The Impacts of COVID-19 on GDP, food prices, and food security

Jayson Beckman  
Economic Research Service, United States Department of Agriculture, USA  
Jayson.beckman@usda.gov  
+001.202.694.5557

Felix Baquedano  
Economic Research Service, United States Department of Agriculture, USA  
Felix.Baquedano@usda.gov

Amanda Countryman  
Colorado State University, USA  
amanda.countryman@colostate.edu

ABSTRACT

COVID-19 has led to a wealth of research examining possible impacts; however, potential impacts to food security have received much less attention. We use a computable general equilibrium model to simulate the potential impacts of COVID-19 using observed changes from 2020 (September) in unemployment, trade, oil prices, and production to inform our model. Estimated GDP and food price changes are then used as inputs into the International Food Security Assessment (IFSA) model which estimates changes in food consumption, and food gaps in developing countries. Results indicate that the COVID-19 lockdowns lead to a decrease in global GDP of 7.2 percent, and a decrease in grain prices of 9 percent. These changes lead to an increase in the number of food-insecure people in 2020 of 211 million (a 27.8 percent increase). We also perform a sensitivity analysis, providing a lower and upper bound of potential impacts from COVID-19.

Keywords: CGE, food security, unemployment, trade, prices

HIGHLIGHTS

- The effects from COVID-19 include unemployment, reduced trade, lower oil prices, and decreased production.
- Using a CGE model, we estimate that global GDP decreases by 7.2%, and grain prices decrease around 9% due to COVID-19.
- The number of food-insecure people in 2020 could increase by 211 million.
1. INTRODUCTION

COVID-19 has disrupted global economies, with restrictions in the movement of people and goods, both domestic and international, leading to large changes in unemployment and gross domestic product (GDP). All facets of the economy have been affected, with large decreases in travel severely disrupting tourism, unemployment rates at levels not seen since the Great Depression, and oil prices decreasing to levels not seen in two decades. The agricultural sector also has been severely affected, with disruptions in the demand and supply of their products. During the initial weeks of the pandemic, agriculture seemed to receive less attention than other sectors of the economy (e.g., airlines), yet disruptions in food supply chains have become a major focus as the global pandemic continues. And, the World Bank and the Food and Agriculture Organization of the United Nations (FAO) have sounded the alarm on the potential impacts of COVID-19 on food security. Accordingly, we provide an integrated economic assessment of the economic effects of COVID-19 market disruptions focusing on global food security.

Although COVID-19 occurred only recently, there has been some research on the economic impacts of the pandemic. Most of this work has focused on the economy-wide change (e.g., GDP), several of these have used computable general equilibrium (CGE) models to try to disentangle the sectoral and country-specific effects. McKibbin and Fernando (2020) consider 7 scenarios based on changes to labor supply, the equity risk premium of economic sectors, the cost of production, consumption demand, and government expenditures. Maliszewska et al. (2020) use a CGE model with shocks to labor and capital, international trade costs, a reduction in travel services, and a redirection of demand away from activities that require proximity between people. These two works are important, but their inputs are fairly generic across sectors and
regions, and they focus more on the impacts to manufacturing, with agriculture modeled as a single sector. A more recent study (ADB, 2020) uses observed data on impacts for China, accounting for several economic dimensions of the pandemic: an increase in trade costs that affects the movement of people and inbound tourism (along with industries linked to transportation and tourism); a negative supply-side productivity shock that cuts wages and corporate earnings (leading to reductions in consumption and investment); and fiscal stimulus through various macroeconomic policy instruments. That work does use actual data to inform their model, but that information is limited to China, and they also largely ignore the impacts to agriculture (and food security).

Our work here also uses a CGE model, but we seek to make two novel contributions. First, we provide more concrete inputs into the CGE model. We consider four major facets of impacts from COVID-19—unemployment, trade, oil prices, and production—using data on observed changes thus far (September) to inform the model. We consider a short-run setup: how COVID-19 might affect the global economy in 2020. The second contribution is to consider the impacts to those most vulnerable to food security issues. As pointed out in Laborde et al. (2020), the most affected regions, globally, could be Sub-Saharan Africa (SSA), low-income countries in Latin America, and parts of South Asia. However, to date, there are little reliable estimates of this increase in food insecurity and which regions will be most affected. To provide information on the food security dimension of COVID-19, we link our CGE results with the United Stated Department of Agriculture (USDA) International Food Security Assessment (IFSA) model. This model projects food demand for 76 low- and middle-income countries—39 in SSA, 4 in North Africa, 11 in Latin America and the Caribbean (LAC), and 22 in Asia—using projected changes in GDP and grain prices to estimate changes in food security.
The next section describes the CGE model that we use to estimate the changes in GDP and grain prices from the pandemic. This section also provides in-depth information on the factors we use to estimate the impacts. The third section provides a brief overview of the CGE results; the fourth section details the IFSA model and discusses the impacts to food security. The fifth section provides a lower and upper bound for some of the important model inputs. Finally, conclusions are provided.

2. CGE MODEL

Given the global, economy-wide impacts of COVID-19, a global CGE model is well suited to examine the impacts of the pandemic. Other types of models forecasting macro changes could also be used (and are used) for economic analysis, but the complex links and interactions between sectors, competition among these sectors for limited economic resources, as well as interactions between the production, consumption, and trade prevalent in the pandemic are best captured in the CGE framework. Analysis of pandemics have been considered in a CGE framework previously (along with those mentioned in Section 1 related to COVID-19, Yang et al. (2020) consider the impacts of COVID-19 on tourism). Arndt and Lewis, 2001; Bell et al., 2004 studied the impacts of AIDS using a CGE framework; McKibbin and Sidorenko (2006) considered the impacts from four different pandemic influenza scenarios; and Yang and Chen (2009) estimated the impacts to tourism from severe acute respiratory syndrome (SARS). Questions could be asked of using the ‘equilibrium’ nature of the CGE model; in particular because a pandemic tends to lead to supply and demand imbalances. This is a fair criticism; but we note that our approach of considering unemployment and production shocks should alleviate some of those concerns.2
For this work, we keep the modeling simple and focus on providing the best inputs possible to the model. CGE models have been used to analyze the potential impacts of COVID-19, but they often rely on ad-hoc inputs. This is understandable given that we are essentially still in an ex-ante timeframe, with an evolving situation. However, there is some evidence of the impacts from COVID-19, including the effects on unemployment and supply chains through trade.

The model we use is the static Global Trade Analysis Project (GTAP) model, which provides a one-time change in the economy in response to a given shock or set of simultaneous shocks. An alternative, the dynamic setup, is useful in modeling various recovery options; but given that we are only concerned with modeling the immediate-year impacts, a static framework is appropriate. Like much of the literature (Maliszewska et al., 2020), we assume a short-run setup (i.e., one year) in which resources are fixed (capital and labor are immobile across sectors).

In the model, producers are described as perfectly competitive cost-minimizers, with technology defined as a nested production function. Producers’ demand for intermediate inputs responds to prices for inputs and outputs, subject to a Leontief intermediates production function. A CES production function over value added allows producers to substitute among primary factors as their relative prices change. Consumer demand is described by a Constant Difference of Elasticity (CDE) demand system, a non-homogeneous function that allows income growth to affect consumer preferences. Cobb-Douglas functions describe government and investment demand, which imply constant budget shares in total expenditure. Import demand is described by nested Armington functions, in which demand is first allocated between the domestic good and the composite import and then among national sourcing of the composite import. Countries (or
regions) are linked through their bilateral trade flows, which explicitly account for transportation and marketing costs in moving goods from port to port.

Table 1 describes the data and scenario design for our modeling approach. Similar to other CGE models used to analyze COVID-19, we rely on the GTAP database for economic information. The latest GTAP database is set to 2014 (i.e., using that database would tell us how the 2014 economy would change with COVID-19 in place). See Appendix 1 for information on regions and sectors. To update this database, we introduce a series of macroeconomic shocks to bring the model to 2020 (this is noted as Phase 1 in fig. 2). This method is often used when providing a baseline analysis or updating a data base, and as detailed in Beckman et al. (2012), involves providing the model information on actual changes to capital, gdp, labor, population, and productivity. These shocks are given in Appendix table 3 and indicate that most countries had an increase in population and labor; although China, Developed Asia, and several countries of the Former Soviet Union have decreases in labor.3

2.1 Modeling Approach

A major goal of our work is to provide better inputs for the COVID-19 ‘Phase 2’ of the model. Several CGE papers have noted the importance of considering changes in employment, trade costs, supply chain disruptions, and demand for certain products (e.g., tourism, (ADB, 2020)). We consider several of these changes as well, focusing on aspects in which data exist on the real-world impacts so far, and those which might impact food security. First, changes in unemployment have been well documented, especially for the United States. Second, information on changes in trade (both value and volume) also exist; although there is often a lag of several months. Third, it has been well noted that oil prices have decreased as a result of less
global movement of people and goods. Finally, work has been done to estimate the changes in domestic output (production) for certain countries.

2.1.1 Unemployment

COVID-19 has forced countries to restrict the movement of people, both within countries and across borders, hampering the use of many products and services. These restrictions have affected the labor market; restaurants that are closed (or only have take-out service), for example, have had to lay off employees. As noted in World Bank (2020), unemployment can occur due to health measures aimed at slowing the spread of the virus e.g., school and daycare closures and businesses related to tourism. Unemployment has been considered previously in other COVID-19-CGE work. Maliszewska et al. (2020) assume an increase in unemployment of 3 percent globally, on average. McKibbin and Fernando (2020) base their unemployment changes on mortality rates and absenteeism in China, extrapolating to other regions in the world. Given that their work was one of the first economic analysis of COVID-19, McKibbin and Fernando’s assumed changes in unemployment are on the lower end (3.44 percent for China). For example, the maximum assumed rate of increase for unemployment in their work for the United States is 1.30 percent; however, recent data show U.S. unemployment reaching nearly 15 percent.

