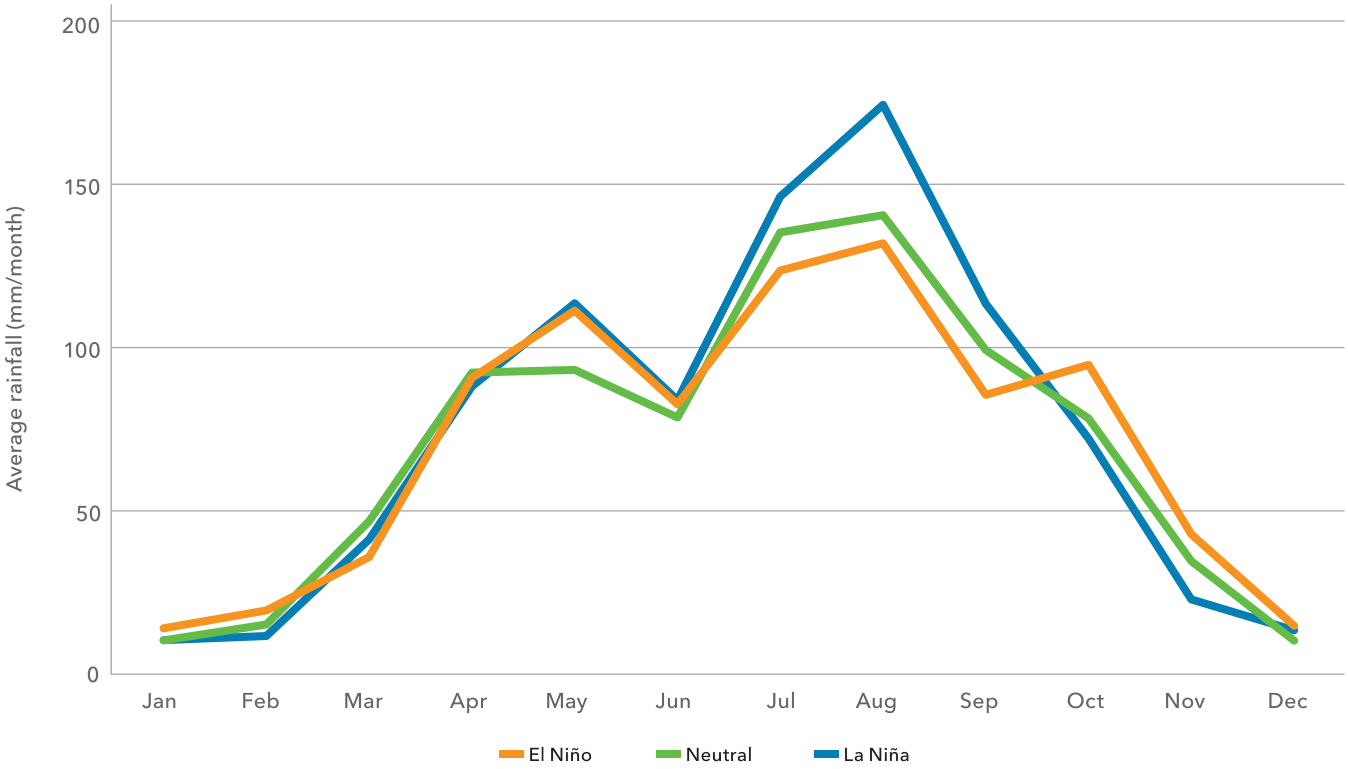
This chapter therefore examines many of the interventions that were prioritized at the end of Chapter 2, including investments in infrastructure (for example, roads, storage, and irrigation), rural services (for example, extension), on-farm technologies (for example, improved seeds and farm management practices), and trade and market efficiency. The chapter's analysis examines the short- to medium-term effects of ENSO, rather than capturing the full recovery period. The latter could extend over many years and is subject to uncertainties that may be driven by social, economic, and political factors that are difficult to quantify or are beyond the scope of this study. The chapter aims to provide quantitative evidence to identify policy options and motivate implementation.

ENSO'S IMPACTS ON WEATHER PATTERNS AND AGRICULTURAL PRODUCTION

Historical climate analysis

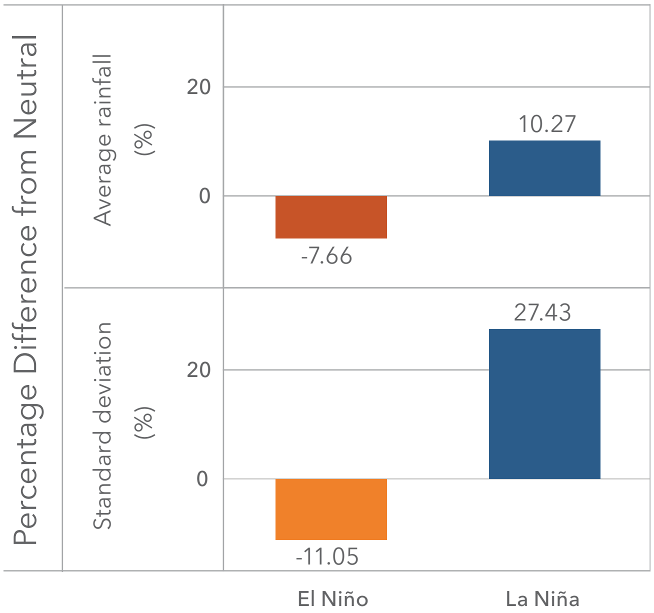
ENSO alters weather patterns in Ethiopia. On average, the warm El Niño phase is drier than La Niña during July–September (Figure 8), coinciding with the main crop-growing period of *meher*. Focusing on 1950–2016, statistical analysis of historical rainfall indicates that, compared with the neutral phase, average annual rainfall across the country was 8 percent lower during El Niño over this period. During La Niña, rainfall was 10 percent higher than during the neutral phase, with greater variability (Figure 9). However,

FIGURE 8 **AVERAGE MONTHLY RAINFALL BY EL NIÑO–SOUTHERN OSCILLATION PHASE**



Source: Authors' reanalysis of the University of East Anglia's CRU-TS v4.01 dataset (CRU, UEA 2018).

FIGURE 9 DEVIATION IN NATIONAL RAINFALL PATTERNS DURING EL NIÑO-SOUTHERN OSCILLATION PERIODS



Source: Authors' reanalysis of the University of East Anglia's CRU-TS v4.01 dataset (CRU, UEA 2018).

Note: Percentage difference in the mean and standard deviation of monthly rainfall during July–September in El Niño and La Niña years relative to the neutral phase.

within the country, climate variability patterns are highly heterogeneous.

As mentioned above, this study separates Ethiopia into five zones depending on rainfall regime and predominant use of farmlands. This includes the drought-prone areas that generally lie toward the eastern half of the country. When compared with the neutral average, the distribution of the difference in rainfall from historical climate data for July–September showed more separation between El Niño and La Niña in the drought-prone highland, humid, moisture-reliable lowland, and moisture-reliable highland—cereal zones than elsewhere (Figure 10). Other zones did not show meaningful differences in rainfall patterns.

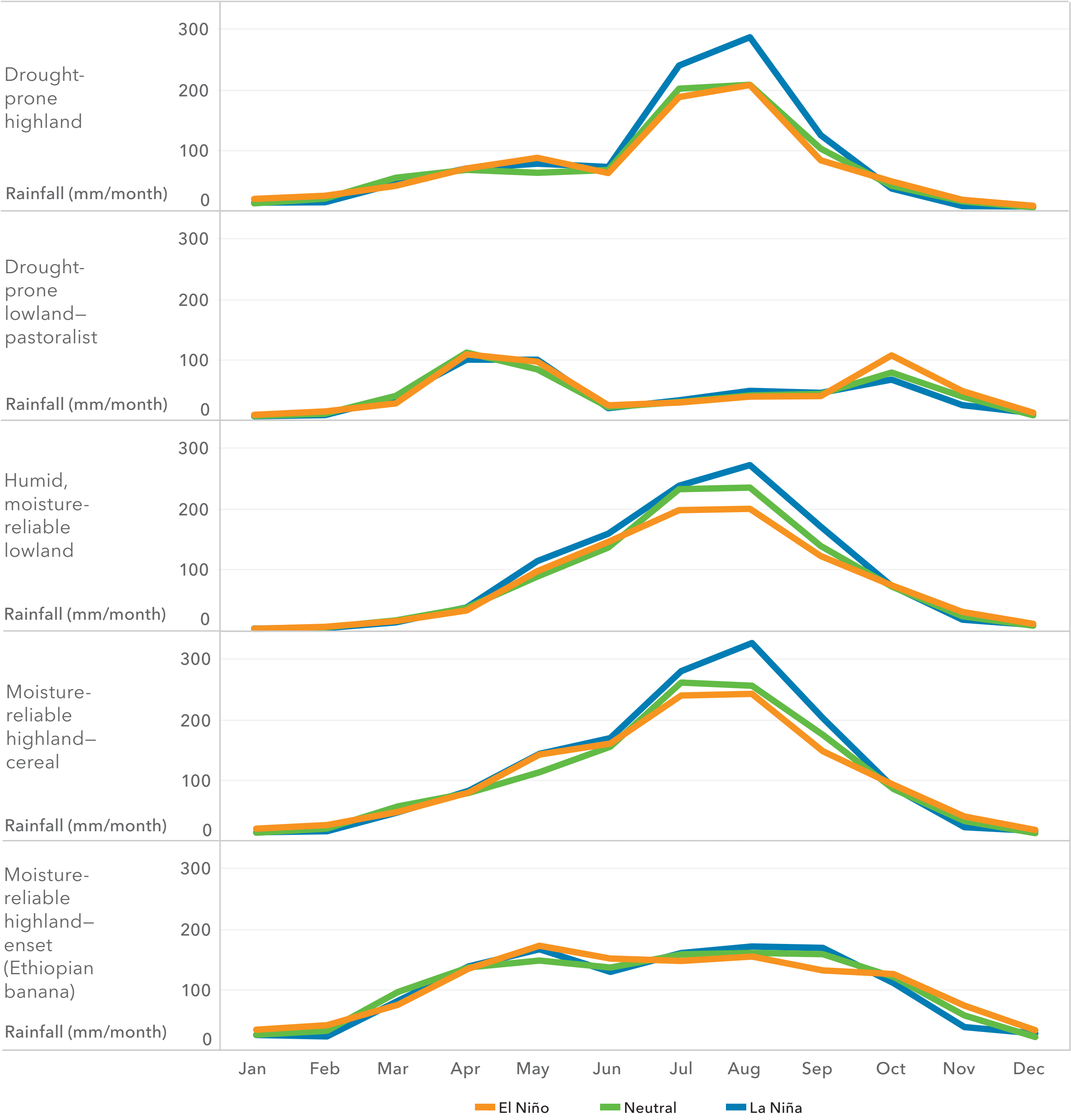
Crop modeling analysis

Crop production data can be confounded by a wide variety of on- and off-farm factors. Before turning to the statistical analysis, crop models are first used to simulate seasonal crop growth and productivity. This allows for isolation of the impact of the ENSO-induced weather variability effects discussed above. The DSSAT crop models simulate the farming situation systematically across the entire country, rather than assessing at a few isolated locations.

