Evaluating Agricultural Productivity's Impact on Food Security

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Abstract

Global agriculture must significantly increase production to meet by mid-century the demands for food, feed, and fiber posed by the world's enlarging population. An important requirement to meeting those demands is a lifting of agricultural total factor productivity (TFP) growth rates. The present analysis evaluates the impact global agricultural TFP growth may have on food security in developing countries over the next decade. The results present an encouraging picture of developing countries' food security status, especially in Asia and Africa. It finds that a continuation of last decade's agricultural performance significantly accelerates food security reductions, highlighting the important role agricultural productivity plays in a country's food security strategy. It also finds that TFP growth alleviates food insecurity primarily through a balanced approach between production and trade in Asia and Latin America but gains in Africa appear heavily tilted toward imports. There are, however, limitations to our approach, such as possible overestimation of import capacity in some countries.

Keywords: agricultural productivity growth, TFP, GTAP, value-added, gross output, food security

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Shortly after the 2007-2008 food price crisis, the Food and Agricultural Organization (FAO) estimated that by midcentury global food production would need to increase by 70% to feed an additional 2.3 billion people (FAO, 2009). That increase in food production will require greater production growth on existing land. Key to meeting that projected food demand is boosting global agricultural total factor productivity (TFP) growth. However, farm TFP growth rates are not uniformly distributed across countries. Indeed, the extent to which productivity growth rates vary across countries is critical to understanding whether increasing production by 70% is feasible, as well as whether productivity growth will directly impact food security in developing countries.

The purpose of the present paper is to analyze the impact of a continuation of the previous decade's (2000-2009) agricultural performance may have on developing countries' food security over the next decade (2012-2022). In doing so, we examine how productivity affects domestic food production and import growth rates by employing global farm TFP growth rates and a 'macro-micro' modeling approach that exploits the production-based and trade-based improvements in food security generated by accelerating agriculture's TFP growth. Agricultural TFP growth improvements stimulate greater farm production which may translate into lower food prices and greater food availability (Johnston and Mellor, 1961). It may also, however, boost household incomes through greater trade, improving economic access to food.

We approach the analysis by first determining how country-specific agricultural TFP growth estimates affect production and trade flows via a computable general equilibrium model (i.e. the macro model). Critical to that analysis is the measure of agricultural TFP employed. We test two alternative measures of TFP, a gross output measure of TFP growth estimated by Fuglie (2012) and a new, comparable value-added measure of TFP growth to determine which measure is more appropriate in computable general equilibrium models.

After selecting a suitable TFP measure and estimating its impact on global production and trade flows, we introduce the macro estimates into our micro model of food security, the Economic Research Service's (ERS') international food security model. The food security model estimates changes in the number of food-insecure people and the food "distribution" gap for the developing countries included in the analysis. By comparing food security estimates generated from our baseline dataset (i.e., the macro data) with those generated by including the impacts of TFP growth, we are able to compute the affect TFP growth may have on food security in a select number of developing countries. We further show how the introduction of technological change to our macro model affects production- and trade-based contributions to food security experienced in Asia, Africa, and Latin America.

Results suggest that the value-added TFP growth rates may most accurately reflect actual production (volume) percentage changes in macro models; that Asian countries appear to enter a period of deteriorating food security, but Latin American and African countries a period of significantly lower insecurity; that replicating last decade's agricultural performance substantially accelerates the number of food insecure people achieving food security by 2022; and that food security achievements in Asia and Latin America are projected to depend on a balance of production and trade increases, whereas Africa food security gains from TFP are projected to be heavily tilted toward imports, presumably as a result of income gains. There are, however, limitations to our broad approach to measuring food security, not least of which may be strong assumptions of import potential in many countries, but particularly in Africa.

Methodological Approach

Agricultural TFP growth rates are available annually between 1961 and 2009 for 172 countries from Fuglie (2012) and reflect production from the entire agricultural sector. The agricultural productivity data developed by Fuglie assume an unrestricted constant-returns-to-scale Cobb-Douglas production technology of the form

(1) $$Y_t^G = TFP_t^G * f(L_t^{\alpha^G}, K_t^{\beta^G}, A_t^{\gamma^G}, M_t^{\delta^G}),$$

where gross output Y^G is a function of gross output total factor productivity TFP_t^G and measurable inputs labor *L*, capital *K*, land *A*, and intermediate inputs *M*; superscript *G* refers to the measurement in terms of gross rather than value-added, subscript *t* refers to time, and α^G, β^G, γ^G and δ^G represent each input's production cost share. Necessarily, the production cost shares sum to unity.

To transform equation (1) into a value-added function, we exploit the property that (1) is multiplicative in inputs and re-arrange terms:

(2) $$\frac{Y_t^G}{M_t^{\delta^G}} = \left(\frac{TFP_t^G * f(L_t^{\alpha^G}, K_t^{\beta^G}, A_t^{\gamma^G})}{M_t^{\delta^G}} \right).$$

Condensing terms in (2) gives

(3) $$Y_t^V = TFP_t^V f(L_t^{\alpha^V}, K_t^{\beta^V}, A_t^{\gamma^V}),$$

where superscript *V* refers to value-added and $\alpha^V = \alpha^G / 1 - \delta^G$, $\beta^V = \beta^G / 1 - \delta^G$, $\gamma^V = \gamma^G / 1 - \delta^G$, and TFP^V is value-added productivity.