We gather data for changes in unemployment from the OECD and IMF. Table 2 describes the change in unemployment in 2020 (since September), relative to 2019, for countries where data is available. As illustrated, unemployment changes differ internationally, with slightly improved unemployment in Egypt, likely resulting from non-COVID-19 related factors, to a double decrease increase in unemployment relative to that in 2019 for Mauritius. For those countries where data is not available, we take a simple average of all others and apply it to them.
Another factor to consider in the unemployment aspect is changes to capital. Although resources cannot switch between sectors in the short-run setup, sectors can still substitute capital for labor. The previously mentioned CGE papers did not consider changes to capital; however, as noted in World Bank (2020), the avoidance of workplaces by employees will inevitably cause capital (e.g., machinery) to be left idle for longer periods of time, and some industries are operating at limited capacity to comply with social distancing guidelines, which will result in lower capital utilization in the economy. We take a similar approach, arguing that the lack of workers has idled capital, or use is at a minimal capacity. Thus, we assume that there is no change in capital.

2.1.2 Trade
The impacts of COVID-19 also have been felt in the international trade market as disruptions in the supply chain can result from both international and domestic pressures. Domestic impacts from unemployment or supply disruptions reduce the quantity of product available for consumption (either domestically or for export). These impacts find their way into the trade market and are compounded by all the domestic interruptions. Changes in the trade market have been handled in previous COVID-19-CGE work through changes in trade costs; i.e., supply chain disruptions increase transport and transactions costs due to additional inspections, reduced hours of operation, road closures, and border closures (Maliszewska et al., 2020). The work by Maliszewaska et al. assumes an increase in trade costs of 25 percent, while ADB (2020) assumes an increase of 1 or 2 percent. We agree that trade costs have likely increased, but there is not a direct way to observe these changes.
The way we model increased trade costs by directly implementing changes in trade in the model, thus allowing trade costs to adjust for the given trade changes. Table 3 presents information on changes in trade quantities (this is the variable we shock in our model) for the sectors in our analysis for the period January-September 2020 compared to the same months in 2019. As indicated, the traded quantities for most agricultural sectors in our model varies, with decreases for rice, roots and tubers, and other agriculture (such as processed food), but increases in wheat and coarse grains. Nonagriculture trade has decreased by 12.07 percent (this is presented in value terms, as the quantities shown in the trade data could not be easily converted), a point made in WTO (2020). Table 3 also presents some additional data for informational purposes, pointing out the percentage of missing data and what country has the largest share of missing data. This arises because countries often are behind in reporting trade data (often reported with a lag of one to two months in most cases).

2.1.3 Oil prices

Given its importance in the global economy, one prominent economic change that has occurred thus far in 2020 is the large decrease in the price of oil. CRS (2020) notes that the decrease has occurred as a result of reduced economic activity and disagreements among oil producers over production cuts in crude oil. There has been a lot of press related to the negative price for monthly contracts, but for our work here, we use the assumption of a 37 percent decrease for the year, as offered by IMF (2020).

2.1.4 Domestic Output

As alluded to before, the impacts of COVID-19 are felt throughout the supply chain. Several pieces of research have attempted to quantify these impacts for various countries. The Center for...
Agricultural and Rural Development at Iowa State University created a database with information that can be used to investigate the impact of COVID-19 on China’s economy (Ha et al., 2020). Their database contains data at the GTAP sector-level (except for agricultural sectors, for which they provide no data), including the cumulative growth rate of investment in fixed assets and the growth in output for each nonagriculture sector (He et al., 2020). The data are provided at the monthly level. For the United States, the Federal Reserve provides data on observed output changes for manufacturing, mining, and utilities. We choose to use the information for the United States given that the yearly change shows a decrease (whereas China’s shows an increase—but this is not really compatible with the decrease in global GDP). Table 4 presents this information.

Given that our focus is on COVID-19’s impacts on food security, we must have a method to extrapolate the data to countries that do not report production changes. To do so, we make use of the pioneering work of Oxford University, which created a database that tracks and compares policy responses to COVID-19 across the world. The Oxford University project collects publicly available information on 17 indicators of government responses. Eight of the policy indicators (C1-C8) record information on containment and closure policies, such as school closures and restrictions in movement. Four of the indicators (E1-E4) record economic policies, such as income support to citizens or provision of foreign aid, and five indicators (H1-H5) record health system policies such as the COVID-19 testing regime or emergency investments into healthcare. The tracker aggregates the policy scores into a ‘Stringency Index’ (Hale et al., 2020)—with measures closer to 100 indicating stricter lock-down measures. Appendix Table 4 shows the average (mean) Stringency Index values for countries from January 1 through September 30. As
illustrated in the table, average stringency index values range from nearly 10 (Nicaragua) to more than 72 for Honduras.

We link the production changes to the COVID Stringency Index, which can provide projections for countries that do not report output changes regularly. A main purpose of the CGE modeling is to provide input into the IFSA model, which relies on changes in GDP and grain prices (i.e., food). Although output would normally be kept as endogenous within a model, we prefer to predetermine output in order to provide information on GDP and price changes based on actual data. To do so, we swap production with the output-augmenting variable in the model, letting technology change to reach the specified change in output.

3. CGE RESULTS
This section provides a brief overview of the CGE results (for the shocks simultaneously), given that our focus is on the changes to food security resulting from simulated changes in GDP and grain prices from our CGE analysis. Accordingly, we only discuss those changes. Results for other sectors and other impacts are available upon request. The model estimates a reduction in global GDP of 7.22 percent. As shown in table 5, all countries have a decrease in GDP. The changes estimated by the model also tend to be larger for the major economies of the world: U.S. GDP decreases by 7.92 percent and China’s decreases by 9.79 percent.

Table 6 presents information on the GDP change by model input when they are introduced independently. The first thing to notice is that the GDP impacts from trade and oil prices are small. There are only two instances of a region having a change in GDP of a percent or more: Other Asia and Central Africa for trade. Thus, although there were some large changes for agriculture and (especially for) nonagricultural trade, the impact on GDP as estimated by our
CGE model is relatively small. Rather, the relatively larger changes to GDP are from unemployment and production. Indeed, the global change in GDP from these two inputs are -1.2 and -6.4 percent (compared to -0.1 and 0.3 percent for trade and oil prices). There is a lot more variation in the GDP change across regions from unemployment because we have a lot more information on actual unemployment changes. Given the importance in the global GDP calculation of unemployment and production (and the variation in unemployment), we conduct some sensitivity analysis on these inputs later in the paper.

Given that agricultural trade generally increased over the time frame, the model estimates decreases in grain prices at a global level. In addition, the decrease in GDP softens the demand for agricultural (and all) products, causing prices to fall. However, some regions see price increases for certain commodities. For rice, the model estimates a decrease of 0.45 percent (the smallest decrease), while declines are larger for wheat (11.48 percent) and coarse grains (23.20 percent).

4. INTERNATIONAL FOOD SECURITY ASSESSMENT (IFSA)

Food security is generally decomposed into multiple components: food availability, food accessibility, and food utilization. In the present analysis, we focus strictly on the availability and accessibility components of food security by employing the U.S. Department of Agriculture (USDA) International Food Security Assessment (IFSA) model to estimate food consumption, food access, and food gaps in developing countries. The IFSA model was developed by Beghin et al. (2017) and implemented by Thome et al. (2019) to project food demand for 76 low- and middle-income countries—(see Appendix Table 9 for the aggregation). Food is divided into four groups: (1) the major grain consumed in the country, (2) other grains, (3) root crops, and (4)
all other food. The IFSA model projects food demand expressed in grain equivalent based on the caloric content of food items to allow for aggregation across food groups.

The IFSA model analyzes the gap between projected food demand, which is a function of per capita income and food prices and a nutritional target of 2,100 calories per capita per day. This allows for the measurement of three indicators of food insecurity: the share of the population that is food insecure, the number of food insecure people, and the food gap. The share of the population that is food insecure is the number of food-insecure people—those who cannot meet the nutritional target—and is based on total population and the population share that consumes below the nutritional target. The food gap measures the food needed to raise consumption at every income level to the nutritional target. In many countries, per-capita consumption is significantly less in the lower income deciles than the average for the country. In these countries, the distribution gap provides a measure of the intensity of hunger—the extent to which the food security of already hungry people deteriorates as a result of income declines or other negative economic conditions. This measure can be expressed on a per-capita basis (in calories per day) or as an aggregate measure (the total quantity of food needed to fill the gap in a country).

The simulation framework used to project food demand is based on partial-equilibrium models for each country in the assessment. Each country model comprises a price-independent generalized log-linear (PIGLOG) demand system for each of the four food groups (Muellbauer, 1975). See Appendix 2 for information on the equations used in the model. The demand system is calibrated on the average for the period 2017-19 of prices and incomes, observed consumption levels, the measure of inequality, and income and price elasticities. Demand projections are based on projected prices and incomes; the model implicitly assumes that both the preferences
represented by the demand system and the income distributions embedded in the calibration and projections are constant over time. The distribution of consumption used to calculate food security measures is described by a constant coefficient of variation, which implies an increasing standard deviation of consumption as consumption rises over the projection period but does not account for potential structural changes in an economy. The implied price and income elasticities evolve over the projection period as prices and incomes change.

Before introducing any of the estimated GDP and food (grain) price changes into the IFSA model (Phase 3 in figure 1), we first generate food security estimates without the COVID-19 shocks. The pre-COVID-19 IFSA results serve as a baseline to measure the impact of the pandemic on food insecurity. Then, the 3-year trend for GDP and prices used to calibrate the IFSA model and to obtain the 2020 projection is changed to include the shocks modeled in the COVID-19 scenario.