IFPRI's grid-based, spatially explicit crop modeling framework was used to generate yield estimates for every 5 arc-minute grid cell (about 10 km on a side) for maize and wheat under both rainfed and irrigated conditions. The flexibility of the crop models allowed for simulation of all planting months and several levels of fertilizer application. Using the historical daily weather data, this modeling framework generated site-specific crop yield variability over the period 2009–2017. Grid cell–specific daily historical weather data were retrieved from the Weather Terrain™ database by aWhere (2018).

The assessment of impacts focused on recent years. The analysis was grouped into three periods: 2015/16 El Niño, 2016/17 La Niña, and neutral years (that is, 2012/13, 2013/14, 2014/15, and 2017/18). The simulated yield consequences of climate variability associated with the ENSO phases on each grid cell were aggregated at the agroecological zone level. Only the *meher* season was considered, because it accounts for around 96 percent of Ethiopia's total annual production and was the worst-affected season during the 2015/16 ENSO event. These data were statistically analyzed to probabilistically examine the extent of potential crop yield changes (benefits and losses) under each ENSO phase. Figure 11 shows how the simulated yields within each phase—El Niño and La Niña—combined to determine the final yield impact. Potential areas suitable for irrigation at a small or large scale were considered in the analysis, based on a previous analysis by Xie and others (2014). In addition, the adoption of complementary management practices and technologies, such as the doubling of nitrogen fertilizer, no-till practices, and integrated soil fertility management, was simulated to assess their potential impacts on yields under ENSO.

FIGURE 10 AVERAGE MONTHLY RAINFALL DURING EL NIÑO–SOUTHERN OSCILLATION PHASES ACROSS AGROCLIMATIC ZONES



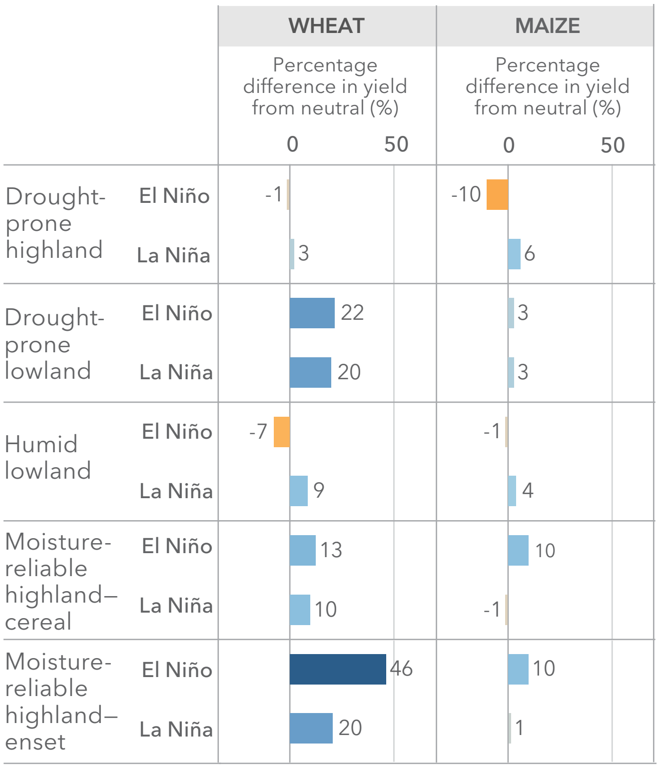
Source: Authors' reanalysis of the University of East Anglia's CRU-TS v4.1 dataset (CRU, UEA 2019).

Note: Historical monthly average rainfall aggregated at the agroclimatic zone level.

When the simulated yields are aggregated to the zonal level, no clear yield patterns emerge for El Niño (2015/16) and La Niña (2016/17) (Figure 11). Some yield losses during El Niño and gains during La Niña are estimated for two zones (drought-prone highlands and humid lowlands), coinciding with historical rainfall variability patterns. Other zones experienced yield increases ranging from 1 percent to 46 percent. However, when the simulated yields for the three zones with the largest rainfall variabilities are further disaggregated, estimated yield losses during the 2015/16 El Niño are concentrated in just a few subregions, namely Afar, Amhara, Harari People's National Regional State, Oromia, Tigray, and Addis Ababa (Figure 12).

When improved agricultural technologies and intensification management practices are adopted, the yield losses during El Niño are reduced. For instance, in Harari Region, maize yields are reduced by 25 percent (420 kg/ha) under the 2015/16 El Niño. Yields would remain at this low level, even during such a severe El Niño event, if the application

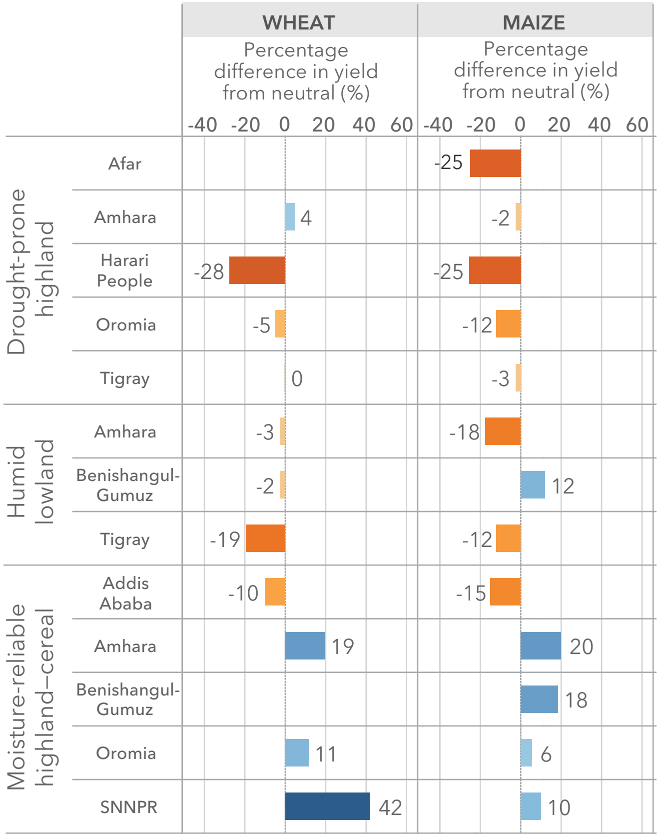
FIGURE 11 SIMULATED YIELD DEVIATIONS FOR MAIZE AND WHEAT BY EL NIÑO–SOUTHERN OSCILLATION PHASE AND AGROCLIMATIC ZONE



Source: Authors' calculations using the International Food Policy Research Institute's Decision Support System for Agrotechnology Transfer crop modeling framework (Hoogenboom et al. 2017; Jones et al. 2003).

Note: Yield deviations during the 2015/2016 El Niño event are relative to average yields from recent neutral years. SNNPR = Southern Nations, Nationalities, and Peoples' Region.