When assuming a Cobb-Douglas production technology the value-added TFP growth estimate is a multiple of the gross-output TFP estimate, the magnitude of the difference between the two determined by the proportion of intermediate or material inputs used in the production process (Domar, 1961):

$$(4) \qquad TFP_t^V = \frac{TFP_t^G}{1 - \delta^G}$$

where the domar weight $1 - \delta^G$ is the sum of all gross output cost shares less the share attributed to intermediate inputs. Because the two TFP measures are unequal, we must be careful interpreting their meaning. We do know, however, that because both measures are derived from the profit function, they both equally reflect technological progress (see Appendix A). We therefore may adjust Fuglie's (2012) gross output measures of TFP growth by applying equation (4); namely, by scaling the TFP growth rates by the domar weight $1 - \delta^G$.

Macro Model

For the macro model, we employ the computable general equilibrium model known as the global trade analysis project (GTAP). Given the complex interrelationships between agricultural commodity markets, as well as the constraining agricultural resource base, and the prominence of food and fuel in household budgets and real income determination, the economy-wide approach of the GTAP model can offer a useful analytical framework for this paper.

The GTAP model has been used heavily for such topics as income distribution impacts from policy changes (Hertel et al., 2009; Keeney and Beckman, 2010), climate change impacts (Ahmed et al., 2009; Hertel et al., 2010), and for biofuel analysis (Taheripour et al., 2008; Keeney and Hertel 2009; Hertel, Tyner, and Birur 2010; Hertel and Beckman 2011; Beckman et al., 2012). For our purposes we use the model version from Beckman et al. (2011) which focused on validating the energy portion of the model. Because the developing countries evaluated in the present analysis do not produce biofuels in large quantities, we do not employ the more biofuel advanced versions of

GTAP. We thus update the GTAP model used by Beckman et al. (2011) to the version 8 (set to 2007) database.

Because we are employing a macro-micro modeling approach, we stylize all information in the food security analysis to only 38 country groupings, all of which are included in the micro model of food security except the industrialized, emerging, and ROW (rest of world) country aggregations (Table 1). Our food security analysis has three agricultural sectors: grains, roots & tubers, and other. Grains in our macro model are an aggregate of wheat, rice, and coarse grains (maize, sorghum, millet, and barley) from the GTAP sectors. The roots & tubers aggregation is split from the GTAP fruits and vegetable sector and is an aggregation of potatoes, sweet potatoes, yams, and cassava. To make this new sector we gather external data on cost shares, production, and trade of roots & tubers compared to the overall fruits and vegetables sector. The final GTAP sector is an aggregate of the remaining horticultural (fruits and vegetable) crops, as well as livestock and dairy products.[1]

In generating our macro production and trade estimates of grain, roots & tubers, and horticultural & livestock products, we use GTAP based projections for population, capital, unskilled and skilled labor, GDP, and investment from Chappius and Walmsley (2011). These authors gather external data from such sources as CEPII and OECD to form projections until 2050. In addition, we use our TFP growth measures, averaged over the 2000-2009 period, for technological change. The CGE model is static; however, we wish to see how results change from year to year. Thus we specify each exogenous shock, along with the technological change, to each year, extract the results, and resolve the model for each year between 2012 and 2022. This does not make the model dynamic, however, as capital accumulation does not occur.

Micro Model

Food security is generally decomposed into its food availability, food accessibility, and food utilization components. In the present analysis, we focus strictly on the availability and accessibility components of food security by employing the ERS International Food Security Assessment model (IFSM) to estimate, annually over the 2012-2022 period, food consumption, food access, and food gaps in developing countries. A country's food security is evaluated based on the gap between estimated domestic food consumption, reflecting domestic production plus imports and net nonfood uses, and a nutritional target.[2] In particular, we measure food distribution gaps, or the amount of food needed to raise per capita consumption in each income decile within a country to the FAO-recommended nutritional target of 2,100 calories per capita per day for 31 developing countries in Asia, Africa, and Latin America. The objective of the food distribution gap is to address food distribution inequalities within a country. As such, our approach accounts for availability of food as well as accessibility by incorporating varying purchasing powers experienced in any country at each income decile when estimating the number of food-insecure people.

As noted above, within the IFSA model, food is divided into three groups: grains, root crops, and other, thus accounting for total food consumption. All commodities included in the micro model are expressed in grain equivalent. Food commodities were converted into grain equivalent based on calorie content to allow aggregation. For example: grain has roughly 3.5 calories per gram and tubers have about 1 calorie per gram. One ton of tubers is therefore equivalent to 0.29 ton of grain, whereas 1 ton of vegetable oil is equivalent to 2.29 tons of grain**.**

Food Availability

Food availability is estimated by a partial equilibrium recursive model of each country. The country models are synthetic, meaning that the parameters employed are either cross-country estimates or are estimated by other studies. Food consumption (*FC*) of grains and root crops (*c*) is defined as domestic supply (*DS*) minus nonfood use (*NF*),

(5) $$FC_{cnt} = DS_{cnt} - NF_{cnt}$$

where *n* indexes countries and *t* indexes time. Nonfood use is the sum of seed use (*SD)*, feed use (*FD*), exports *(EX),* and other uses (*OU*)

(6) $$NF_{cnt} = SD_{cnt} + FD_{cnt} + EX_{cnt} + OU_{cnt.}$$

Domestic supply of a commodity group in equation (5) is the sum of domestic production (*PR*) plus commercial imports (*CI*), changes in stocks (*CSTK*), and food aid (*FA*).