Table 7 summarizes the food security results from the IFSA model by region. The full set of results by country are presented in Appendix Table 10. Across the 76 countries covered by the IFSA model COVID-19 is anticipated to increase the number of food insecure people in 2020 by 211.2 million (or almost 27.8 percent), for a total of 972 million people in food insecurity. The prevalence of food insecurity, or the share of the population that cannot consume a 2100 kcal/day diet, is estimated to increase by 6.1 percentage points to almost 19.6 percent of the population in 2020. In relative terms the Commonwealth of Independent States (CIS) (largest changes are to Moldova and Tajikistan), Central and South Asia (CSA) (Afghanistan, Bangladesh, and Pakistan are the most impacted), and South East Asia (SEA) (Cambodia has the largest change) are projected to see the highest increases in food insecurity in 2020. The share of food insecure people is anticipated to increase by 2.8 percentage points (or 36 percent) from its pre-COVID-19
estimates in CIS. The prevalence of food insecurity is estimated to increase by 40 percent and 35 percent in CSA and SEA respectively from the pre-COVID-19 estimate. In absolute terms CSA and East Africa (EAF) are projected to see the highest increases in the number of food-insecure people. In CSA it is estimated that the number of food-insecure people will increase by 109.3 million and in EAF by 30 million. For CSA, the increase is largest in Bangladesh (who, the CGE model estimates has the largest decrease in GDP), India and Pakistan. The largest increase in EAF is in Ethiopia (11.7 million), but they are the largest country in terms of population in the sub-region. Asia --CSA, CIS, Middle East, SEA, and Other Asia-- is anticipated to account for most of the food insecure people in 2020 and record the highest increase in food-insecurity from COVID-19. The number of food insecure people in Asia is estimated to increase by 131.8 million people and reach almost 464 million in 2020. Sub-Saharan Africa (SSA)--Central Africa, East Africa, Southern Africa, and West Africa—follows closely behind SSA, with the number of food insecure people anticipated to increase due to COVID-19 by almost 68 million and reach almost 458 million in 2020.

The food gap, which measures the gap between observed consumption and the 2,100 kcal/day target, is estimated to increase 8 percent to almost 373 Kcal/ per capita across the 76 IFSA countries as a result of COVID-19. CSA, West Africa (WAF), EAF and Central Africa (CAF) are anticipated to have the sharpest relative increase in the food gap in 2020. In CAF the food gap is anticipated to increase by 43 Kcal/per capita to 563 in 2020. In EAF the food gap is estimated to increase by 39.2 Kcal/ per capita to almost 506 Kcal. In CSA and WAF the food gap is anticipated to remain below 400 Kcal/ per capita but increase 10.4 percent and 7.6 percent, respectively, in 2020 due to COVID-19.
5. SENSITIVITY ANALYSIS

Given the wide differences in lockdown approaches across the world (Appendix Table 4), we provide a sensitivity analysis of our results. Other reasons for a sensitivity analysis involve the recovery of China’s production, despite the lockdown (see data from He et al., 2020); and the model assumption that the average Stringency Index is applied for the entire year—whereas many countries followed a similar example to the United States with little lockdown at the beginning of the year, but two peak periods of lockdown during the year. The GTAP framework has a system in place to conduct sensitivity analysis, known as Systematic Sensitivity Analysis, which explores the sensitivity of model results to uncertainty, either parametric or by policy shocks. We use this framework to explore potential deviations from the earlier scenario by allowing the policy shocks for unemployment and production (recall, these were the two of the four shocks that impacted GDP, substantially) to vary by 50 percent. So, for example, the model will solve for the variation in U.S. unemployment of 3.3—by having two scenarios of 3.3 ± 50 percent, so 1.65 and 4.95 percent. Systematic Sensitivity Analysis allows for the specification of either a triangular or uniform distribution, given that we are providing a potential range of results based on how locked down a region is, we choose the uniform distribution—basically saying that the impacts under COVID-19 could fall under any of the scenarios, equally. These results are then used in the IFSA model, to provide a range of potential food security impacts.

5.1 CGE results

The results for GDP and grain prices for the sensitivity analysis are presented in table 8. These results indicate that global GDP could range between -3.36 percent to -10.76 percent. These changes tend to be larger than those estimated by CGE models in earlier work, such as ADB (2020); Maliszewska et al. (2020); or McKibbin and Fernando (2020). Of these, the more recent
piece (ADB, 2020) does have a decrease in global GDP close to ours (their upper bound is 9.7 percent), but they assume that the impacts from COVID-19 are only felt for half a year. In terms of prices, none of those previously mentioned papers report prices in their publication; but McKibbin and Fernando (2020) provided estimates to the authors where prices increased between 5-10 percent.

We also compare the GDP estimates in our model to actual GDP changes, using information from OECD (2020), presented in Appendix table 5. The first thing to notice is that some countries have an increase in actual GDP, in particular, China—which is along the lines of the production increases shown by He et al. (2020). But, aside from Turkey, all other countries have a decrease in their GDP for 2020 so far. Another piece to notice is that the GDP changes for countries that have just reported 2nd quarter results are bigger than those who have reported 3rd quarter changes. One reason for this is that the 3rd quarter saw many countries relax their lockdown restrictions. The third thing to note is that the 2nd quarter GDP changes tend to be similar to those estimates at the upper end of our sensitivity analysis, while the 3rd quarter estimates tend to be closer to our lower end estimates; hence, the variability in degree of shutdown does tend to play out in both our model and actual GDP changes.

5.2 IFSA results

When the lower and upper bound estimates are taken into account the increase in food insecurity due to COVID-19 ranges from 135.6 million to 271.4 million additional food-insecure people (Table 9). Bringing the total number of food-insecure people to between 896 million (lower bound) and 1.03 billion. The most impacted regions in absolute terms are still CSA, EAF, and WAF. Together the three regions account for between 12 percent (lower bound) and 21 percent
of the number of food-insecure people in 2020. They also account for most of the increase in the prevalence of insecurity and the food gap. While these results may seem large, they are not unreasonable. For example, Laborde et al. (2020), who also use a CGE model, estimate that a 5 percent reduction in global GDP will lead to an increase in extreme poverty of 140 million people. Our results at the country and regional level show a sharper decline in GDP so with sharper income declines food insecurity could be affected within the range of our results.

6. CONCLUSIONS

COVID-19 has led to a wealth of research examining potential impacts on GDP and other macroeconomic variables (e.g., unemployment, trade). The potential impacts to food security, however, have received much less attention as research has tended to focus on major economies or developed countries. However, COVID-19 could lead to changes in income and food prices, which could alter food security. Our work here uses an integrated modeling approach where we employ a combination of a simulation model to estimate changes in GDP and food (grain) prices, then those results are used in the U.S. Department of Agriculture’s International Food Security Assessment (IFSA) model to estimate food consumption, food access, and food gaps in developing countries. Rather than relying on ad-hoc inputs for our simulation model, we collect data on actual changes to unemployment, trade, oil prices, and production thus far (up to September). The simulation results indicate that global GDP could decrease by 7.22 percent, and grain prices could decrease by about 9 percent. These results are then used by the IFSA model to estimate the changes to food security from COVID-19. The economic shocks caused by the measures implemented to slow infections of COVID-19 are projected to increase the total
number of people that are food insecure in 2020 between 136 million and 271 million across 76 low- and middle-income countries.

Given the ongoing nature of COVID-19, economy-wide and food security results remain fluid. Although we provide actual changes to many factors which could affect both GDP and food security, ultimately, we do not know what these changes will be for the rest of the year. We do note that our model estimated decrease in GDP is closer to the 9.7-percent decrease estimated in ADB (2020), compared to the earlier analysis which might not have assumed that the effects from COVID-19 would last as long. Given our emphasis on food security, we focus more on providing the best possible inputs to agriculture, while the rest of the literature has largely been more focused on manufacturing and services. Additional work could try to integrate these two approaches. Given the fact that the COVID-19 pandemic is still underway, data on unemployment and trade will need continual updating. Thus, future research on the pandemic could focus on model validation--investigating how well the model performed at estimating potential changes of the COVID-19 pandemic and explaining its actual changes once those effects are fully known.
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1 This is what has been assumed by most COVID-19-CGE studies.

2 As we note, a CGE framework has been used to model pandemics, but as pointed out by a reviewer, there has not been an effort to evaluate how accurate those responses were. As such, work should be done after the effects of COVID-19 has exited the global economy to evaluate how accurate model estimates were, as a form of model evaluation.
The choice of regions follows those explicit in the IFSA (International Food Security Assessment) model.

There are many organizations (e.g., FAO, IMF) that forecast changes in GDP for 2020 (and beyond); but those forecasts tend to very vague in how they arrived at such a number. By using a CGE model that takes into accounts many facets that could impact the economy, we are able to discuss the contribution of each.