FIGURE 12 YIELD DEVIATIONS WITHIN THREE AGROCLIMATIC ZONES DURING THE 2015/16 EL NIÑO

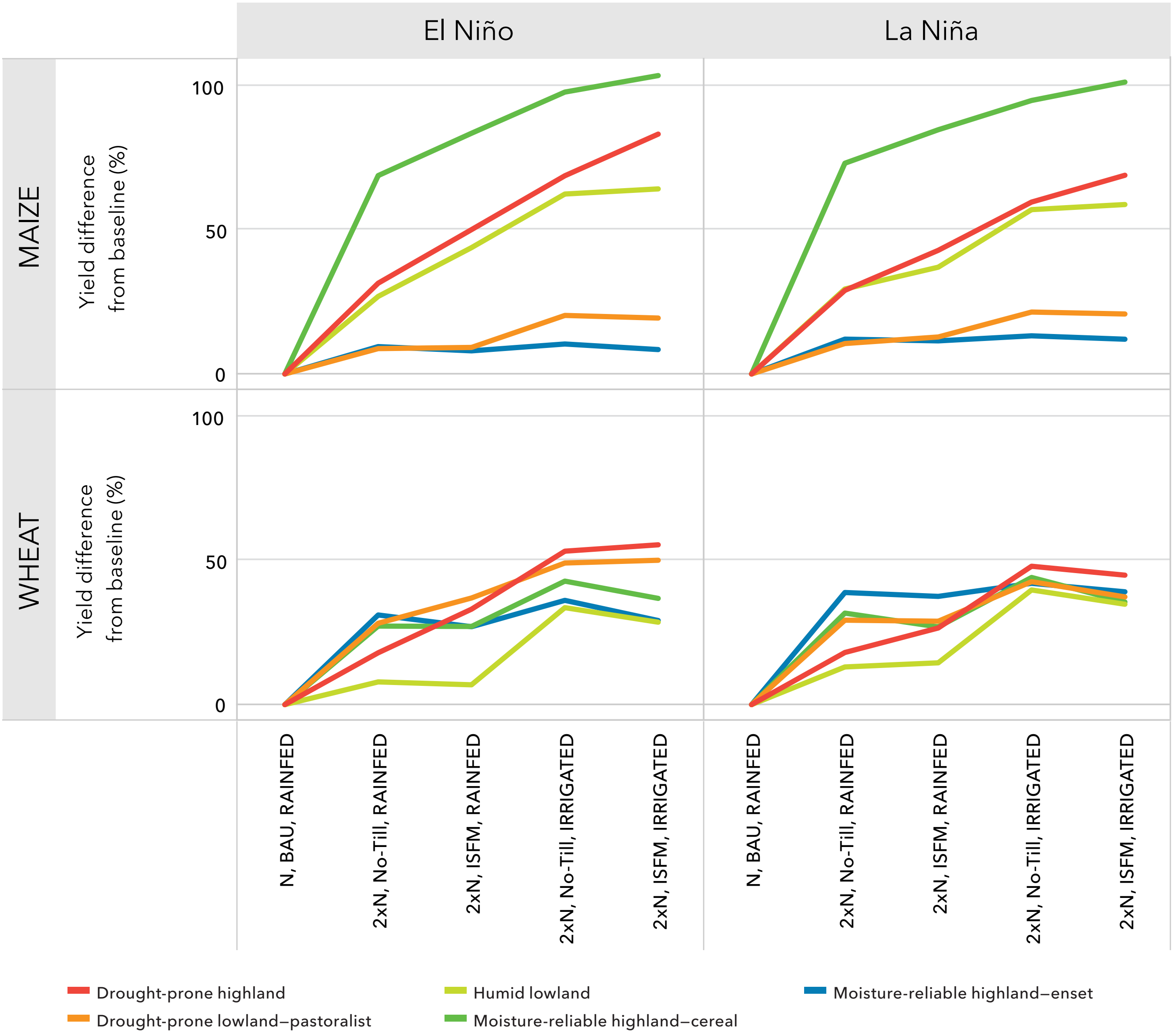


Source: Authors' calculations using the International Food Policy Research Institute's Decision Support System for Agrotechnology Transfer crop modeling framework (Hoogenboom et al. 2017; Jones et al. 2003).

Note: Yield deviations during the 2015/2016 El Niño event are relative to average yields from recent neutral years. SNNPR = Southern Nations, Nationalities, and Peoples' Region.

rate of nitrogen fertilizer doubled. Figure 13 shows the relative yield increases under the various farm management practices considered in this report. The crop modeling analysis concludes that investing in the kinds of interventions that raise on-farm productivity can be highly effective in preventing cereal yields from declining to the low levels expected under current management practices during a severe El Niño event.

FIGURE 13 **EFFECTS OF FARM TECHNOLOGIES IN RAISING YIELDS UNDER EL NIÑO AND LA NIÑA BY AGROCLIMATIC ZONE**



Source: Authors' calculations using the International Food Policy Research Institute's Decision Support System for Agrotechnology Transfer crop modeling framework (Hoogenboom et al. 2017; Jones et al. 2003).

Note: ISFM = integrated soil fertility management; N = nitrogen, BAU = business as usual.

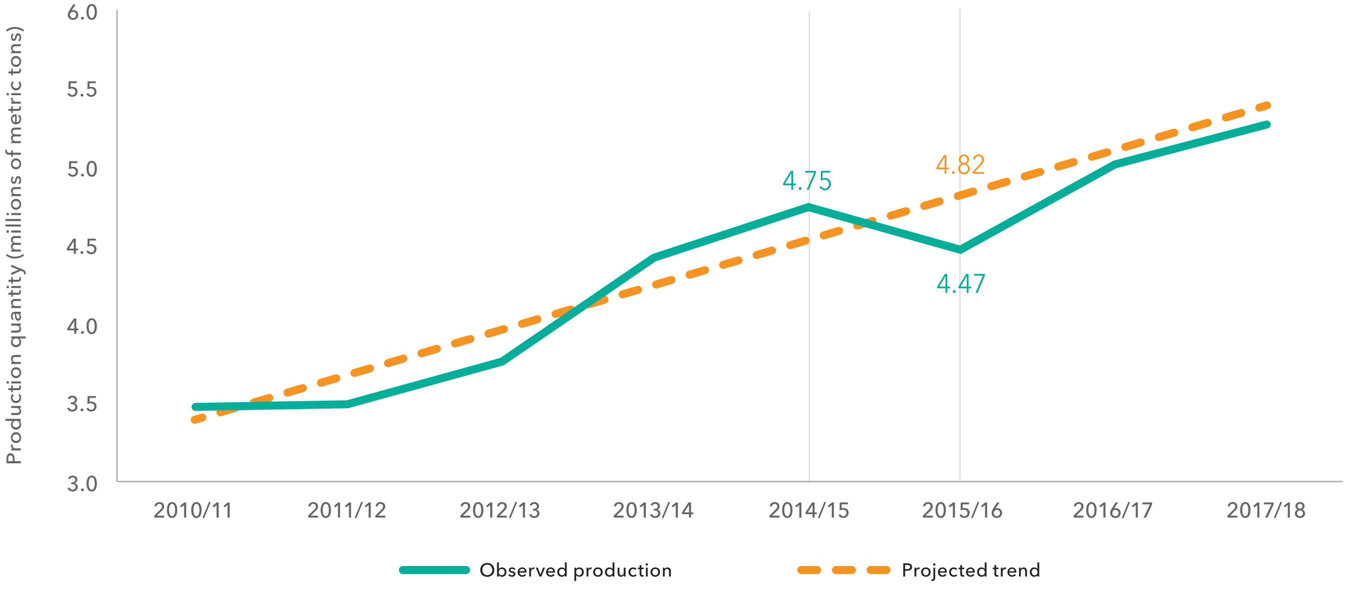
Statistical crop and livestock analysis

The crop modeling analysis revealed wide variation in ENSO's impacts across subnational regions and across El Niño and La Niña events. Historical production data are now used to estimate the production losses that occurred during the 2015/16 El Niño event. Information on crop production quantities, harvested area, and yields was extracted from annual Agricultural Sample Surveys (Ethiopia, CSA, various years). As with the above weather analysis, production outcomes during 2015/16 are estimated relative to production trends from recent neutral years for which data are available (that is, 2010/11 to 2014/15 and 2016/17 to 2017/18).

Figure 14 illustrates this approach using national production quantities for teff—Ethiopia's main staple crop—during the *meher* season. The simplest approach would be to compare the production quantity in 2015/16 (that is, 4.47 million tons) with the production quantity in the preceding year, 2014/15 (that is, 4.75 million tons). This would suggest that El Niño reduced the national average teff yield by 5.9 percent (that is, 4.47/4.75 = 0.941). However, this ignores the expected increase in production that would have occurred without the ENSO shock, and so underestimates the losses that occurred due to El Niño. To generate a more accurate counterfactual, production levels are first projected using historical data for the non-ENSO years. As shown in Figure 14, the trend line slopes upward, indicating that production levels were increasing year over year and would likely continue to do so in the absence of the ENSO shock. More specifically, national teff production would have been an estimated 4.82 million tons in 2015/16 without ENSO, somewhat higher than observed production levels in 2014/15. The revised estimate is that El Niño caused national teff production to fall by 7.3 percent rather than by 5.9 percent (that is, 4.47/4.82 = 0.927).

The approach above is replicated for other grain crops; Table 2 shows the resulting yield deviations. The final column reports the estimated percentage change in yields caused by the 2015/2016 El Niño event, with -7.3 percent for national teff production.

FIGURE 14 **ESTIMATING NATIONAL TEFF PRODUCTION LOSSES DURING THE 2015/16 EL NIÑO**



Source: Authors' calculations using crop production data from Agricultural Sample Surveys (Ethiopia, CSA, various years).

Large production losses were also estimated for barley, maize, and other cereals—the latter includes rice and oats, which are far less important for Ethiopia than the other cereals. These changes in production quantities are caused by either declines in crop yields or reduced area harvested. As shown in the first and second columns of the table, reductions in harvested land area can be a major driver of overall production losses. For example, teff production fell by 7.3 percent, but most of these losses were caused by a reduction in harvested area (4.0 percent) rather than a reduction in yield (3.3 percent). Area losses also exceeded yield losses for barley and other cereals. (Note that the sum of yield and area losses need not equal production losses due to interaction effects.) Overall, yield losses dominate the decline in total cereals production caused by El Niño.

The estimated yield losses are smaller for wheat than for maize, broadly consistent with the findings from the crop models. For both crops, however, the statistical analysis indicates that declining yields were offset by increased harvested land area at the national level. This underscores the need to assess ENSO's impact at the subnational level.

Following the same approach, Table 3 reports the estimated ENSO-related changes in cereal production levels during 2015/16 across the five agroclimatic zones. The first column in Table 3 is the national weighted average loss and so corresponds to the final column of Table 2. The results show that El Niño's negative impacts on production quantities are consistently larger in the drought-prone lowlands (DPL-P) and humid or moisture-reliable lowlands (MRL). Total cereal production fell by an estimated 10 percent in both of these regions. Losses were smaller, but still significant, in the other three regions.