(7) $$DS_{cnt} = PR_{cnt} + CI_{cnt} + CSTK_{cnt} + FA_{cnt}$$

Production of grain and root crops from equation (7) are divided into yield *(YL)* and area *(AR)* responses:

(8) $$PR_{cnt} = AR_{cnt} * YL_{cnt}$$

The crop area response from equation (8) is a function of 1-year lagged crop area, lagged returns (real price times yield) to crop production *(RPY)*, lagged returns to substitute crops *(RNPY)*, and other exogenous policies *(Z)*,

(9) $$AR_{cnt} = f\,(AR_{cnt-1}\,,\, RPY_{cnt-1}\,,\, RNPY_{cnt-1\,,}\, Z_{cnt}\,),$$

where

(10) $$RPY_{cnt} = YL_{cnt} * DP_{cnt},$$

and

(11) $$RNPY_{cnt} = NYL_{cnt} * NDP_{cnt.}$$

Note that *DP* is the real domestic price, *NDP* is the real domestic substitute price, *NYL* is the yield of a substitute commodity. Crop yields from equation (8), however, are assumed to respond only to input use:

(12) $YL_{cnt} = f(LB_{cnt}, FR_{cnt}, K_{cnt}, T_{cnt})$,

where *LB* is rural labor, *FR* is fertilizer use, *K* is an indicator of capital use, *T* is the indicator of technology change.

Commercial imports are assumed to be a function of domestic price, world commodity price, and foreign exchange availability. Food aid received by countries is assumed constant at the base level from the initial year period. Foreign exchange availability is a key determinant of commercial food imports and is the sum of the value of export earnings and net flow of credit. Foreign exchange availability is assumed to be equal to foreign exchange use, implying that foreign exchange reserves are assumed constant during the projection period. The commercial import demand function is defined as:

(13) $CI_{cnt} = f(WPR_{ct}, NWPR_{ct}, FEX_{nt}, PR_{cnt}, M_{nt})$

where *WPR* is real world food price, *NWPR* is real world substitute price, *FEX* is real foreign exchange availability, and *M* is import restriction policies.

Countries are further assumed to be price takers in the international market. However, producer prices are linked to the international market through food imports and their impact on domestic supply. The real domestic price is defined as:

(14) $DP_{cnt} = f(DP_{cnt-1}, DS_{cnt}, NDS_{cnt}, GDP_{nt}, EXR_{nt})$

where *NDS* is the supply of a substitute commodity, *GDP* is real income, and *EXR* is the real exchange rate. It is important to note that consumption of the “other” commodities is estimated from a trend that follows the food crops’ supply growth (grains plus root crops).

<u>Food Accessibility</u>

Inadequate economic access to food is the most important cause of chronic food insecurity among developing countries and is related to income. One advantage of our approach to estimating food insecurity is that we take into account the distribution of food consumption among different income groups. A lack of consumption distribution data for the study countries, though, prevents food consumption estimation by income group. We fill the information void by using an indirect method of projecting calorie consumption by different income groups based on income distribution data.[3] This approach uses the income/consumption relationship to allocate estimated total food availability among different income groups in each country. Yet, the approach is still limited when calculating food consumption for the poorest 10% of the population for any countries. While results may indicate consumption for that income decile exceeds the nutritional target, we recognize that people within that decile are consuming below the target and are therefore food insecure, even if the result indicates zero food insecurity. The approach also does ignore consumption substitutions across different food groups by income class and assumes income distributions remain invariant over time.

If we assume that consumption increases with income, but at a declining rate, then we may assume the income/consumption relationship in semi-log form as:

(15) $$C = a + b \ln Y$$

where a is an intercept, b is the consumption income propensity, and C and Y are known average per capita food consumption and per capita income. Parameter b is estimated based on cross-country (76 low-income countries) data for per capita calorie consumption and income, while parameter a is estimated for each country based on the known data for average per capita calorie consumption and per capita income. Per capita food consumption, specified in grain equivalents, is the ratio of total food consumption C_o to the total population P,

(16) $$C = C_o/P,$$

and per capita income, averaged across income deciles, is the ratio of total income Y_o to the total population,

(17) $Y = Y_o/P$,

where the total population is summed across each income decile *i* (e.g. $P = \sum_{i=1}^{10} P_i$). A consumption-income elasticity, *b/C*, is then calculated for individual countries and allows for the allocation of consumption over income deciles.

Results

The aggregate food security estimates are provided in Tables 4 and 5, the country-specific food security data from which those tables are drawn are available in Appendix B. Recall that the food distribution gap measures the tonnage of food required at each income decline for the population to achieve 2,100 calories per day, providing a measure of food access. Decadal averages and growth rates of production and trade estimated from our macro model and employed by our micro model are available in Appendix C. Food production and import growth rates computed from our micro food security model are provided in Table 6.