The 2100 kcal/per capita/ day threshold was an internationally agreed upon level set by United Nations as the recommended level of dietary energy intake for a healthy, well-nourished individual (FAO, 2004)
| Phase | Inputs                          | Database   | Output                                |
|-------|---------------------------------|------------|---------------------------------------|
| 1     | Update:                         | 2014       | 2020 data base (baseline)             |
|       | - population                    |            |                                       |
|       | - labor                         |            |                                       |
|       | - capital                       |            |                                       |
|       | - GDP                           |            |                                       |
|       | - productivity                  |            |                                       |
| 2     | COVID-19:                       | 2020       | 2020 with COVID-19                    |
|       | - unemployment                  |            |                                       |
|       | - trade                         |            |                                       |
|       | - oil prices                    |            |                                       |
|       | - output                        |            |                                       |
| 3     | CGE results:                    | 2020 with COVID-19 | Food security changes |
|       | - GDP                           |            |                                       |
|       | - prices                        |            |                                       |
Table 2. Changes in relative unemployment from 2019 to September 2020

| Country          | OECD | IMF  |
|------------------|------|------|
| Australia        | 1.7  | 4.3  |
| Canada           | 3.4  | -0.3 |
| Chile            | 3.4  | 2.7  |
| Colombia         | 6.0  | 1.6  |
| EU               | 1.1  | 2.7  |
| Iceland          | 1.3  | 1.5  |
| Israel           | 1.1  | 3.0  |
| Japan            | 0.7  | 1.6  |
| Mexico           | 1.0  | 14.3 |
| New Zealand      | 1.1  | 2.9  |
| Norway           | 1.5  | 2.0  |
| South Korea      | 0.2  | 3.3  |
| Switzerland      | 0.8  | 4.5  |
| Turkey           | 0.7  | 2.9  |
| USA              | 3.3  | 0.4  |
|                  | IMF  | Paraguay 0.9 |
| Albania          | 0.3  | 5.9  |
| Algeria          | 2.7  | 5.3  |
| Argentina        | 1.2  | 1.0  |
| Armenia          | 3.4  | 2.5  |
| Azerbaijan       | 1.7  | 0.0  |
| Bahrain          | 0.9  | 0.7  |
| Belarus          | 1.1  | 8.3  |
| Belize           | 3.6  | 3.6  |
| Bolivia          | 4.0  | 2.9  |
| Bosnia and Herzegovina | 3.3  | 2.2  |
| Brazil           | 1.5  | 0.9  |
| China            | 0.2  | 2.5  |
| Costa Rica       | 9.6  | 0.8  |
| Dominican Republic | 9.8  | 1.1  |

Source: Authors’ collected from OECD (2020) and IMF (2020)

Note: Values indicate the relative difference between 2019 and 2020 unemployment levels.
| Sectors            | Percent change quantity exported |
|--------------------|----------------------------------|
| Rice               | -4.86                            |
| Wheat              | 8.52                             |
| Coarse grains      | 12.74                            |
| Roots and tubers   | -0.93                            |
| Other agriculture* | -0.87                            |
| Non agriculture*   | -12.07                           |

Source: Trade Data Monitor (2020)
Note: An ‘*’ indicates that value was used.
Table 4. Changes in output for the United States

| Sector                                      | Change in production index |
|---------------------------------------------|----------------------------|
| Agriculture                                 | -0.3                       |
| Coal#                                       | -10.9                      |
| Oil#                                        | -10.9                      |
| Gas#                                        | -10.9                      |
| Other Extraction                            | -14.4                      |
| Beverages and tobacco products              | -0.1                       |
| Textiles                                    | -6                         |
| Wearing apparel                             | -10                        |
| Leather products                            | -10                        |
| Wood products                               | -3.1                       |
| Paper products, publishing                  | -9.1                       |
| Petroleum, coal products                    | -14.8                      |
| Chemical products                           | -2.3                       |
| Basic pharmaceutical products               | -4                         |
| Rubber and plastic products                 | -4                         |
| Mineral products nec                        | -3.8                       |
| Ferrous metals                              | -10                        |
| Metals nec                                  | -10                        |
| Metal products                              | -7.5                       |
| Motor vehicles and parts                    | 6.9                        |
| Transport equipment nec                     | -12.5                      |
| Electrical equipment                        | -4.6                       |
| Computer, electronic and optical products   | 1.3                        |
| Machinery and equipment nec                 | -5                         |
| Manufactures nec                            | -3.9                       |
| Electricity                                 | -2.8                       |
| Gas manufacture, distribution              | -4.3                       |

Source: The United States Federal Reserve
Note: # provided for mining and quarrying.
Table 5. CGE results for GDP and grain prices

| Regions                  | GDP  | Rice | Wheat | Coarse grains |
|--------------------------|------|------|-------|---------------|
| Oceania*                 | -7.03| 4.69 | 9.99  | 12.81         |
| China*                   | -9.79| -0.91| -0.19 | -1.35         |
| Developed Asia*          | -4.04| 4.60 | -6.69 | -10.54        |
| Other Asia               | -7.62| -4.09| -4.01 | -3.44         |
| Other South East Asia*   | -3.53| 2.65 | 6.36  | -4.93         |
| South East Asia          | -6.81| -0.07| -6.61 | -6.69         |
| Central and South Asia   | -6.19| 9.88 | 7.90  | 8.51          |
| North America*           | -6.31| -1.73| 0.62  | -6.71         |
| United States*           | -7.92| 5.94 | 4.84  | 6.08          |
| Other South America*     | -6.02| 0.42 | -5.26 | 4.51          |
| Latin America and the Carribean | -8.24| -4.44| -7.36 | -8.47         |
| Europe*                  | -6.97| 1.66 | -0.66 | 1.35          |
| Former Soviet Union*     | -5.06| -2.15| 3.67  | 3.25          |
| Commonwealth of Independent States | -5.92| -4.20| -7.86 | -6.59         |
| Middle East*             | -4.51| -9.40| -9.66 | -11.32        |
| North Africa             | -4.73| 1.57 | 2.18  | 15.11         |
| West Africa              | -4.90| -0.52| 2.94  | 0.18          |
| Central Africa           | -6.17| -2.17| -5.76 | -9.16         |
| East Africa              | -6.57| -11.56| -5.06 | -15.12        |
| Southern Africa          | -6.66| -4.37| -5.39 | -5.69         |
| Other Africa             | -7.21| -16.22| -13.17| -24.58        |

Global         -7.22  -0.45   -11.48  -23.20

Note: An ‘*’ refers to a region that is not in the IFSA model.
Table 6. GDP by model input

| Region                | Unemployment | Trade | Oil | Production | Total |
|-----------------------|--------------|-------|-----|------------|-------|
| Oceania*              | -1.0         | -0.1  | 0.2 | -6.2       | -7.0  |
| China*                | -0.2         | -0.4  | 0.3 | -9.6       | -9.8  |
| Developed Asia*       | -0.1         | 0.0   | 0.5 | -4.4       | -4.0  |
| Other Asia            | -0.6         | -1.6  | -0.1| -6.0       | -7.6  |
| OSEAsia*              | -0.9         | 0.0   | 0.7 | -3.3       | -3.5  |
| South East Asia       | -1.2         | -0.2  | 0.3 | -5.7       | -6.8  |
| Central and South Asia| -1.0         | 0.3   | 0.8 | -6.2       | -6.2  |
| North America*        | -0.5         | -0.1  | 0.1 | -5.8       | -6.3  |
| USA*                  | -2.4         | 0.2   | 0.3 | -6.1       | -7.9  |
| Other South America*  | -0.6         | 0.0   | 0.3 | -5.9       | -6.0  |
| LAC                   | -2.4         | -0.1  | 0.1 | -6.2       | -8.2  |
| Europe*               | -0.6         | -0.2  | 0.3 | -6.6       | -7.0  |
| FSR*                  | -0.5         | -0.3  | 0.9 | -5.2       | -5.1  |
| CIS                   | -1.1         | -0.2  | 0.4 | -4.5       | -5.9  |
| Middle East*          | 0.1          | -0.3  | 0.3 | -4.8       | -4.5  |
| North Africa          | -2.1         | 0.1   | 0.5 | -5.7       | -4.7  |
| West Africa           | -1.2         | -0.6  | -0.3| -3.0       | -4.9  |
| Central Africa        | -1.4         | -1.0  | -0.8| -5.6       | -6.2  |
| East Africa           | -1.4         | -0.5  | -0.1| -4.5       | -6.6  |
| Southern Africa       | -2.1         | -0.2  | 0.0 | -4.0       | -6.7  |
| Other Africa          | -1.6         | 0.1   | 0.4 | -7.2       | -7.2  |
| **Global**            | -1.2         | -0.1  | 0.3 | -6.4       | -7.2  |

Note: An ‘*’ refers to a region that is not in the IFSA model.
Table 7. COVID-19 food security indicators for International Food Security Assessment (IFSA) regions.

| Region                          | Population food insecure | Share of population food insecure | Food gap (per capita) | Population food insecure | Share of population food insecure | Food gap (per capita) | Change from pre-COVID-19 estimate |
|---------------------------------|--------------------------|-----------------------------------|-----------------------|--------------------------|-----------------------------------|-----------------------|-----------------------------------|
| Central and South Asia          | 1,792.3                  | 242.5                             | 13.5                  | 294.3                    | 351.8                             | 19.6                  | 325.0                             |
| Commonwealth of Independent States | 67.5                     | 5.3                               | 7.9                   | 207.4                    | 7.2                               | 10.7                  | 221.8                             |
| Middle East                     | 29.88                    | 17.43                             | 58.32                 | 450.62                   | 18.15                             | 60.75                 | 462.50                            |
| South East Asia                 | 499.3                    | 50.2                              | 10.1                  | 256.1                    | 67.9                              | 13.6                  | 275.9                             |
| Other Asia                      | 33.7                     | 16.4                              | 48.5                  | 319.3                    | 18.6                              | 55.0                  | 346.1                             |
| Latin America and the Caribbean | 173.0                    | 31.3                              | 18.1                  | 314.4                    | 40.2                              | 23.2                  | 337.5                             |
| North Africa                    | 193.8                    | 8.2                               | 4.2                   | 245.2                    | 10.8                              | 5.6                   | 256.0                             |
| Central Africa                  | 127.5                    | 86.4                              | 67.8                  | 520.2                    | 92.1                              | 72.3                  | 563.3                             |
| East Africa                     | 372.2                    | 132.4                             | 35.6                  | 466.5                    | 162.4                             | 43.6                  | 505.7                             |
| Southern Africa                 | 147.0                    | 72.4                              | 49.2                  | 426.6                    | 82.1                              | 55.8                  | 455.2                             |
| West Africa                     | 401.6                    | 98.4                              | 24.5                  | 336.9                    | 120.8                             | 30.1                  | 362.4                             |
| Total IFSA countries            | 3,837.8                  | 760.8                             | 19.8                  | 346.3                    | 972.0                             | 25.3                  | 372.7                             |
Table 8. CGE model results from sensitivity analysis