The regional results from the statistical analysis differ from those of the crop modeling analysis. The latter reported yield gains in the moisture-reliable highland regions (MRH-C and MRH-E in Table 3) during the 2015/16 El Niño event. One explanation for this difference is that, as discussed above, production quantities are determined by both yield and area, and so the yield deviations estimated by

TABLE 2 ESTIMATED NATIONAL GRAIN PRODUCTION LOSSES DURING THE 2015/16 EL NIÑO

	Deviation from trend projection (%)		
	Crop yield (MT/ha)	Harvested area (ha)	Production quantity (MT)
Cereals	**-3.72**	**-0.90**	**-4.75**
Teff	-3.25	-4.02	-7.30
Barley	-2.33	-3.48	-5.59
Wheat	-1.40	0.29	-1.30
Maize	-6.06	1.01	-5.26
Sorghum and millet	-5.58	1.96	-4.03
Other cereals	0.53	-9.92	-9.69
Noncereals	**-3.73**	**0.66**	**-2.87**

Source: Authors' calculations using crop production data from Agricultural Sample Surveys (Ethiopia, CSA, various years).

Note: MT = metric ton.

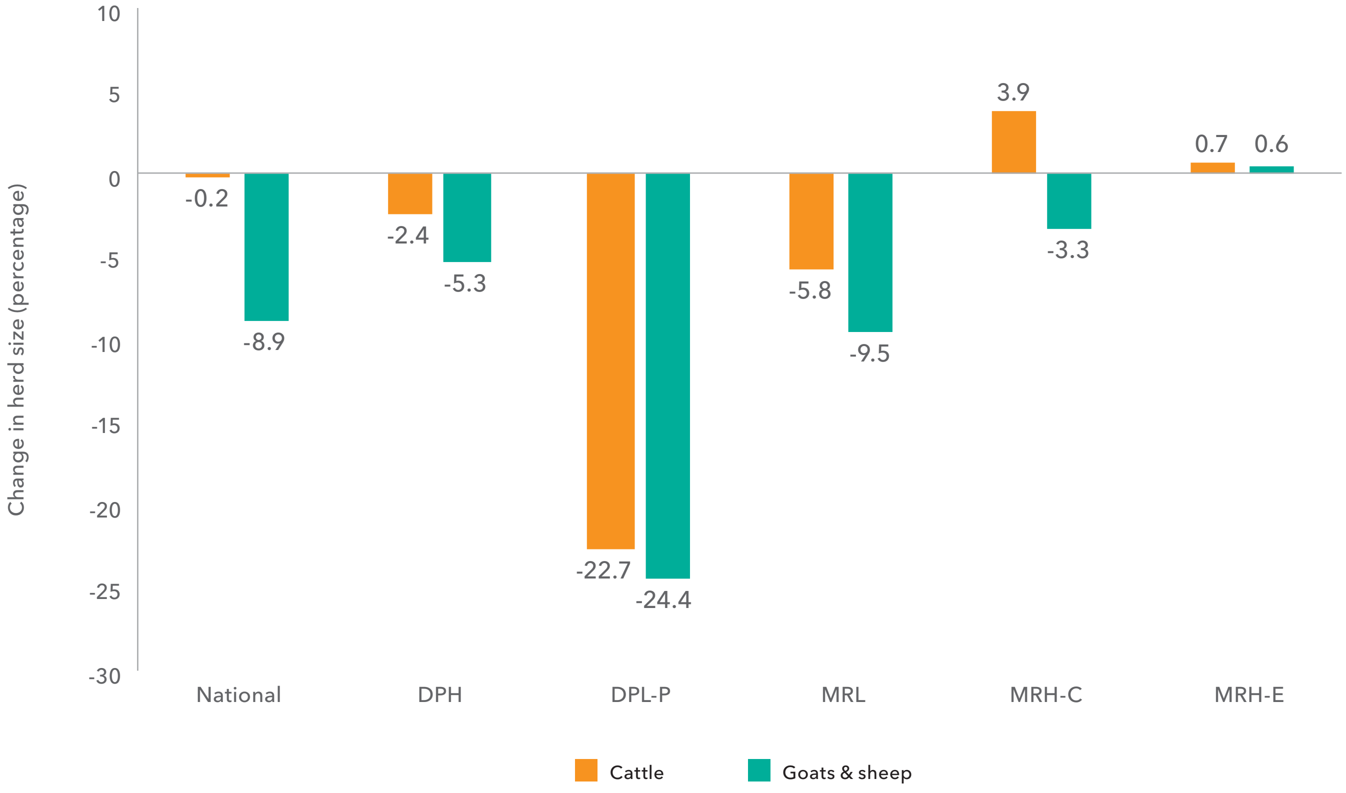
TABLE 3 ESTIMATED GRAIN PRODUCTION LOSSES BY SUBNATIONAL REGION DURING THE 2015/16 EL NIÑO

	Quantity deviation from trend projection by region (%)					
	National	DPH	DPL-P	MRL	MRH-C	MRH-E
Cereals	**-4.75**	**-5.69**	**-10.36**	**-9.76**	**-3.80**	**-7.26**
Teff	-7.30	-9.81	-18.78	-17.90	-5.47	-18.08
Barley	-5.59	-6.67	-0.20	-5.85	-6.13	3.05
Wheat	-1.30	-5.13	10.85	-13.37	-1.11	3.35
Maize	-5.26	-3.28	-12.31	-8.18	-4.73	-6.14
Sorghum and millet	-4.03	-4.61	-15.48	-7.93	-1.96	-16.35
Other cereals	-9.69	-1.31	-9.21	-45.69	-10.00	-7.43
Noncereals	**-2.87**	**-5.67**	**-2.02**	**-5.61**	**-2.85**	**2.55**

Source: Authors' calculations using crop production data from Agricultural Sample Surveys (Ethiopia, CSA, various years).

Note: DPH = drought-prone highland; DPL-P = drought-prone lowland–pastoralist; MRL = humid, moisture-reliable lowland; MRH-C = moisture-reliable highland–cereal; and MRH-E = moisture-reliable highland–enset (Ethiopian banana).

FIGURE 15 **ESTIMATED LIVESTOCK LOSSES BY SUBNATIONAL REGION DURING THE 2015/16 EL NIÑO**



Source: Authors' calculations using crop production data from Agricultural Sample Surveys (Ethiopia, CSA, various years).

Note: DPH = drought-prone highland; DPL-P = drought-prone lowland–pastoralist; MRL = humid, moisture-reliable lowland; MRH-C = moisture-reliable highland–cereal; and MRH-E = moisture-reliable highland–enset (Ethiopian banana).

the crop yield models may not adequately capture the factors that led to a decline in harvested land area. The historical production data appear to confirm this explanation.

For example, small increases in average yields were reported in Amhara and Oromia Regions during the 2015/16 *meher* season, but overall production quantities fell, implying that a decline in harvested land area was the sole driver of the decline in production levels. It should also be recognized that the historical data include more than just the effects of ENSO-related weather patterns—they also include market and other economic responses to the food shortages in specific regions and throughout the economy. This might include lower demand for food products caused by falling farm incomes, as well as an increase in food prices that would encourage unaffected regions to increase production to supply deficit regions. To untangle the interactions of these complex economic forces, it is necessary to use the CGE model, which captures the workings of the AFS and the national economy.

Finally, the impact of the 2015/16 El Niño on livestock herd sizes is estimated following the same approach used to estimate crop production losses (Figure 15). Livestock numbers from recent neutral years (that is, 2010/11 to 2014/15 and 2016/17 to 2017/18) are used to project what herd sizes would have been in the absence of the ENSO shock. Historical information was drawn from the livestock section of the country's Agricultural Sample Surveys, which measures herd sizes at a single point during the year. In other words, the data do not fully capture seasonal variations, although stock-based analysis, as opposed to flow-based analysis, is less affected by seasonality.

The figure reports the estimated deviations in herd sizes caused by the 2015/16 El Niño. At the national level, cattle herds were only slightly lower than is typical, at -0.2 percent. However, this hides considerable variation at the subnational level. Cattle herds are estimated to have fallen by 22.7 percent in the drought-prone lowlands (DPL-P in Figure 15), where most pastoralists reside. Cattle herds also declined in the humid lowlands (MRL) and drought-prone highlands (DPH), but they were slightly larger in the two moisture-reliable highland regions (MRH-C and MRH-E), relative to what would have been expected without the effects of ENSO. The figure shows similar regional variation for small ruminant herds. The same analysis was conducted for poultry and other livestock, not shown in the figure. Results indicate large declines in poultry flocks, although this may reflect some substitution between animal-sourced foods resulting from cattle and small ruminant deaths.

In summary, the 2015/16 ENSO event is found to have had a significant impact on both weather patterns and agricultural production in Ethiopia. National weather conditions were generally drier during El Niño and wetter during La Niña, although the extent of these trends varied considerably across subnational regions. The crop modeling analysis showed how ENSO's impacts varied across regions, even within agroclimatic zones. That said, crop simulations indicated that maize and wheat yields declined in the more drought-prone parts of Ethiopia during El Niño. This was confirmed by the statistical analysis, which estimated substantial declines in production of cereals and livestock herds, particularly in the drought-prone lowlands. The next section imposes these estimated production losses on an economywide model to translate productivity changes into changes in economic indicators, taking account of spillovers between agriculture and other sectors of the economy.

ENSO'S IMPACTS ON THE NATIONAL ECONOMY

Agriculture in the national economy

El Niño's impacts may be felt throughout Ethiopia, although this analysis has focused only on changes in agricultural production. This is because agriculture's direct contribution to production and employment hides the sector's indirect importance for many other parts of the economy. Using a spatial economywide model, it is possible to measure the direct and indirect effects of the agricultural production shocks estimated in the previous section. IFPRI's Rural Investment and Policy Analysis model (2017) is used; it has, as its core database, a social accounting matrix (SAM) that captures all income and expenditure flows between all economic actors in the country, including producers, consumers, government, and the rest of the world (Box 3).