Testing Gross Output and Value-added TFP

Gross output and value-added measures of productivity differ by the same proportion that intermediate inputs account for total gross production costs. This is readily seen at the global scale, divergence between the two measures increasing by the same magnitude as agriculture's reliance on fertilizer and other materials (Figure 1). Such proportionate differences between the two TFP estimates are larger for those agricultural sectors which rely heavily on intermediate inputs (Figure 2) and smaller for those that do not (Figure 3). Because value-added and gross output productivity growth measures are both widely employed in the literature, we conduct a validation experiment using our macro model to determine which measure best replicates historical volume changes.

We specify exogenous shocks to our macro model in the form of historical changes in population, capital, unskilled and skilled labor, GDP, and investment. In addition, we include energy price changes, necessary information when estimating global historical changes (Beckman et al., 2011).   We then analyze three scenarios, all incorporating these exogenous shocks: no productivity changes, value-added productivity changes, and gross output productivity changes. Because the exogenous shocks are uniform across all three economies, the differences in results reflect the alternative productivity growth specifications.

The TFP growth estimates used in the analysis are presented in Table 2. In determining which productivity measure more accurately reflects actual production growth, we compare the percentage change in FAO grain production between 2007 and 2011 for each country grouping in Table 1 with the gross-output- and value-added-induced GTAP grain production percentage changes over the same time period. To generate the gross output- and value-added-induced grain growth, we employ 2007-2009 average productivity growth rates in the macro model.

We find that for most country grouping the pair-wise correlations between grain production induced by the value-added TFP growth rates in GTAP and FAO production are most strongly correlated (Table 3). For all sample countries, the value-added TFP growth-induced production changes have a 0.45 pair-wise correlation with FAO grain production percentage changes; whereas gross output TFP growth-induced changes have only a 0.31 pairwise correlation. The correlations resulting from the value-added TFP growth rates are higher than those from gross output productivity growth in industrialized countries, developing countries, and across various geo-political aggregations of the developing countries (Table 3). The only country groupings for which the grain production growth correlations are not in favor of the value-added measure are the emerging countries, which are interestingly negatively correlated with actual production changes and favor the gross output productivity measure. From Table 3 we conclude that for the present analysis, the value-added TFP growth rates may be more suitable than are the gross output TFP growth rates. The remainder of the analysis thus focuses strictly on evaluating the impact of value-added productivity growth.

Examining Regional Food Security Improvements

The baseline food security estimates, generated by entering the baseline (i.e. GTAP with no technological change) macro dataset into our micro model, unsurprisingly indicates Africa to have in 2012 the largest number of food insecure people (Table 4). Africa is the most vulnerable region in the world with the lowest per capita consumption levels. The region accounts for 45% of the total population included in this analysis, but accounts for 61% of the food insecure people in 2012. Assuming no technological change, our macro estimates suggest that the number of food insecure people would increase nearly 62% in the Asian countries by 2022, driven almost entirely by the Philippines. Unlike the Asian countries, the Latin American and African countries are projected to experience food security improvements over the next decade. Indeed, as shown in Table 4, our macro estimates indicate the African countries may become nearly food secure by the end of the next decade (Figure 4a). These estimates are supported by equally strong trends in Africa's food distribution gap (Figure 5a, Table 5).

We are particularly interested in determining the driving factor behind Africa's food security improvements in our baseline food security model. The most populous African country, Nigeria, is estimated by our macro model to experience sharp average annual increases in grain production (4.3% per annum) between 2012 and 2022, despite stagnant TFP growth over the previous decade (Table 2). Our baseline macro results also suggest high average annual grain production growth rates in, Madagascar (5.2%), Uganda (4.6%), and Malawi (4.3%). Moreover, average per annum grain import growth rates are sufficiently high enough in Nigeria (4.5%), Uganda (10.5%), Tanzania (8.4%) and Zimbabwe (4.7%) that, when combined with the production growth estimates, show food insecurity is nearly eradicated by 2022 (Table 4).[4]

Introducing the TFP estimates to our analysis supports the already strong trend in Africa's food security without significantly changing it. TFP impacts on Asian and Latin American countries are, however, significant (Table 4). Indeed, the introduction of technological change to the Asian country macro estimates indicates a deterioration of the region's food security status, which would mark a reversal of recent trends. A continuation of the previous decade's agricultural performance is projected to lead to relatively low, albeit steady, grain and root crop production and import growth over the next decade (Figures 6-9). Thus, productivity improvements are projected to substantially affect food security in Asia, the central driver of that change being improvements in the Filipino population's food availability and accessibility.

Latin American countries also experience a significant impact from the introduction of technological change, as this region's number of food insecure people declines by average annual 6.5% between 2012 and 2022, compared to the average annual 9.5% decline indicated by the baseline model (Table 4). Among the Latin American countries, only Peru is estimated to be food secure by our baseline estimates throughout the upcoming decade, Nicaragua achieving food security within only a few years. Food insecurity in Latin America is often due to unequal access to food supplies rather than lack of availability as the region has some of the most skewed income distribution in the world. Because the food distribution gap accounts for purchasing power by income decile, it is particularly useful for examining the Latin American countries. The measure does indeed suggest significant changes, improvements reflected by the sharp decline in the distribution gap, from 544 thousand tons in 2012 to 32 thousand tons in 2022 (Table 5).