| Region                        | Lower end | Upper end |
|-------------------------------|-----------|-----------|
|                              | GDP       | Prices    |          | GDP       | Prices    |
|                              | Rice      | Wheat     | Coarse grains | Rice      | Wheat     | Coarse grains |
| Oceania*                      | -3.47     | 0.95      | 6.82      | 8.10      | -10.59    | 8.56      | 13.28      | 17.68      |
| China*                        | -4.22     | -1.83     | -2.34     | -3.35     | -15.36    | -0.05     | 1.98       | 0.63       |
| Developed Asia*               | -1.50     | 1.92      | -7.58     | -11.32    | -6.57     | 7.32      | -5.75      | -9.72      |
| Other Asia                    | -4.47     | -7.52     | -7.85     | -7.72     | -10.76    | -0.52     | -0.03      | 1.02       |
| Other South East Asia*        | -1.59     | 0.07      | 4.20      | -5.72     | -5.48     | 5.31      | 8.60       | -4.10      |
| South East Asia               | -3.47     | -1.36     | -7.21     | -7.89     | -10.15    | 1.25      | -5.97      | -5.47      |
| Central and South Asia        | -2.56     | 9.33      | 7.15      | 7.82      | -9.82     | 10.41     | 8.67       | 9.20       |
| North America*                | -2.95     | -2.89     | -1.22     | -6.95     | -9.67     | -0.54     | 2.52       | -6.44      |
| United States*                | -4.33     | 4.26      | 4.15      | 5.36      | -11.51    | 7.67      | 5.57       | 6.86       |
| Other South America*          | -2.65     | -2.65     | -6.61     | 1.92      | -9.38     | 3.60      | -3.86      | 7.18       |
| Latin America and the Carribean | -4.59   | -6.03     | -7.98     | -9.84     | -11.89    | -2.78     | -6.69      | -7.05      |
| Europe*                      | -3.18     | -0.64     | -2.25     | -1.08     | -10.76    | 4.03      | 0.99       | 3.86       |
| Former Soviet Union*          | -2.11     | -3.83     | 1.75      | 1.94      | -8.01     | -0.42     | 5.64       | 5.23       |
| Commonwealth of Independent States | -3.25  | -5.48     | -9.01     | -8.66     | -8.59     | -2.89     | -6.68      | -4.48      |
| Middle East*                  | -1.66     | -11.07    | -10.28    | -12.79    | -7.37     | -7.72     | -9.01      | -9.82      |
| North Africa                  | -1.94     | -0.19     | -0.08     | 8.95      | -7.51     | 3.34      | 4.51       | 21.34      |
| West Africa                   | -2.48     | -1.47     | 1.64      | -2.65     | -7.32     | 0.48      | 4.29       | 3.09       |
| Central Africa                | -3.28     | -3.88     | -6.98     | -15.31    | -9.06     | -0.43     | -4.52      | -2.77      |
| East Africa                   | -3.57     | -13.42    | 7.28      | -16.94    | -9.58     | -9.64     | -2.75      | -13.21     |
| Southern Africa               | -0.21     | -0.25     | -5.61     | -3.21     | -3.97     | 1.60      | -2.03      | -0.19      |
| Other Africa                  | -4.51     | -18.12    | -13.43    | -27.18    | -9.91     | -14.31    | -12.89     | -21.94     |
| Global                        | -3.36     | -0.08     | -11.12    | -22.16    | -10.76    | -0.81     | -11.82     | -24.24     |
Table 9. COVID-19 upper and lower bound estimates for food security indicators in International Food Security Assessment (IFSA) regions.

| Region                        | Pre-COVID-19 | COVID-19 | COVID-19 (Lower bound estimates) | COVID-19 (Upper bound estimates) |
|-------------------------------|--------------|----------|----------------------------------|----------------------------------|
|                               | Population   | Share of population food insecure | Food gap (per capita) | Population food insecure | Share of population food insecure | Food gap (per capita) | Population food insecure | Share of population food insecure | Food gap (per capita) |
|                               | Million      | Million  | Percent                          | Kilocalories                    | Million | Percent | Kilocalories        | Million | Percent | Kilocalories        | Million | Percent | Kilocalories        |
| Central and South Asia        | 1,792.3      | 242.5    | 13.5                             | 294.3                           | 351.8   | 19.6    | 325.0                | 318.1   | 17.7    | 314.9                | 386.7   | 21.6    | 334.9                |
| Change from pre-COVID-19 estimate | 109.3      | 6.1      | 30.7                             | 76.6                            | 4.2     | 20.6    | 144.2               | 8.0     | 40.6    |                          |                     |         |                     |
| Commonwealth of Independent States | 67.5         | 5.3      | 7.9                              | 207.4                           | 7.2     | 10.7    | 221.8               | 6.7     | 9.9     | 217.9               | 8.0     | 11.9    | 227.6               |
| Change from pre-COVID-19 estimate | 0.7         | 2.4      | 11.9                            | 3.0                            | -0.1    | -0.4    | 1.81                | 0.1     | 3.0    |                          |                     |         |                     |
| Middle East                  | 29.9         | 17.4     | 58.3                             | 450.6                           | 18.2    | 60.7    | 462.5               | 17.4    | 58.2    | 450.2               | 19.2    | 64.4    | 481.3               |
| Change from pre-COVID-19 estimate | 1.9         | 2.8      | 14.4                            | 1.4                            | 2.0     | 10.5    | 2.7                 | 4.0     | 2.0    |                          |                     |         |                     |
| South East Asia              | 499.3        | 50.2     | 10.1                             | 256.1                           | 67.9    | 13.6    | 275.9               | 60.0    | 12.0    | 268.3               | 71.8    | 14.4    | 279.9               |
| Change from pre-COVID-19 estimate | 17.7        | 3.5      | 9.8                             | 2.0                            | 12.2    | 21.6    | 4.3                 | 23.8    | 3.0    |                          |                     |         |                     |
| Other Asia                   | 33.7         | 16.4     | 48.5                             | 319.3                           | 18.6    | 55.0    | 346.1               | 17.5    | 52.0    | 334.4               | 16.5    | 48.9    | 349.800             |
| Change from pre-COVID-19 estimate | 2.2         | 6.5      | 26.8                            | 1.2                            | 3.4     | -11.7   | 1.81                | 0.1     | 3.0    |                          |                     |         |                     |
| Latin America and the Caribbean | 173.0       | 31.3     | 18.1                             | 314.4                           | 40.2    | 23.2    | 337.5               | 36.3    | 21.0    | 327.4               | 44.4    | 25.7    | 348.4               |
| Change from pre-COVID-19 estimate | 8.9         | 5.2      | 23.0                            | 5.1                            | 2.0     | 13.0    | 7.6                 | 34.0    | 3.0    |                          |                     |         |                     |
| North Africa                 | 193.8        | 8.2      | 4.2                              | 245.2                           | 10.8    | 5.6     | 256.0               | 9.7     | 5.0     | 251.5               | 12.0    | 6.2     | 260.9               |
| Change from pre-COVID-19 estimate | 2.6         | 1.3      | 10.9                            | 1.5                            | 0.8     | 6.3     | 3.8                 | 3.0     | 1.5    |                          |                     |         |                     |
| Central Africa               | 127.5        | 86.4     | 67.8                             | 520.2                           | 92.1    | 72.3    | 563.3               | 90.1    | 70.7    | 547.6               | 93.6    | 73.4    | 576.0               |
| Change from pre-COVID-19 estimate | 7.8         | 4.5      | 43.0                            | 3.7                            | 2.9     | 27.4    | 7.2                 | 5.7     | 5.7    |                          |                     |         |                     |
| East Africa                  | 372.2        | 132.4    | 35.6                             | 466.5                           | 162.4   | 43.6    | 505.7               | 152.1   | 40.9    | 490.9               | 172.6   | 46.4    | 519.3               |
| Change from pre-COVID-19 estimate | 30.0        | 8.1      | 39.2                            | 19.6                            | 5.3     | 24.4    | 40.1               | 10.8    | 5.7    |                          |                     |         |                     |
| Southern Africa              | 147.0        | 72.4     | 49.2                             | 426.6                           | 82.1    | 55.8    | 455.2               | 75.5    | 51.4    | 434.1               | 79.8    | 54.3    | 452.0               |
| Change from pre-COVID-19 estimate | 9.7         | 6.6      | 28.6                            | 3.1                            | 2.1     | 7.5     | 7.5                 | 5.1     | 2.5    |                          |                     |         |                     |
| West Africa                  | 401.6        | 98.4     | 24.5                             | 336.9                           | 120.8   | 30.1    | 362.4               | 113.0   | 28.1    | 354.6               | 127.5   | 31.8    | 368.9               |
| Change from pre-COVID-19 estimate | 22.5        | 5.6      | 25.5                            | 14.6                            | 3.6     | 17.7    | 29.1               | 7.3     | 3.2    |                          |                     |         |                     |
| Total IFSA countries          | 3,837.8      | 760.8    | 19.8                             | 346.3                           | 972.0   | 25.3    | 372.7               | 896.4   | 23.4    | 361.8               | 1,032.2 | 26.9    | 380.0               |
| Change from pre-COVID-19 estimate | 211.2       | 5.5      | 26.3                            | 135.6                           | 3.5     | 15.5    | 271.4              | 7.1     | 3.1    |                          |                     |         |                     |
Appendix 1. CGE model and data work

We utilize the 2014 GTAP database for this work. The disaggregated GTAP base data contain over 141 regions and 62 sectors; researchers often aggregate these to make the results easier to comprehend and interpret. Sectors are aggregated based on those which are used in the IFSA model (Appendix table 1). Thus, grains (No 1-3) are disaggregated in our model, plus we ‘split’ roots and tubers from fruits and vegetables, given their prominence in the IFSA model. To split the commodity, we use the SplitCom utility developed by Horridge (2008). SplitCom is a matrix balancing program that allows the user to subdivide the rows and columns of a commodity from a balanced social accounting matrix (SAM). The user provides data to disaggregate a GTAP sector’s input demands, uses in intermediate and final demand and trade, and tax and tariff payments. SplitCom then uses methods similar to maximum entropy to balance the disaggregated SAM and to satisfy accounting identities. The utility manipulates only the disaggregated sectors, which can be re-aggregated to restore the original values in the GTAP SAM.