The economywide model of Ethiopia is benchmarked to a SAM for 2010/11. It is necessary to adopt a base year that predates the ENSO event of interest and that represents a neutral or non-ENSO-affected year. As mentioned above, the most recent neutral year prior to the 2015/16 ENSO event was 2014/15. Unfortunately, the data needed to construct a detailed spatial SAM for that year were not available at the time of the analysis. In using a 2010/11 benchmark, we are effectively assessing the economic impacts of the 2015/16 ENSO event, assuming that an event of similar magnitude and profile had occurred in 2010/11. Since the Ethiopian economy grew between 2010/11 and 2014/15, the dollar-dominated damages reported in this chapter should be treated as lower-bound estimates. However, despite its rapid economic growth, Ethiopia has yet to experience significant structural change, and so the sectoral linkages between agriculture and the rest of the economy are unlikely to have changed dramatically over this four-year period.

BOX 3 IFPRI'S RURAL INVESTMENT AND POLICY ANALYSIS MODEL

Rural Investment and Policy Analysis (RIAPA) is a recursive dynamic computable general equilibrium model that simulates the functioning of a market economy, including markets for products and factors (that is, land, labor, and capital). RIAPA measures how impacts are mediated through prices and resource reallocations, and ensures that resource and macroeconomic constraints, such as limits on inputs or foreign exchange, are respected. RIAPA provides a consistent "simulation laboratory" for quantitatively examining value-chain interactions and spillovers at the national, subnational, and household levels.

RIAPA divides the national economy into different sectors and household groups that act as individual economic agents. Producers maximize profits and supply output to national markets, where it may be exported, combined with imports, or both, depending on relative prices, with foreign prices affected by exchange rate movements. Producers combine factors and intermediate inputs using sector-specific technologies. Maize farmers, for example, use a unique combination of land, labor, machinery, fertilizer, and purchased seeds. Workers are divided by education level, and agricultural capital is separated into crop and livestock categories. Labor and capital are in fixed supply, but less-educated workers are treated as underemployed. Producers and households pay taxes to the government, which uses these and other revenues to finance public services and social transfers. Remaining revenues are added to private savings and foreign capital inflows to finance investment; that is, investment is driven by levels of savings. RIAPA is dynamic, with past investment determining current capital availability.

RIAPA tracks changes in incomes and expenditures for different household groups, including changes in food and nonfood consumption patterns. Poverty impacts are measured using survey-based microsimulation analysis. Individual survey households map to the model's household groups. Estimated consumption changes in the model are applied proportionally to survey households, and post-simulation consumption values are recalculated and compared with a poverty line to determine households' poverty status.

Source: Benfica and Thurlow (2017).

Using a 2010/11 SAM for Ethiopia, the size of the country's AFS can be estimated (Table 4). Agriculture was only 12.5 percent of total GDP in 2011. However, when downstream agricultural processing, input production, and agriculture-related trading and transporting are included, the contribution of AFS rises to 30.3 percent of GDP (that is, 2.5 times agriculture's direct GDP share). Shocks to agriculture can therefore have important economywide implications.

The SAM separates the Ethiopian economy into 49 sectors (producers) and 30 household groups (consumers), both of which are further separated across the five agroclimatic zones (Figure 7). Together, these household groups capture the entire population, separated across rural and urban areas and per capita expenditure levels. Similarly, the

TABLE 4 AGRICULTURE–FOOD SYSTEM SHARE OF GDP AND EMPLOYMENT, 2010/11

	Share of national total (%)	
	GDP	Employment
National economy	**100**	**100**
Agriculture–food system	**52.9**	**84.4**
Direct production	**44.1**	**79.8**
Agriculture	42.1	79.0
Agroprocessing	2.1	0.7
Input production	**1.3**	**0.4**
Trade and transport	**7.5**	**4.2**

Source: Authors' calculations based on computable general equilibrium model using 2010/2011 Ethiopia social accounting matrix data from the International Food Policy Research Institute's Rural Investment and Policy Analysis Model (Benfica and Thurlow 2017).

Notes: Employment is defined as workers in primary jobs. GDP = gross domestic product.

TABLE 5 ETHIOPIA'S NATIONAL ECONOMIC STRUCTURE, 2010/11

	Share of total (%)			
	GDP	Employment	Exports	Imports
All sectors	**100**	**100**	**100**	**100**
Agriculture	**42.1**	**79.0**	**49.0**	**4.2**
Crops	30.7	56.9	44.3	4.2
Livestock	7.9	12.6	4.7	0.0
Forestry and fishing	3.4	9.6	0.0	0.0
Industry	**11.5**	**3.2**	**7.6**	**73.1**
Mining	1.6	0.4	2.6	0.0
Manufacturing	3.7	1.3	5.0	69.0
Agroprocessing	2.1	0.7	1.7	6.0
Other manufactures	1.6	0.6	3.3	63.0
Other industry	6.3	1.4	0.0	4.0
Services	**46.4**	**17.8**	**43.4**	**22.8**

Source: Authors' calculations based on computable general equilibrium model using 2010/2011 Ethiopia social accounting matrix data from the International Food Policy Research Institute's Rural Investment and Policy Analysis Model (Benfica and Thurlow 2017).

Note: Employment is defined as workers in primary jobs. GDP = gross domestic product.

TABLE 6 HOUSEHOLD INCOME AND CONSUMPTION PATTERNS, ETHIOPIA, 2010/11

	National	Rural	Rural poor	Urban
Population (millions)	**53.4**	**45.0**	**9.4**	**8.4**
Consumption per capita (US$)	**456.6**	**403.0**	**187.8**	**742.4**
Food consumption share (%)	**100**	**100**	**100**	**100**
Cereals and roots	28.6	29.5	38.8	25.3
Vegetables	6.8	6.6	7.1	7.8
Fruits	4.8	4.9	5.4	4.5
Meat, fish, and eggs	27.9	26.0	10.3	34.3
Milk and dairy	7.4	7.9	10.4	5.6
Pulses and oilseeds	9.5	9.7	11.6	9.0
Other foods	14.9	15.3	16.4	13.5
Household income share (%)	**100**	**100**	**100**	**100**
Cropland returns	12.4	16.7	26.7	0.0
Labor remuneration	39.5	42.6	56.1	30.7
Capital profits	46.2	38.6	16.8	67.6
Other sources	2.0	2.1	0.4	1.7

Source: Authors' calculations based on computable general equilibrium model using 2010/2011 Ethiopia social accounting matrix data from the International Food Policy Research Institute's Rural Investment and Policy Analysis Model (Benfica and Thurlow 2017).

Note: Food consumption excludes meals prepared outside the household. Processed foods exclude products processed and consumed within the household. Other income sources include social and foreign remittances.

various sectors together capture all production that occurs in the country, including home production of agricultural products consumed by the household.

Agricultural production shocks in the model affect farmers as well as workers in downstream sectors and consumers purchasing food in local and national markets. The model captures how changes in agricultural production lead to changes in farm incomes as well as producer and consumer prices. For example, ENSO's direct impact may be to reduce teff production in a region, leading to higher consumer prices for teff. This may encourage households to reduce teff consumption or shift toward cheaper foods, including those produced in regions less affected by ENSO. Farmers in such regions may also respond to higher prices by increasing teff production, although this is constrained by land-planting decisions that may have already been made. Finally, the country may respond to production losses by increasing food imports, although this requires foreign exchange, which must be either borrowed or earned from exports. A country's production and trade structure is therefore a key determinant of the overall impact of ENSO events. Table 5 shows the broad structure of the Ethiopian economy.

The model includes household groups that have distinct income and expenditure patterns (Table 6). The population consumes, on average, US$457 of goods and services per person each year (at market exchange rates unadjusted for purchasing power parity). Consumption levels are much lower in rural areas (US$403), especially among the rural poor (US$188). ENSO's effects on cereals, for example, will have serious implications for poorer rural consumers, who spend a large share of their income on cereals. Finally, the poorest households, even in rural areas, rely on incomes from cropland and labor—the latter dominated by less-educated workers. Urban households, in contrast, rely more on the profits earned by nonfarm enterprises. Other sources of income include remittances and social transfers, neither of which contributes much to average household incomes.

ENSO's economywide impacts

The CGE model is used to estimate the economywide outcomes associated with the agricultural production losses during El Niño presented in the previous section. The model also simulates various nonfarm policy options that could mitigate damages during ENSO events. Some scenarios reflect existing policies in the country, such as expanding social transfers for poorer households, which is similar in intent to Ethiopia's Productive Safety Net Programme (PSNP). Other scenarios consider policies that may not exist today, such as major investment in and use of grain storage and distribution systems. The scenarios are scaled, however, to reflect existing conditions. For example, the extent to which social transfers can be used to mitigate welfare losses is informed by the scale and distribution system of current public safety net programs. The scenarios are therefore a combination of expanding current interventions and introducing new policies.

Whereas the crop modeling focused on on-farm interventions, the CGE modeling focuses on the kinds of market and social policy interventions identified in Chapter 2:

- *Trade policy (food import subsidies)*. Introduce a 25 percent price subsidy for imported cereals and processed foods during El Niño years. The aim of an import subsidy is to offset any increases in food prices caused by ENSO's disruption of domestic production. In the model, demand shifts toward imported foods, and consumers would benefit from lower prices (relative to a situation without the subsidy). Note that for farmers who are hurt by an ENSO shock, the subsequent increase in market prices offsets some of their losses. Providing an import subsidy limits any price increases, and so can make farm revenue losses larger. Moreover, subsidies have fiscal implications. The fiscal burden of providing import subsidies is "internalized" in the CGE model through lower government revenues and larger deficits, which in turn has economywide implications. Net impacts are reported here.
- *Market infrastructure (grain storage)*. Distribute 1 million metric tons of cereals from public and private stocks. Depleting stocks addresses short-term supply shortfalls during ENSO events and offsets some of the price increases caused by production losses. Like import subsidies, depleting grain stores benefits consumers but may prevent market forces from limiting farm revenue losses via higher prices for agricultural products. The scenario assumes that storage facilities already have been or can be expanded to achieve this capacity. Food balance sheets of the Food and Agriculture Organization of the United Nations (FAO) indicate that over the last decade, Ethiopia depleted collective grain stocks by an average 1 million metric tons per year (FAO 2017). This suggests that the grain storage scenario is consistent with the country's average capacity to achieve. That said, the reliability of the FAO data can be questioned, especially because grain stocks have declined every year between 2009 and 2013. The CGE analysis does not consider the financial cost of restocking public and private grain stores in the years following an ENSO event. Note that the grain storage scenario is equivalent to an alternative scenario in which the government procures grain in foreign markets (financed by foreign borrowing) and distributes the grain in domestic markets.
- *Social protection (cash transfers)*. Provide short-term cash transfers to poorer households (income quintiles 1–3) equal to US$4.50 per capita. Currently, the government's various social protection and pension programs transfer, on average,

US$9.60 per person per year. The social transfer scenario roughly doubles this national average for poor households during an El Niño year. Households in the model use these funds to either offset higher food costs or purchase nonfood products, whose prices may also rise during ENSO events as economic shocks spill over from agriculture to nonfarm sectors. The fiscal cost of expanding social transfers is internalized through higher direct taxes (for example, pay-as-you-earn and corporate taxes). The scenario assumes that the distribution of new social transfers occurs through existing social protection systems and does not increase the administrative cost of this system. This is equivalent to assuming that additional administrative costs (not actual transfers) are borne by foreign development partners.