The above estimates suggest productivity growth is an important driver in reducing food insecurity, particularly in Asia and Latin America, but does not address how the impact occurs. Are productivity-induced food security improvements driven by greater domestic food production, or are countries able to import more food because they hold a comparative advantage producing cash crops for the international market? To answer this question we evaluate food production and import growth rates, in grain equivalents, from our baseline and TFP-induced micro estimates of food security. The results show that food insecurity alleviation is primarily due to a combination of production and trade effects in Asia and Latin America, with production effects slightly more important in Asia and trade effects slightly more important in Latin America (Table 6). Africa, though, shows strong import growth. To the extent that we have confidence in the Africa results, this suggests that the importance of trade in improving food security may be underestimated in other discussions of food security in the region. .

Conclusion

This study presents several changes to the current state of using global computable generate equilibrium models for developing country assessment. It provides a new global productivity dataset that is internally consistent with the GTAP data, and tests the impact of that new dataset vis-à-vis the generally employed gross output measures. It also highlights the important role agricultural productivity growth will likely play in future food security improvements. Indeed, our findings suggest that a replication of last decade's farm performance will enable a balanced approach – between boosting domestic food production and food imports – to food security improvements in Latin American and Asian countries.

The study does, however, suggest some limitations to this method for measuring food security. One limitation is the strong assumptions within the macro model regarding import capacity for many countries; projected rates are many times above historical rates for some countries. A second limitation lies within our micro model of food security. The aggregate approach taken assumes an average distribution of projected consumption over income deciles, an approach that may be an improvement over previous models to obtain greater detail, but one that still may not accurately reflect true food security for those income levels. Another limitation is the sample, individual countries included had to be present within both macro and micro models. This narrowed down our sample to a subset of the world's most food insecure countries, which may also be broadly considered to have the poorest quality data, in turn affecting our productivity estimates as well as our macro and micro model results. Despite these limitations, we are, at least for broad country aggregations, able to obtain insight into the role of total factor productivity growth in shaping developing countries' food security.

The primary extension to the present analysis is to conduct a policy analysis to determine in which countries – industrialized, emerging, or Latin American, Asian, or African developing countries – TFP growth must increase to provide the greatest boost to developing countries' food security. That is to say, if the international community is interested in eradicating food insecurity, in which geo-political regions is it most vital to raise TFP growth for the end result to be global food security. Another extension may include testing, for a much broader set of countries than is available in the present analysis, the appropriate TFP growth measure to include in further computable general equilibrium models that wish to include productivity.