Appendix Table 1: Sector Aggregation Scheme

| No. | Name | Description | GTAP sector code | Aggregation of sectors for results |
|-----|------|-------------|------------------|-----------------------------------|
| 1   | rice | Paddy and milled rice | pdr, pcr | rice |
| 2   | wheat | Wheat | wht | wheat |
| 3   | coarse grains | Cereal grains | gro | coarse grains |
| 4   | roots | Roots and tubers | v_f | roots |
| 5   | other food | Other foods | v_f, c_b, osd, ool, oap, rnk, cmr, omt, vpl, sp | other food |
| 6   | other agriculture | Other agricultural activities | pfb, occ, wol, qfd, b_f | other agriculture |
| 7   | extraction | Extraction activities | frs, fsh, coa, gas, ext | non agriculture |
| 8   | oil | Petroleum | oil | non agriculture |
| 9   | textiles | Textiles | tex, wpp | non agriculture |
| 10  | light manufacturing | Light manufacturing | lea, lom, spp, fmp, mvh, onf, omf | non agriculture |
| 11  | heavy manufacturing | Heavy Manufacturing | p_c, ccm, bps, rpp, mmr, l_s, rfs, eie, eeq, ome | non agriculture |
| 12  | utilities | Utilities | eie, gdt, wtr, cns | non agriculture |
| 13  | services | Services | trd, st, hhs, cmm, olt, ins, rsa, obs, ros, oes, edu, iht, dwe | non agriculture |

The categories ‘other food’ and ‘other agriculture’ capture the rest of the agricultural GTAP sectors. Nonagricultural sectors are designed to capture the major elements of manufacturing and services, and we keep oil disaggregated to be able to provide the price shock in the CGE model. Note that we present the results for all nonagricultural sectors as one sector but results for the individual sectors (6-13) are available upon request. Further mapping was needed to bring the table 3 changes into the model. To do so, we apply a production-weighted average based on the sector aggregation scheme in Appendix table 1.

The regional aggregation is also based heavily on the IFSA regions, Appendix table 2 notes those which are not in that model with an asterisk (*). The IFSA model has 76 disaggregated countries, the majority of which (49) are also disaggregated in GTAP. Most of the other IFSA regions are in a GTAP regional grouping (e.g., the ‘XAC’ region (South Central Africa) features Angola and the Democratic Republic of Congo. For ease of presentation, the results shown in this paper are by IFSA region, but the modeling was done with the full set of regions. Those noted without an asterisk are disaggregated in both models and those results are available upon request.
Appendix Table 2. Region Aggregation Scheme

| No. | Country/region               | Included GTAP country/regions       |
|-----|------------------------------|------------------------------------|
| 1   | Oceania*                     | aus, nzl, xoc, xtw                 |
| 2   | China*                       | chn, hkg                           |
| 3   | Developed Asia*              | jpn, kor, twn, sgp                 |
| 4   | Other Asia                   | mng, xea                           |
| 5   | Other South East Asia*       | brn, mys, tha, xse                 |
| 6   | South East Asia              | khm, idn, lao, phi, vnm            |
| 7   | Central and South Asia       | bgdm ind, npl, pak, lka, xsa       |
| 8   | North America*               | can, mex, xna                      |
| 9   | United States*               | usa                                |
| 10  | Other South America*         | arg, bra, chl, pry, ury, ven, xsm, cri, pan, xsa |
| 11  | Latin America and the Caribbean | bol, col, ecu, per, gtm, hnd, nic, slv, dom, jam, pri, tto, xcb |
| 12  | Europe*                      | aut, bel, bgr, hrv, cyp, cze, dnk, est, fin, fra, deu, grc, hun, irl, ita, lva, ltu, lux, mlt, nd, pol, pr, rou, svk, svn, esp, swe, gbr, che, nor, xef, alb, xer |
| 13  | FSR*                         | blr, rus, ukr, kaz                 |
| 14  | CIS                          | xee, kgz, tjk, xsu, arm, aze, geo   |
| 15  | Middle East*                 | bhr, irn, isr, jor, kwt, omn, qat, sau, tur, are, xws |
| 16  | North Africa                 | egy, mar, tun, xnf                 |
| 17  | West Africa                  | ben, bfa, civ, gh, gin, nga, sen, tgo, xwf |
| 18  | Central Africa               | cmr, xcf, xac                      |
| 19  | East Africa                  | eth, ken, rwa, tza, uga, xec       |
| 20  | Southern Africa              | mdg, mwi, moz, zmb, zve, nam, xsc  |
| 21  | Other Africa*                | zaf, bwa, mus                      |

Note: A ‘*’ indicates a region that is not in the IFSA model.

Appendix table 3 notes the shocks to update the model. As we mention, both models are conducted for the full set of regions, but we aggregate the results for brevity.
| Country                        | Population | GDP  | Labor | Capital | Productivity |
|-------------------------------|------------|------|-------|---------|--------------|
| Oceania                       | 6.94       | 16.06| 4.82  | 18.93   | 9.65         |
| China                         | 2.40       | 46.58| -0.21 | 57.73   | 33.79        |
| Developed Asia                | 0.38       | 8.37 | -0.10 | 15.15   | 11.71        |
| Mongolia                      | 7.27       | 28.92| 6.75  | 57.63   | 23.59        |
| North Korea                   | 6.83       | 17.68| 6.40  | 21.69   | 10.40        |
| Other South East Asia         | 3.93       | 26.95| 3.94  | 29.10   | 4.22         |
| Cambodia                      | 9.50       | 50.13| 11.01 | 46.25   | 18.80        |
| Indonesia                     | 5.29       | 34.44| 10.39 | 26.41   | 6.55         |
| Philippines                   | 9.46       | 48.24| 15.43 | 34.22   | 14.52        |
| Vietnam                       | 9.86       | 44.37| 14.27 | 35.40   | 13.26        |
| Bangladesh                    | 6.28       | 51.06| 10.77 | 26.76   | 15.11        |
| India                         | 7.26       | 52.49| 10.46 | 35.59   | 20.56        |
| Nepal                         | 7.12       | 30.79| 14.64 | 29.99   | 17.96        |
| Pakistan                      | 8.94       | 31.89| 14.54 | 33.56   | 8.55         |
| Sri Lanka                     | 4.68       | 25.74| 2.76  | 33.20   | 15.40        |
| Rest of South Asia            | 14.77      | 19.71| 26.15 | 26.46   | 16.35        |
| North America                 | 5.87       | 11.92| 8.01  | 20.51   | 10.20        |
| USA                           | 4.29       | 14.75| 2.96  | 15.51   | 5.64         |
| Other South America           | 5.00       | -5.41| 6.79  | 23.93   | 8.56         |
| Bolivia                       | 9.49       | 28.22| 14.52 | 25.89   | 9.48         |
| Colombia                      | 6.14       | 15.27| 8.66  | 20.37   | 1.47         |
| Ecuador                       | 7.99       | 2.68 | 12.50 | 21.57   | -1.02        |
| Peru                          | 5.86       | 23.32| 11.05 | 36.49   | 11.22        |
| Guatemala                     | 17.11      | 20.93| 20.69 | 19.82   | 3.94         |
| Honduras                      | 10.08      | 25.22| 18.68 | 25.94   | 10.14        |
| Nicaragua                     | 6.07       | 4.85 | 13.30 | 20.74   | 10.94        |
| El Salvador                   | 1.49       | 15.15| 9.26  | 19.72   | 11.03        |
| Europe                        | 1.27       | 12.32| -1.47 | 12.46   | 10.22        |
| Former Soviet Union           | -0.96      | 4.28 | -5.34 | 23.09   | 35.84        |
| Moldova                       | -6.11      | 21.06| -3.37 | 39.73   | 30.58        |
| Kyrgyzstan                    | 6.44       | 25.42| 7.62  | 25.13   | 30.64        |
| Tajikistan                    | 10.21      | 43.80| 11.35 | 41.11   | 20.96        |
| Rest of Soviet Union          | 5.84       | 44.04| 9.96  | 33.95   | 2.83         |
| Armenia                       | -1.28      | 26.80| -1.91 | 26.02   | 50.55        |
| Azerbaijan                    | 5.36       | 5.39 | 5.84  | 53.28   | 32.30        |
| Georgia                       | -0.12      | 25.26| -2.95 | 26.46   | 41.90        |
| Middle East                   | 12.80      | 15.15| 10.21 | 29.19   | 8.86         |
| Egypt                         | 15.75      | 32.84| 12.06 | 37.52   | 19.74        |
| Morocco                       | 5.97       | 20.87| 8.64  | 22.98   | 12.43        |
| Tunisia                       | 6.24       | 12.67| 4.80  | 30.96   | 16.64        |
| Rest of North Africa          | 10.78      | 17.99| 7.32  | 19.37   | 9.33         |
| Benin                         | 17.67      | 35.52| 20.09 | 26.29   | 11.16        |
| Burkina Faso                  | 13.45      | 38.31| 21.57 | 40.34   | 15.57        |
| Cameroon                      | 16.60      | 29.60| 18.92 | 27.77   | 9.25         |
| Cote d’Ivoire                 | 20.27      | 54.23| 16.17 | 29.47   | 4.45         |
| Ghana                         | 13.91      | 36.56| 15.99 | 28.22   | 12.34        |
| Guinea                        | 9.18       | 35.28| 18.51 | 31.97   | 8.09         |
| Nigeria                       | 20.81      | 9.38 | 17.26 | 54.03   | 20.81        |
| Senegal                       | 15.40      | 47.38| 20.15 | 41.13   | 6.41         |
| Togo                          | 17.10      | 34.62| 17.80 | 27.43   | 15.32        |
| Rest of West Africa           | 18.51      | 27.22| 20.62 | 26.10   | 12.59        |
| Rest of Central Africa        | 19.32      | 19.32| 16.13 | 28.41   | 0.37         |
| South Central Africa          | 17.01      | 5.35 | 21.04 | 49.66   | 14.38        |
| Ethiopia                      | 18.63      | 64.45| 22.38 | 35.03   | 8.91         |
| Kenya                         | 19.77      | 39.60| 19.61 | 30.06   | 10.05        |
| Madagascar                    | 16.18      | 27.82| 21.48 | 3.36    | 4.17         |
| Malawi                        | 21.98      | 24.07| 21.62 | 30.75   | 9.29         |
| Other Africa                  | 6.57       | 6.57 | 5.93  | 25.86   | 14.12        |
| Mozambique                    | 15.84      | 26.29| 18.12 | 54.62   | 34.27        |
| Rwanda                        | 14.02      | 52.00| 21.12 | 39.97   | 26.42        |
| Tanzania                      | 17.96      | 43.27| 20.94 | 41.11   | 28.12        |
| Uganda                        | 21.16      | 36.47| 25.14 | 25.88   | 12.76        |
| Zambia                        | 19.05      | 21.29| 24.77 | 37.23   | 17.38        |
| Zimbabwe                      | 6.83       | 17.68| 24.56 | 10.30   | -6.45        |
| Rest of Eastern Africa        | 24.26      | 24.26| 18.67 | 19.51   | 4.23         |
| Namibia                       | 12.37      | 8.33 | 18.19 | 30.41   | 9.88         |
| Rest of South African Customs Union | -8.56     | 8.33 | 10.03 | 26.27   | 5.81         |