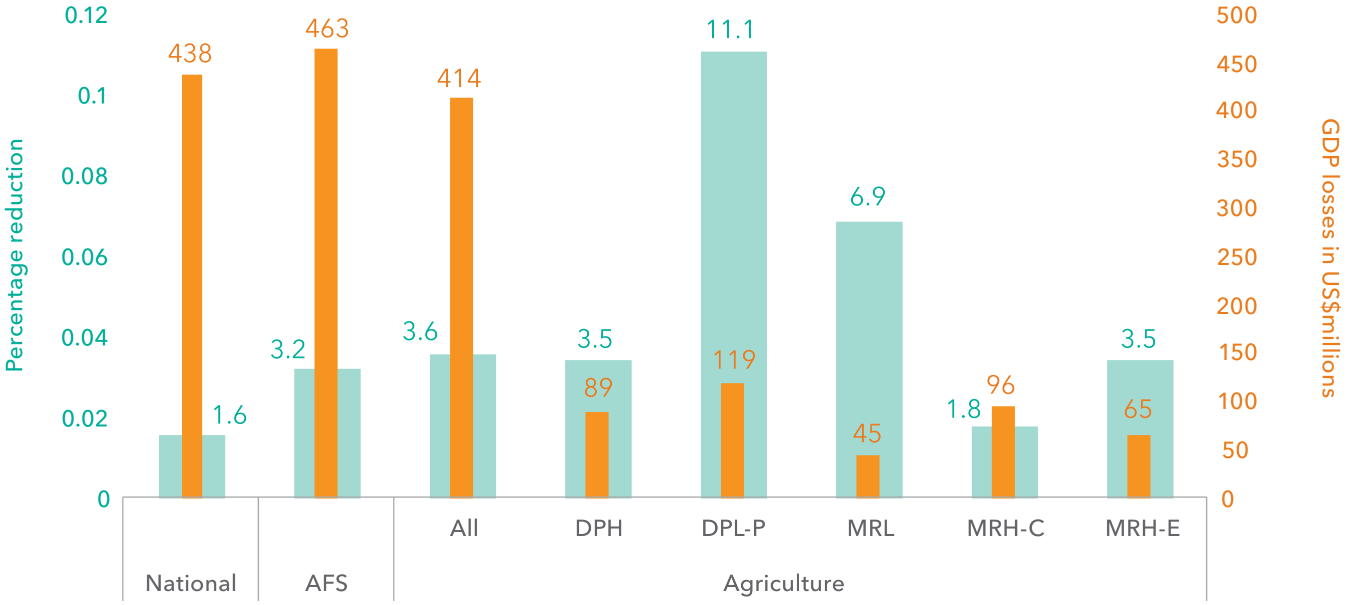
- *Combined.* Implement all three of the above policy scenarios concurrently.

A feature of economywide models is that they capture the economywide benefits and costs of different policies. First, the model captures both direct on-farm impacts and indirect downstream impacts on food processing, trading, and the rest of the economy. In this way, all sectors in the economy are affected, albeit to varying extents. Second, the model measures the trade-offs associated with each policy scenario. Subsidizing food imports or distributing stored grains is expected to benefit consumers more than farmers. Similarly, allocating more productive resources to agriculture reduces the resources available to nonagriculture sectors. As a result, winners and losers often arise from a given policy change. Third, as mentioned, the model internalizes the fiscal cost of certain policy options. Import subsidies (cash transfers) require either an increase in taxes to offset revenue losses (to pay for higher spending) or an increase in the fiscal deficit. The latter means that the government borrows more from private financial corporations, and this reduces the amount of loanable funds available for private investment. Simply put, there is no “free lunch” in this class of economic model.

Model results indicate that the scale of the ENSO shock experienced during 2015/16 causes significant economic losses (Figure 16). National GDP falls by 1.6 percent relative to a neutral climate year. Losses are larger in agriculture itself, where GDP falls by 3.6 percent, and particularly within the drought-prone lowlands, where agricultural GDP falls by 11.1 percent. However, it should be noted that even small percentage reductions in national GDP can imply substantial monetary losses. For example, a 1.6 percent drop in national GDP is equal to US$438 million in lost value-added or national income (measured in 2010/11 prices).

CGE models track economic spillovers or linkages between sectors. Figure 16 summarizes the GDP losses occurring in different sectors of the economy during a strong El Niño year. Percentage GDP losses are largest in agriculture (3.6 percent). This reflects this study’s focus on direct impacts to agriculture. Percentage losses fall when considering the broader AFS (3.2 percent) and the national economy (1.6 percent). However, absolute (dollar value) losses increase as the focus broadens beyond agriculture to include the entire AFS. This is due to negative spillovers between sectors. Lower agricultural production, for example, constrains the supply of raw materials to agriculture-related processing and trading. As a result, GDP losses in the AFS are larger (US$463 million) than those in primary agriculture (US$414 million). Overall, the CGE model estimates that more than one-tenth of the damages to the AFS caused by El Niño occur outside of agriculture. That said, losses in agriculture and the food system encourage workers to migrate to nonfarm sectors in search of employment and income. This inflow of new workers into the non-AFS parts of the economy offsets some of the production losses occurring within the AFS. The final decline in national GDP caused by El Niño is lower than AFS losses, at US$438 million.

FIGURE 16 GDP LOSSES DURING THE 2015/16 EL NIÑO EVENT



Source: Simulation results from computable general equilibrium model using 2010/2011 Ethiopia social accounting matrix data from the International Food Policy Research Institute's Rural Investment and Policy Analysis Model (Benfica and Thurlow 2017).

Note: AFS = agriculture–food system; DPH = drought-prone highland; DPL-P = drought-prone lowland–pastoralist; MRL = humid, moisture-reliable lowland; MRH-C = moisture-reliable highland–cereal; and MRH-E = moisture-reliable highland–enset (Ethiopian banana).

TABLE 7 GDP CHANGES DURING STRONG EL NIÑO EVENTS, AND INTERVENTION SCENARIOS

	Without interventions	With interventions			
		Import subsidies	Stored grains	Social transfers	Combined
Percentage change in GDP (%)					
National	-1.60	-1.61	-1.67	-1.60	-1.68
Agriculture-food system	-3.21	-3.23	-3.11	-3.21	-3.13
Agriculture	-3.60	-3.61	-3.43	-3.60	-3.43
Absolute change in GDP (US$ millions)					
National	-437.6	-438.3	-457.2	-437.6	-457.7
Agriculture-food system	-463.4	-465.9	-449.4	-463.2	-451.9
Agriculture	-413.8	-414.5	-393.9	-413.7	-394.5

Source: Simulation results from computable general equilibrium model and 2010/2011 Ethiopia social accounting matrix from the International Food Policy Research Institute's Rural Investment and Policy Analysis Model (Benfica and Thurlow 2017).

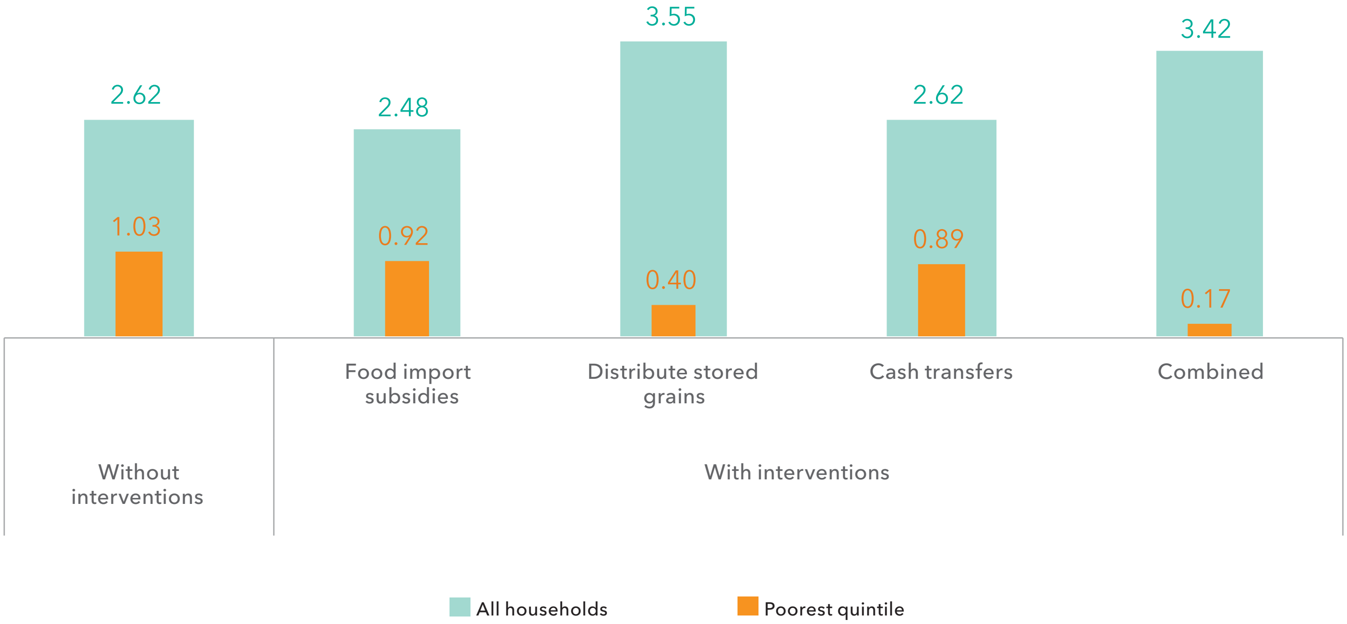
Note: GDP = gross domestic product.