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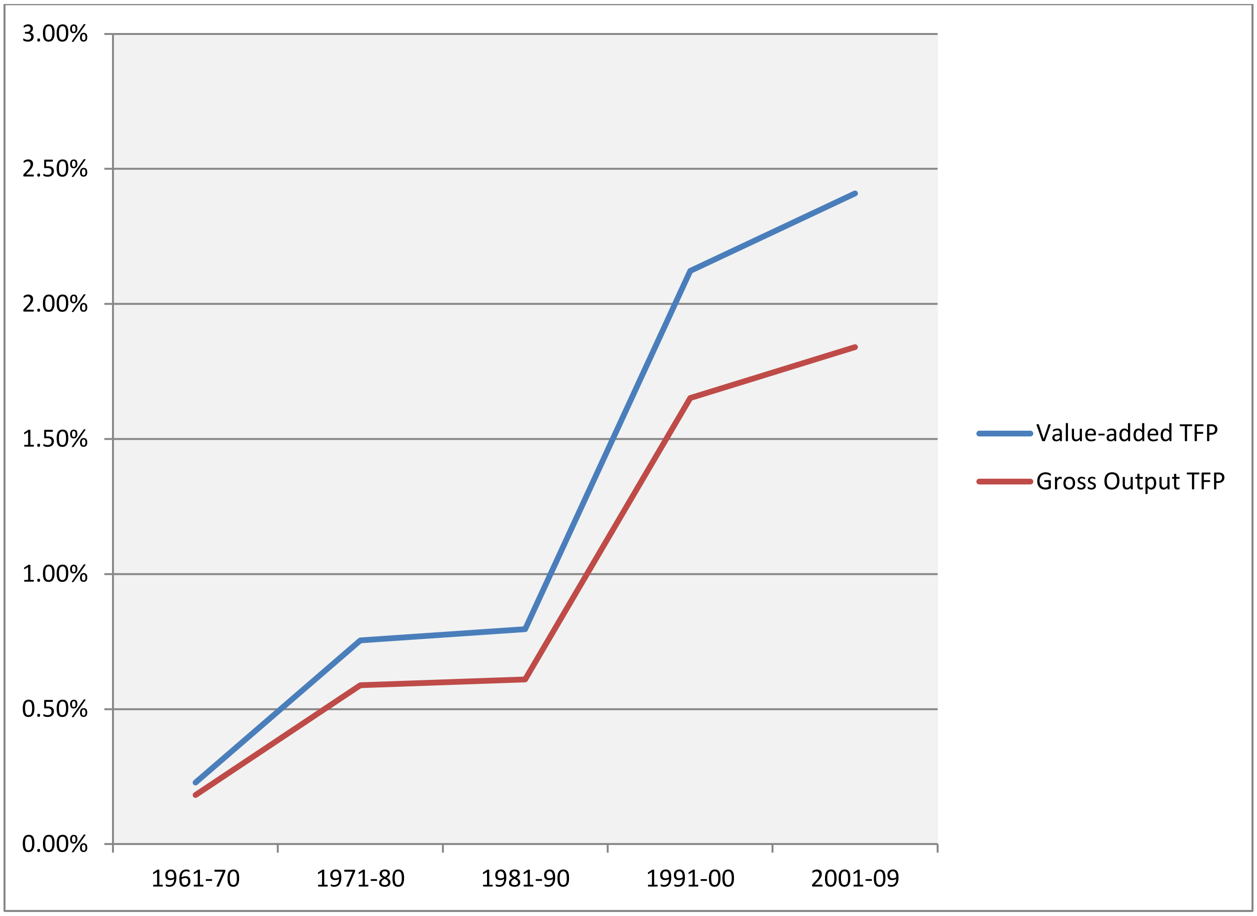
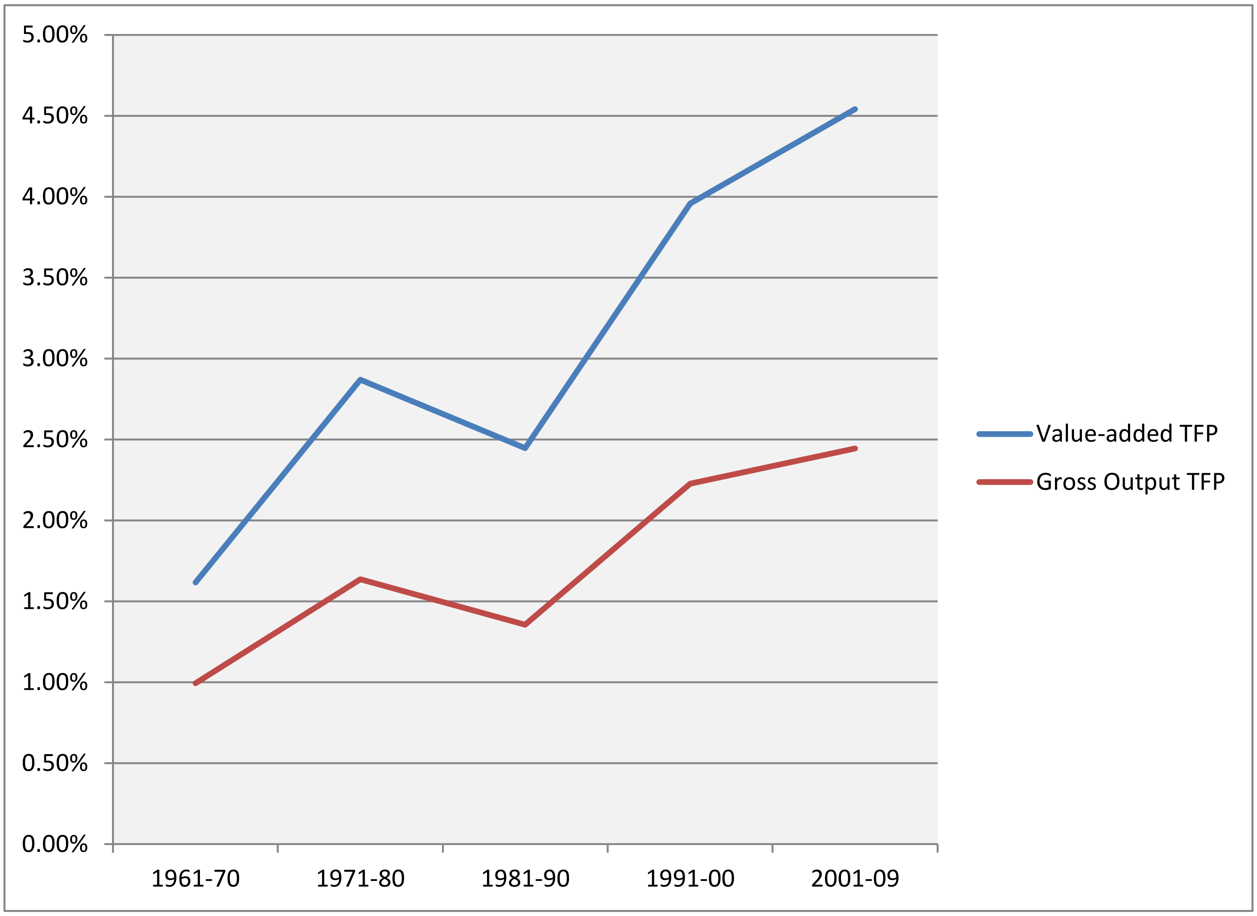
Figure 1. Comparing Decadal Averages of Global Gross Output (GO) and Value-added (VA) TFP Growth Rates



Note: Gross output TFP growth rates are from Fuglie (2012). Both TFP measures here reflect the 172 countries included in that analysis.

Figure 2. Comparing Decadal Averages of Industrialized Countries' Gross Output (GO) and Value-added (VA) TFP Growth Rates



Note: Gross output TFP growth rates are from Fuglie (2012). Both TFP measures here reflect the broader set (28) of industrialized countries included in that analysis.