Note: ¹ indicates data from ERS (2018) and ² indicates data from Four et al. (2016)
Appendix Table 4. COVID-Stringency Index average values

| Country                        | Avg. Index | Country          | Avg. Index | Country                  | Avg. Index | Country                   | Avg. Index |
|--------------------------------|-----------|------------------|-----------|--------------------------|-----------|---------------------------|-----------|
| Afghanistan                    | 42.9      | Denmark          | 44.8      | Laos                     | 35.2      | San Marino                | 39.9      |
| Albania                        | 54.6      | Djibouti         | 46.4      | Latvia                   | 41.3      | Saudi Arabia              | 56.4      |
| Algeria                        | 59.1      | Dominica         | 37.0      | Lebanon                  | 55.0      | Senegal                   | 40.3      |
| Andorra                        | 36.3      | Dominican Republic| 63.0     | Lesotho                  | 49.9      | Serbia                    | 48.1      |
| Angola                         | 57.7      | Ecuador          | 58.7      | Liberia                  | 55.0      | Seychelles                | 34.2      |
| Argentina                      | 70.6      | Egypt            | 53.5      | Libya                    | 69.3      | Sierra Leone              | 35.4      |
| Aruba                          | 44.3      | El Salvador      | 65.1      | Lithuania                | 42.7      | Singapore                 | 50.9      |
| Australia                      | 53.8      | Eritrea          | 66.6      | Luxembourg               | 38.6      | Slovak Republic           | 43.5      |
| Austria                        | 43.9      | Estonia          | 31.2      | Macao                    | 30.2      | Slovenia                  | 44.2      |
| Azerbaijan                     | 64.3      | Eswatini         | 57.0      | Madagascar               | 48.0      | Solomon Islands           | 30.7      |
| Bahrain                        | 56.1      | Ethiopia         | 57.0      | Malawi                   | 44.6      | Somalia                   | 31.9      |
| Bangladesh                     | 64.3      | Fiji             | 52.1      | Malaysia                 | 52.8      | South Africa              | 54.1      |
| Barbados                       | 45.5      | Finland          | 36.2      | Mali                     | 38.8      | South Korea               | 46.0      |
| Belarus                        | 13.1      | France           | 53.0      | Mauritania               | 36.6      | South Sudan               | 52.7      |
| Belgium                        | 50.4      | Gabon            | 56.6      | Mauritius                | 29.9      | Spain                     | 54.6      |
| Belize                         | 55.5      | Gambia           | 52.9      | Mexico                   | 55.7      | Sri Lanka                 | 45.4      |
| Benin                          | 37.8      | Georgia          | 57.5      | Moldova                  | 52.3      | Sudan                     | 53.4      |
| Bermuda                        | 44.3      | Germany          | 49.7      | Monaco                   | 33.1      | Suriname                  | 58.6      |
| Bhutan                         | 63.2      | Ghana            | 42.0      | Mongolia                 | 56.3      | Sweden                    | 43.6      |
| Bolivia                        | 68.8      | Greece           | 50.5      | Morocco                  | 58.5      | Switzerland              | 40.5      |
| Bosnia and Herzegovina         | 48.5      | Greenland        | 34.6      | Mozambique               | 48.3      | Syria                     | 57.7      |
| Botswana                       | 50.9      | Guam             | 53.8      | Myanmar                  | 61.2      | Taiwan                    | 24.5      |
| Brazil                         | 56.9      | Guatemala        | 65.4      | Namibia                  | 42.6      | Tajikistan                | 36.4      |
| Brunei                         | 38.6      | Guinea           | 50.3      | Nepal                    | 66.4      | Tanzania                  | 22.4      |
| Bulgaria                       | 39.1      | Guyana           | 60.9      | Netherlands              | 47.1      | Thailand                  | 45.2      |
| Burkina Faso                   | 38.1      | Haiti            | 46.0      | New Zealand              | 36.7      | Timor-Leste               | 31.7      |
| Burundi                        | 11.6      | Honduras         | 72.7      | Nicaragua                | 9.7       | Togo                      | 44.1      |
| Cambodia                       | 35.4      | Hong Kong        | 53.6      | Niger                    | 23.5      | Trinidad and Tobago       | 58.5      |
| Cameroon                       | 44.1      | Hungary          | 46.3      | Nigeria                  | 54.3      | Tunisia                   | 42.5      |
| Canada                         | 52.4      | Iceland          | 38.0      | Norway                   | 37.8      | Turkey                    | 52.3      |
| Cape Verde                     | 57.1      | India            | 63.0      | Oman                     | 64.6      | Turkmenistan              | 35.9      |
| Central African Republic       | 42.8      | Indonesia        | 52.8      | Pakistan                 | 53.6      | Uganda                    | 62.0      |
| Chad                           | 52.2      | Iran             | 45.8      | Palestine                | 65.6      | Ukraine                   | 52.4      |
| Chile                          | 61.1      | Iraq             | 66.3      | Panama                   | 63.5      | United Arab Emirates      | 46.7      |
| China                          | 67.2      | Ireland          | 54.2      | Papua New Guinea         | 41.6      | United Kingdom            | 55.4      |
| Colombia                       | 63.5      | Israel           | 56.2      | Paraguay                 | 63.8      | United States             | 54.7      |
| Congo                          | 52.4      | Italy            | 56.1      | Peru                     | 67.0      | Uruguay                   | 36.5      |
| Costa Rica                     | 54.2      | Jamaica          | 60.1      | Philippines              | 66.4      | Uzbekistan                | 52.2      |
| Cote d'Ivoire                  | 40.1      | Japan            | 32.1      | Poland                   | 44.6      | Vanuatu                   | 39.8      |
| Croatia                        | 42.0      | Jordan           | 54.6      | Portugal                 | 55.0      | Venezuela                 | 66.3      |
| Cuba                           | 60.8      | Kazakhstan       | 63.5      | Puerto Rico              | 60.7      | Vietnam                   | 55.1      |
| Cyprus                         | 51.5      | Kenya            | 61.0      | Qatar                    | 60.5      | Yemen                     | 31.4      |
| Czech Republic                 | 43.2      | Kosovo           | 55.5      | Romania                  | 47.4      | Zambia                    | 38.1      |
| Democratic Republic of Congo   | 45.9      | Kuwait           | 62.1      | Russia                   | 51.2      | Zimbabwe                  | 60.4      |

Source: Oxford University

Note: The Table provides the average (mean) COVID Stringency Index values over the period January 1 through November 30, 2020.
Appendix Table 5. Actual changes in GDP (percent change)

| Country   | Change in GDP (%) | Time period               |
|-----------|-------------------|---------------------------|
| Argentina | -19.7             | 2020-2nd quarter 2021     |
| Australia | -4.2              | 2020-3rd quarter 2021     |
| Brazil    | -4.1              | 2020-3rd quarter 2021     |
| Canada    | -5.3              | 2020-3rd quarter 2021     |
| Chile     | -6.2              | 2020-3rd quarter 2021     |
| China     | 3.2               | 2020-3rd quarter 2021     |
| Colombia  | -10.1             | 2020-3rd quarter 2021     |
| EU        | -4.4              | 2020-3rd quarter 2021     |
| Iceland   | -12.1             | 2020-3rd quarter 2021     |
| India     | -24.8             | 2020-3rd quarter 2021     |
| Indonesia | -4.7              | 2020-3rd quarter 2021     |
| Israel    | -2.6              | 2020-3rd quarter 2021     |
| Japan     | -4.2              | 2020-3rd quarter 2021     |
| New Zealand | -13.4          | 2020-2nd quarter 2021     |
| Norway    | -1.8              | 2020-3rd quarter 2021     |
| Saudi Arabia | -5.8            | 2020-2nd quarter 2021     |
| South Africa | -16.7          | 2020-2nd quarter 2021     |
| South Korea | -2.4            | 2020-3rd quarter 2021     |
| Switzerland | -2.1            | 2020-3rd quarter 2021     |
| Turkey    | 3.3               | 2020-3rd quarter 2021     |
| USA       | -3.5              | 2020-3rd quarter 2021     |

Source: OECD (2020)
Appendix 2. IFSA Model

We specify demand $q_i^h$ for a given food group $i$, for income decile $h$ as:

$$q_i^h = (x_i^h / p_i) (A_i(p_i) + B_i(p_i) \ln(x^h))$$

where $p_i$ is the price (expressed in real local currency), and $x^h$ is the decile-level income. We further specify $A_i(p_i) = a_{i0} + a_{i1} p_i$, and $B_i(p_i) = b_{i0} + b_{i1} p_i$.