The policy scenarios focus on mitigating the adverse effects of El Niño. Table 7 reports GDP losses (in absolute and percentage terms) with and without the effects of the policy interventions. The first column repeats the national GDP losses shown in Figure 16. None of the market or social policy options considered here are effective at limiting GDP losses. Depleting grain stocks offsets the effects of domestic production shortfalls on downstream processing and eases upward pressure on consumer food prices. However, it does not curb the production losses that occur on the farm during the ENSO event, and by outcompeting local producers, distributing stored grains further reduces agricultural production.

The effects of restocking grain storage are not captured in this analysis, because the simulations focus on the immediate effects of ENSO events. Similarly, cash transfers to the poor increase their demand for domestically produced goods and services, but these transfers are financed by higher taxes, and hence lower consumption spending by higher-income households. Ultimately, on-farm investments, such as those identified by the crop modeling analysis, are needed to reduce agricultural GDP impacts and prevent negative knock-on impacts to the rest of the economy.

Changes in GDP are distributed across households, investors, and the government. Impacts on private household consumption (or welfare) are larger than the impacts on national GDP (Figure 17). This partly reflects this study's focus on direct damages to agriculture and food prices, which is of greater importance for household spending than for investment or government spending. The figure reports consumption losses for all households and for households in the poorest per capita expenditure quintile. All households experience a decline in consumption, or welfare, during a strong El Niño event. Consumption losses are smaller for poorer

FIGURE 17 **HOUSEHOLD CONSUMPTION LOSSES DURING EL NIÑO BY POLICY SCENARIO (PERCENTAGE)**



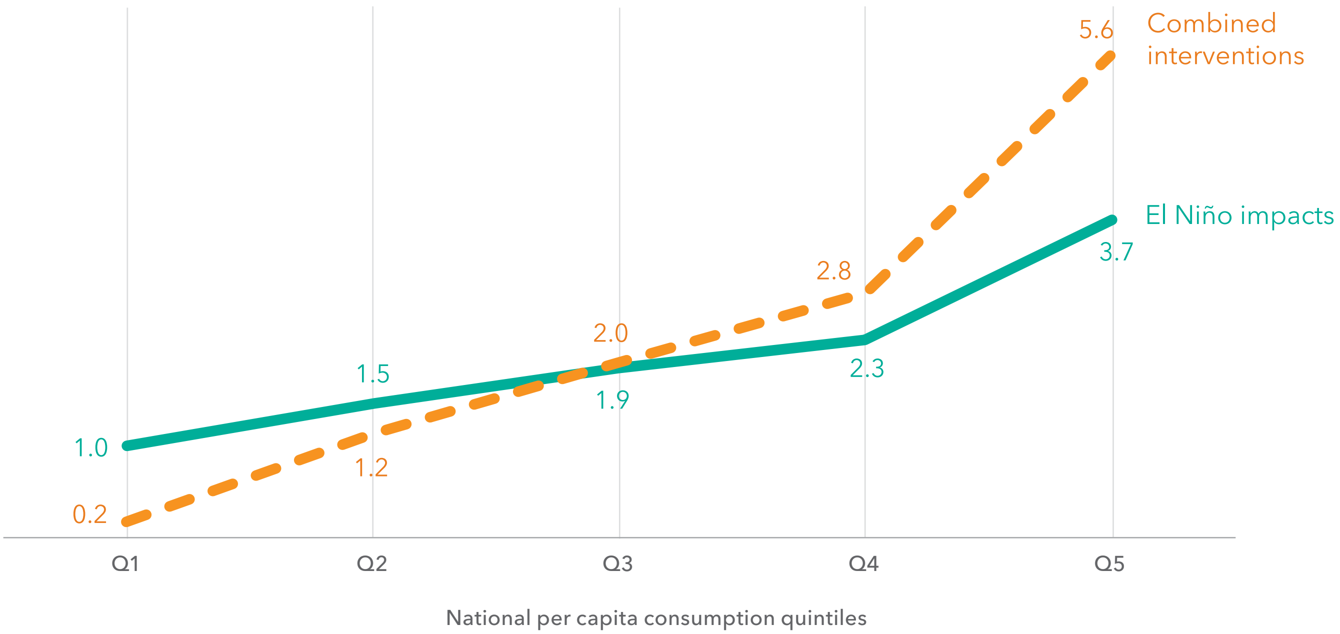
Source: Simulation results from computable general equilibrium model and 2010/2011 Ethiopia social accounting matrix from the International Food Policy Research Institute's Rural Investment and Policy Analysis Model (Benfica and Thurlow 2017).

households, who tend to be smallholder farmers, because they are more likely to rely on labor wages and earnings from nonfarm self-employment, and less likely to own farmland (Table 6). Note that whereas lower-income households may be less affected by El Niño, their ability to smooth consumption, such as by selling assets, is more limited than that of higher-income households. In the absence of supporting evidence, the modeling analysis presented here does not include the short-term benefits and longer-term costs of disposing of household assets.

Policy interventions are effective at reducing household welfare losses. Food import subsidies reduce total consumption losses (that is, from a 2.62 percent decline to a 2.48 percent decline). Figure 17 shows that cash transfers reduce losses for poorer households but leave total consumption outcomes unchanged, at 2.62 percent. This is because the additional cash transfers are financed through greater taxation of higher-income households, which make up most of the national tax base. In other words, the simulated program is designed to be a transfer from higher- to lower-income households, and this explains why there is little change in national GDP in the transfer scenario. Distributing stored grains is very effective at reducing welfare losses for poorer households, which spend a larger share of their incomes on cereals, but this comes at the cost of larger welfare losses for higher-income households. Finally, when all policy scenarios are implemented at the same time, the consumption losses of poor households are largely eliminated, but losses rise for higher-income households (Figure 18).

The impact of severe El Niño events on poor households can be directly measured by changes in the national poverty headcount rate, which shows the share of the population living below the official poverty line. In the base year of the model, the national poverty rate was about 30 percent, meaning

FIGURE 18 HOUSEHOLD CONSUMPTION LOSSES BY QUINTILE, WITH ALL INTERVENTIONS COMBINED (PERCENTAGE)



Source: Simulation results from computable general equilibrium model and 2010/2011 Ethiopia social accounting matrix from the International Food Policy Research Institute's Rural Investment and Policy Analysis Model (Benfica and Thurlow 2017).

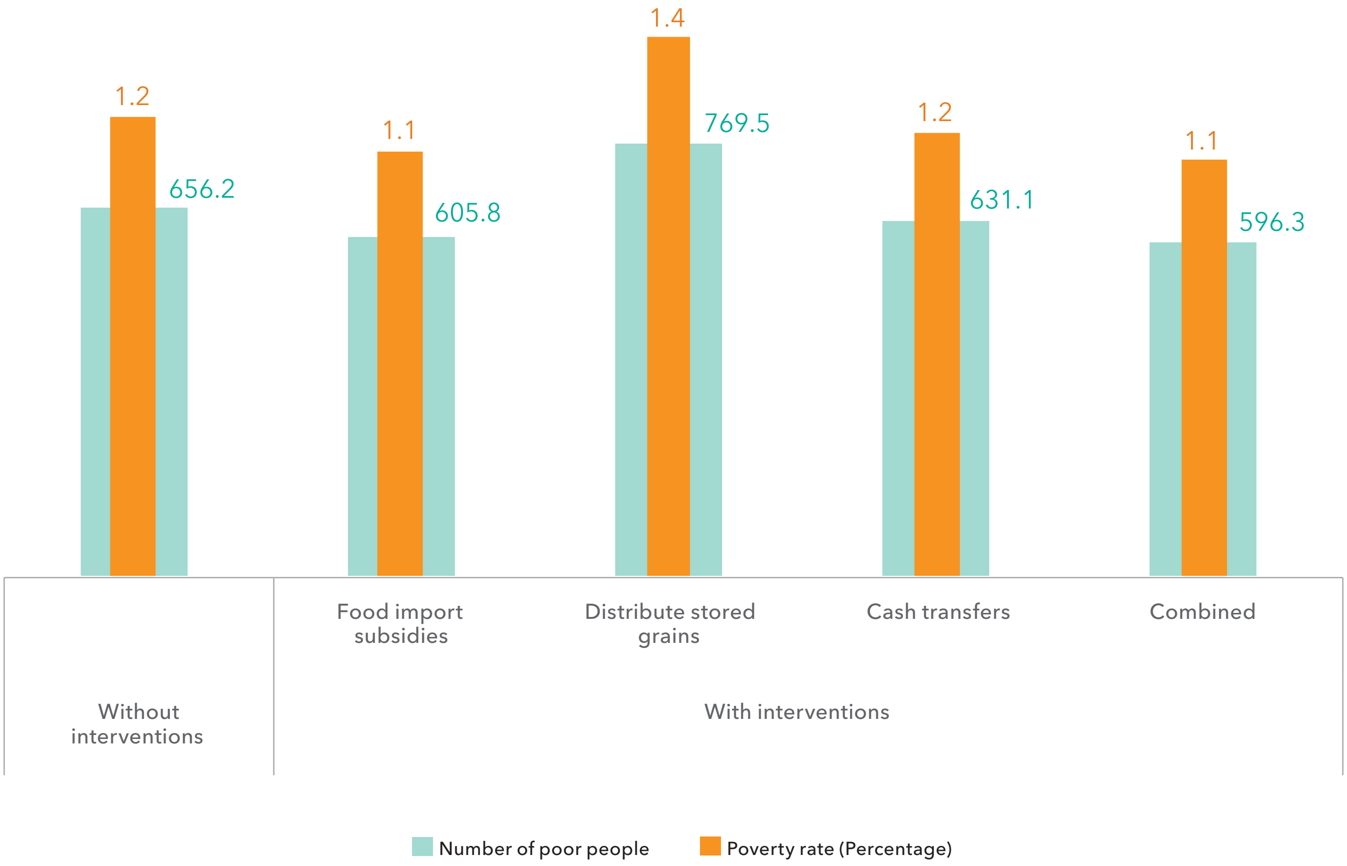
that changes in consumption for households in the second-lowest quintile will determine changes in the poverty rate. The CGE model measures these changes using a survey-based microsimulation module that links changes in consumption for households in the CGE model to changes in consumption for a more detailed set of households captured in the survey. Figure 19 shows the change in both the poverty headcount rate and the number of poor people. Without interventions to mitigate impacts, an El Niño event like the one that occurred during 2015/16 causes the national poverty rate to increase by 1.2 percentage points. This is equivalent to an additional 656,200 people living below the poverty line during the event period. Policy interventions can be effective in helping avoid some of the increase in the incidence of poverty, although they are more effective in reducing the poverty gap (that is, the numbers of the poorest).