Figure 3. Comparing Decadal Averages of Sub-Saharan African Countries' Gross Output (GO) and Value-added (VA) TFP Growth Rates

Note: Gross output TFP growth rates are from Fuglie (2012). Both TFP measures here reflect the broader set (47) of Sub-Sahara African countries included in that analysis.

Figure 4a. Baseline Number of Food Insecure

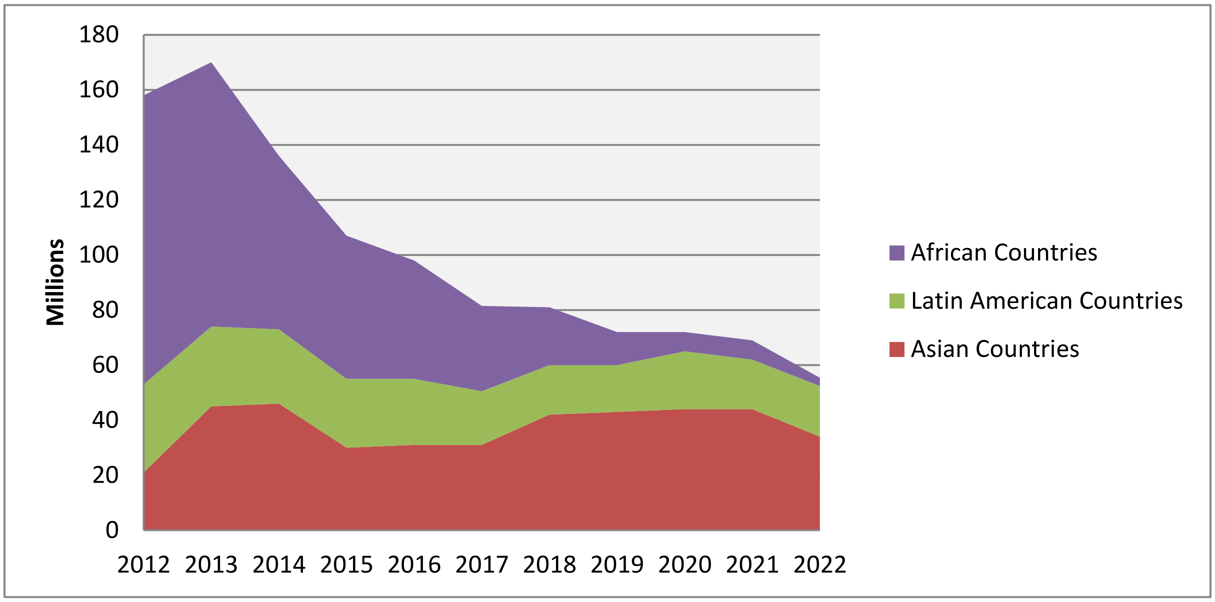