The PIGLOG demand formulation allows for aggregation of income decile-level demands in (1) into average per capita market demand for each food group $i$ (2).

$$\tilde{q}_i = \left( \frac{x_i}{p_i} \right) ((a_{i0} + a_{i1} p_i) + (b_{i0} + b_{i1} p_i) (\ln(\bar{x}) + \ln(\frac{10}{z}))$$

The latter is a function of average per capita income $\bar{x}$ and Theil’s entropy measure of income inequality $z$.

We also define average expenditure share for good category $i$ as:

$$\tilde{w}_i = (a_{i0} + a_{i1} p_i) + (b_{i0} + b_{i1} p_i) (\ln(\bar{x}) + \ln(\frac{10}{z}))$$

The elasticity of average demand for good $i$ with respect to average income (or total expenditure) is:

$$\varepsilon_{\tilde{q} \bar{x}} = 1 + (b_{i0} + b_{i1}) / \tilde{w}_i.$$

The own-price elasticity of the average demand is:

$$\varepsilon_{\tilde{q} p_i} = -1 + (\frac{p_i}{\tilde{w}_i}) (a_{i1} + b_{i1} (\ln(\bar{x}) + \ln(\frac{10}{z})))$$.

In each country, consumers at different income levels have similar underlying preferences over good $i$ as embodied in parameters $a_{i0}, a_{i1}, b_{i0}, b_{i1}$, but their respective consumptions vary because their respective incomes vary.

For each country, we calibrate a demand system for each of the four food groups based on income, consumption levels, and prices from the 3 years preceding the 2020 projection. We determine the major grain (which varies across countries) based on caloric share in the diet. The “other grains” food group contains all other grains; the prices for this food group are weighted by its components’ caloric shares. At the calibration stage, we either observe domestic food prices (from FAO, 2020) (including the components of a price index for other grains that is weighted by caloric share) or create synthetic prices.

For the food prices not observed in the calibration stage, we create a synthetic domestic price, $p_i^{\text{dom}}$, that is linked to the world price, $p_i^{\text{w}}$, and expressed in local currency. The parameter $\theta$ is the price transmission slope, which we assume is 0.7. The parameter $trc^{\text{int}}$ represents international transportation and market costs [e.g., cost, insurance, and freight (CIF) and free on board (FOB)], which we assume are 10 percent, and $trc^{\text{dom}}$ are domestic trade costs, which we assume are $20 per ton in real terms.
(6) $p^{ds}_t = \theta^* p^w_t * (1 + \text{trc}^{\text{int}} \text{trc}_{\text{int}} / \theta) * (1 + \text{tariff} / \theta) + \text{trc}^{\text{dom}}$.

At this stage, we also calibrate a price transmission equation that links the domestic price $p^{\text{dom}}_t$ (either observed or synthetic) to the world price. The generic price transmission equation is:

(7) $p^{\text{dom}}_t = \theta^* p^w_t + \hat{I}$.

During the calibration stage, we solve for the intercept, $I$, in real terms and hold it constant for the 2020 projection.

The IFSA food security indicators (share of food insecure population, number of food insecure people, and food gap) are derived from the levels of food demand projected using the calibrated demand system. For each country, we use the demand parameters and projected income, $x_t$, and prices, $p_{it}$, to project food demand, $q_{it}$, for each of the four food groups $i$ in each year $t$ so that $q_{it} = \tilde{A}_i(x_t/p_{it})(p_{it}) + \tilde{B}_i(p_{it})\ln(x_t)$. We aggregate demand for the four food groups into total food demand (expressed in calories), so that $\sum q_{it} = Q_t$, which we also refer to as food or caloric consumption. We use this measure of total demand to calculate the food security indicators.

We follow FAO et al. (2019) to estimate the distribution of calorie consumption beginning with a coefficient of variation (CV) of food availability, which characterizes consumption distributed with mean $m$ and variance $v$, so that $CV = (\sqrt{v}/m)$. Given the CV and the projected mean caloric consumption ($Q_t$), we can recover the variance, $v$, of the empirical distribution for a given year $t$.

Assuming food consumption $Q_t$ is distributed lognormal, then $\ln(Q_t)$ is distributed $N(\mu, \sigma^2)$ with $\mu = \ln\left(\frac{m^2}{\sqrt{v} + m^2}\right)$ and $\sigma^2 = \ln(1 + v/m^2)$. Once $\mu$ and $\sigma$ are computed, we recover the proportion of the population that falls below the calorie target (2,100 calories per capita per day) using the standard normal cumulative distribution function (CDF), $\Phi$: $\Phi^{\text{insecure}} = \Phi\left(\frac{\ln(210)}{\sigma}\right)$. Here, $\Phi^{\text{insecure}}$ indicates the share of the population that is food insecure. Using this share and total population in the respective country, we obtain the total number of food insecure people in this country.

Next, the expected average food intake of food insecure people, $q^{\text{food insecure}}_{\text{cal average}}$, can be recovered using the partial mean of the calorie availability below the target (2,100), which we calculate as $q^{\text{food}}_{\text{cal}} = e^{\mu - \sigma/\Phi^{\text{2100}}} \Phi^{\text{2100}}(\Phi(\ln(210) - \mu)/\sigma)$, where $\phi$ is the standard normal density function.

The food gap is the difference between the caloric target of 2,100 and the average calorie availability for food insecure people. This provides a measure of the food gap in calories per day per food-insecure person.
### Appendix Table 6. Country and regional coverage in USDA’s International Food Security Assessment Model

| Asia                      | Latin America and the Caribbean | North Africa       | Sub-Saharan Africa |
|---------------------------|---------------------------------|--------------------|--------------------|
| **Central and South Asia**|                                 |                    |                    |
| Afghanistan               | Bolivia                         | Algeria            | Cameroon           |
|                           | Colombia                        | Egypt              | Central African    |
| Bangladesh                | Dominican Rep                   | Morocco            | Republic           |
| India                     | Ecuador                         | Tunisia            | Congo, Rep. of the |
| Nepal                     | El Salvador                     |                    | Congo, Democratic  |
| Pakistan                  | Guatemala                       |                    | Rep. of the       |
| Sri Lanka                 | Haiti                           |                    | **East Africa**    |
| **Common Wealth of Independent States** | Honduras |                    | Burundi            |
| Armenia                   | Jamaica                         | Chad               |                    |
| Azerbaijan                | Nicaragua                       | Eritrea            |                    |
| Kyrgyzstan                | Peru                            | Ethiopia           | Kenya              |
| Tajikistan                |                                 | Rwanda              |                    |
| Uzbekistan                |                                 | Somalia            |                    |
| Moldova                   |                                 | Sudan              |                    |
| Turkmenistan              |                                 | Tanzania           |                    |
| **Middle East**           |                                 | Uganda             |                    |
| Yemen                     |                                 |                    | **Southern Africa**|
| **South East Asia**       |                                 | Angola             |                    |
| Cambodia                  |                                 | Lesotho            | Madagascar         |
| Indonesia                 |                                 | Madagascar         | Malawi             |
| Laos                      |                                 | Mozambique         | Namibia            |
| Philippines               |                                 |                    | Eswatini           |
| Vietnam                   |                                 |                    | Zimbabwe           |
| **Other Asia**            |                                 | Benin              |                    |
| Georgia                   |                                 | Guinea Bissau      |                    |
| Democratic People’s Republic of Korea |                     | Burkina Faso      |                    |
| Mongolia                  |                                 | Cabo Verde         |                    |
|                           |                                 | Côte d’Ivoire      |                    |
|                           |                                 | Gambia             |                    |
|                           |                                 | Ghana              |                    |
|                           |                                 | Guinea             |                    |
|                           |                                 | Liberia            |                    |
Mali
Mauritania
Niger
Nigeria
Senegal
Sierra Leone
Togo
### Appendix Table 7. COVID-19 country and regional food security indicators

| Country                  | Pre-COVID | COVID-19 | COVID-19 (Lower bound) | COVID-19 (Upper bound) |
|--------------------------|-----------|----------|------------------------|------------------------|
| **Share of population**  |           |          |                        |                        |
| **Food insecure**        | Million   | Million  | Million                | Million                |
| **Population**           | Percent   | Percent  | Percent                | Percent                |
| **Total for SSA countries** |         |          |                        |                        |
| &nbsp;                  | 3,877.9   | 16.8    | 746.5                  | 3,378.3                |
| &nbsp;                  | 436.3     | 25.6    | 572.0                  | 372.7                 |
| &nbsp;                  | 26.3      | 1,099.4  | 361.8                  | 26.9                   |
| **Total for IFSA countries** |         |          |                        |                        |
| &nbsp;                  | 26.9      | 1,099.4  | 361.8                  | 26.9                   |
| **For the Americas and the Caribbean** |         |          |                        |                        |
| **Pre-COVID**            |          |          |                        |                        |
| &nbsp;                  | 173.0     | 18.1     | 31.75                  | 221.6                  |
| &nbsp;                  | 314.6     | 23.6     | 287.6                  | 329.3                  |
| &nbsp;                  | 318.3     | 32.9     | 366.9                  | 357.5                  |
| **COVID-19**             |          |          |                        |                        |
| &nbsp;                  | 318.3     | 32.9     | 366.9                  | 357.5                  |
| **For the Africa**       |          |          |                        |                        |
| **Pre-COVID**            |          |          |                        |                        |
| &nbsp;                  | 1,449.3   | 37.5     | 386.1                  | 720.0                  |
| &nbsp;                  | 435.9     | 31.6     | 386.1                  | 720.0                  |
| &nbsp;                  | 435.9     | 31.6     | 386.1                  | 720.0                  |
| **COVID-19**             |          |          |                        |                        |
| &nbsp;                  | 435.9     | 31.6     | 386.1                  | 720.0                  |

**Note:** Figures may not add up due to rounding.