RECOMMENDATIONS

In response to the interest of Ethiopia's government and development partners, this study reviewed ongoing resilience programming, consulted stakeholders on opportunities for strengthening such programming, and provided quantitative modelling of a series of alternative resilience strategies.

The analysis of historical weather data indicated that El Niño causes drier conditions in most of the country, whereas La Niña causes wetter conditions.

FIGURE 19 CHANGES IN NATIONAL POVERTY RATE AND POOR POPULATION DURING EL NIÑO BY POLICY SCENARIO



Source: Simulation results from computable general equilibrium model and 2010/2011 Ethiopia social accounting matrix from the International Food Policy Research Institute's Rural Investment and Policy Analysis Model (Benfica and Thurlow 2017).

High-resolution crop modeling analysis showed that for maize and wheat, yield deviations caused by El Niño vary substantially across crops and subnational regions. In general, cereal yields in drought-prone areas and the lowlands fall during El Niño but rise during La Niña.

The former was confirmed by in-depth statistical analysis of historical production data, which showed that additional production losses for key staple crops were caused by reduced harvested land area, rather than just lower crop yields. The analysis also showed that substantial crop and livestock production losses occurred in the lowlands and drought-prone regions.

Based on the estimated deviations in agricultural production, the economywide assessment showed that El Niño causes major losses in gross domestic product (GDP), and that a significant share of the agriculture–food system (AFS) GDP losses occur outside of agriculture itself (via intersectoral and demand linkages). Welfare losses are found to be larger for net food-consuming urban households than for rural smallholder households. A large increase in the number of poor people also occurs following ENSO events.

Based on these analyses, we propose the following recommendations:

Build on the strength of Ethiopia's current resilience programming

A wealth of experience in past and current work on resilience in Ethiopia clearly exists. Efforts to improve resilience in the agriculture sector should build upon this expertise in the context of the evolving Ethiopian conditions. Although some of these efforts are recorded in the peer-reviewed and gray literature, forming a clear picture of where activities have been concentrated is of enormous importance. As several program reviews and key informants pointed out, developing a clear understanding of where and how interventions relate one to another in terms of thematic and geographic areas is essential to achieving effective coordination among the various agencies and pursuing potential synergies. Strengthening regional cooperation between national and international development partners rests on the availability of this information.

Develop new monitoring tools for resilience and improve coordination

The coordination should start with the government of Ethiopia and partners developing and applying a resilience framework according to which its many development programs can be structured and monitored for progress and outcomes. This can be supplemented by a database with an up-to-date record of the programs and organizations that have worked on and are working on resilience-building projects and interventions. With this information agencies will be able to identify common avenues for future collaboration and potential gaps in investments.

Furthermore, it is essential to strengthen existing coordination mechanisms, such as the Disaster Risk Management Technical Working Group, facilitated by the National Disaster Risk Management Commission; the intercluster coordination meeting, facilitated by UNOCHA (the United Nations Office for the Coordination of Humanitarian Affairs); and the national and regional experience sharing forums on coordination for resilience, facilitated by the European Union and the Food and Agriculture Organization of the United Nations. Platforms such as these provide a place to share resources and expertise through mutual engagement, as well as to support humanitarian organizations, development partners, and government agencies to strengthen their respective resilience-building agendas. Bridging diverse institutional interests, mandates, policies, and resources is a challenging but necessary task, and coordination efforts will reduce the risk of duplication in programs and strategies. Integrating selected resilience-related priorities, such as reproductive health and rights, and gender equality, into the various sectors would provide a large step toward strengthening resilience in the long term.

The early warning system and assessment results are not always consistent with regional beneficiary numbers. The system's performance needs to be strengthened in lowland areas, where shocks are not always identified fast enough. It is also important to develop long-term climate early warning systems with the participation of local communities to limit the unfavorable impacts of ENSO on livestock populations and productivity.

Impact assessments, monitoring, and evaluation need to be strengthened in programs beyond the Productive Safety Net Programme (PSNP) to ensure that the intended benefits, impacts, and outcomes are achieved and that programs that do not perform as well can be corrected in time.

Improve targeting and linkages between short- and long-term programming

The accumulated experience indicates that programs and policies need to be customized and targeted toward communities and regions based on their geographic location, needs, and circumstances. Coordination and information sharing across agencies need to be improved to integrate efforts to improve resilience and move away from one-size-fits-all types of policies and interventions. Agencies need to jointly determine where and how resources need to be allocated. Beyond immediate responses to shocks, funds should also be used for recovery and long-term rehabilitation.

At the same time, it is important that food security initiatives be linked to poverty reduction, shorter-term disaster response, and longer-term disaster risk reduction. Examples of improved targeting include tailoring of the Targeted Supplementary Feeding Programme allotments to the nutrient requirements of different groups. Potential recipients who might adopt negative coping strategies that deplete their natural resource and asset base should be particularly identified and targeted.

Because lowland pastoralist areas are particularly vulnerable, a strategy specifically tailored to their livelihoods should be developed. The strategy should focus on the timing of assessments, types of livelihood systems in the area, public works projects appropriate for lowland areas, and management of food resources in the lowlands context, focusing on climatic extremes and targeting of communities. The focus should be on interventions targeted toward building livestock infrastructure to improve the resilience of these communities. Dividing the responsibility for livestock between two ministries might not be ideal for coordination in this area.

Substantial investments are still needed for access to basic health and education services in the lowlands. Public works should be integrated into comprehensive regional plans, and the PSNP component tailored more appropriately to the pastoral and lowlands context, in terms of the timing and types of public works and who participates in the program, to reduce inclusion and exclusion errors.

Humanitarian organizations should systematically assess and analyze the impacts of crises on livelihoods as a basis for designing, implementing, and monitoring livelihood interventions. Supporting livelihoods requires an in-depth understanding of and support for affected populations' assets, capabilities, and activities to ensure their means of living. Special attention is needed during mass internal displacements, such that pregnant women have access to safe and clean deliveries attended by skilled birth attendants, and all children, including separated and unaccompanied children, and women are protected.

Strengthen the enabling environment

Ethiopia has made substantial progress in building the resilience of its agriculture–food system. It has successfully raised the productivity of cereal producers and provided social protection to poor rural households. The government has also invested heavily in rural roads and other infrastructure needed to ensure that markets operate to smooth production and consumption shocks. Despite this progress, smallholder productivity remains low and scope remains to further expand modern input use and water management practices.

The development of microfinance institutions and village savings and loan associations should be enhanced to allow communities to diversify their livelihoods or invest additional resources in current productive activities to increase efficiency, productivity, and profitability while improving resilience. Female-headed households should be prioritized as targets for financial and cash support.

Develop multipronged investment strategies

No single intervention can fully eliminate all GDP and welfare losses in all places and for all people in Ethiopia. Instead, a portfolio of farm, market, and social policies will be needed to cushion ENSO's economywide impacts. In terms of investments in agricultural technologies, the analysis finds that an increase in irrigation combined with integrated soil fertility management and increased application of nitrogen fertilizer can dramatically reduce adverse ENSO impacts in all agroecological zones and during both ENSO events (El Niño and La Niña).

In terms of complementarity investments, although food import subsidies reduce total consumption losses to some extent, cash transfers reduce losses for poorer households but tax higher-income households. Distributing stored grains is very effective for reducing welfare losses for poorer households, which spend a larger share of their incomes on cereals, but this comes at the cost of larger welfare losses for higher-income households. A combination of these three policies largely eliminates the consumption losses of poor households but makes losses rise for higher-income households.

In the medium to long term, enhancing rural resilience and achieving middle-income status by 2025 will require a permanent cash transfer program, similar to the PSNP. Rural resilience can be achieved only if infrastructure development accelerates and if investments in agricultural research and development are increased. Even today only one-half of all Ethiopian farmers use chemical fertilizers, and recent growth in irrigated area, though commendable, remains too low to dramatically affect resilience outcomes in the next two decades.

Achieving climate resilience in rural areas will also require much faster generation of economic livelihood options outside of agriculture, which in turn will necessitate a much faster opening to and support of foreign direct investment. Despite an expected gradual decline in the share of people employed in the agriculture sector, an expected increase of 60 percent in the number of rural households in arid and semi-arid land areas suggests that rural investments need to substantially increase to ensure that rural–urban income gaps and income and food poverty do not increase.