Figure 4b. TFP-induced Number of Food Insecure

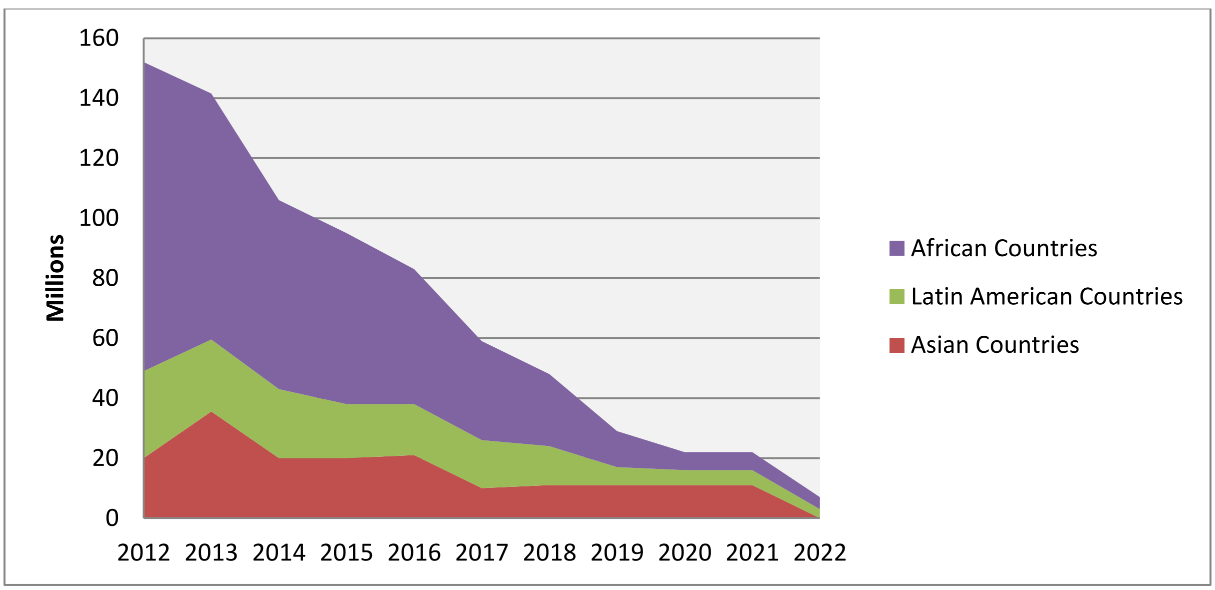


Figure 5a. Baseline Food Insecurity Distribution Gap

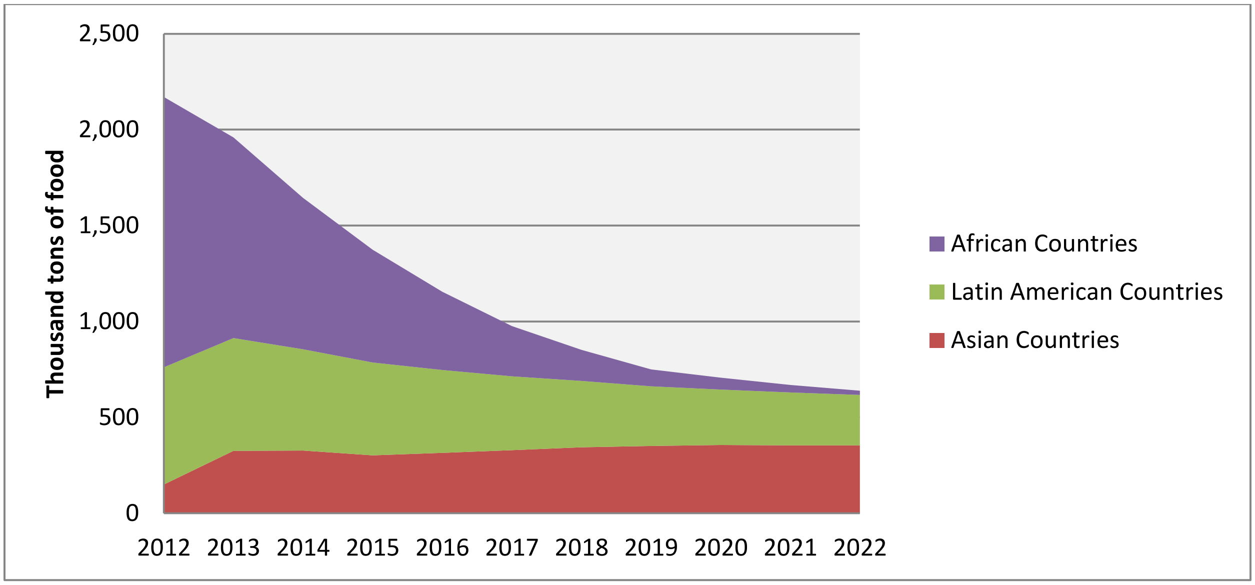


Figure 5b. TFP-induced Food Insecurity Distribution Gap

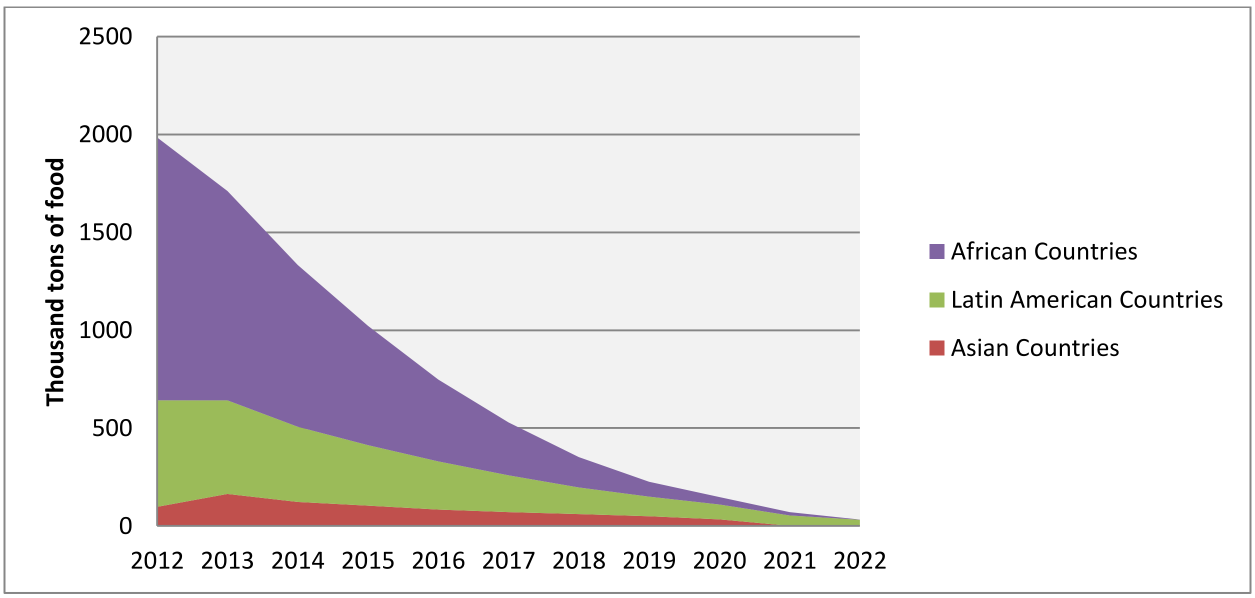


Figure 6. TFP-induced Grain Production Growth Rates from GTAP

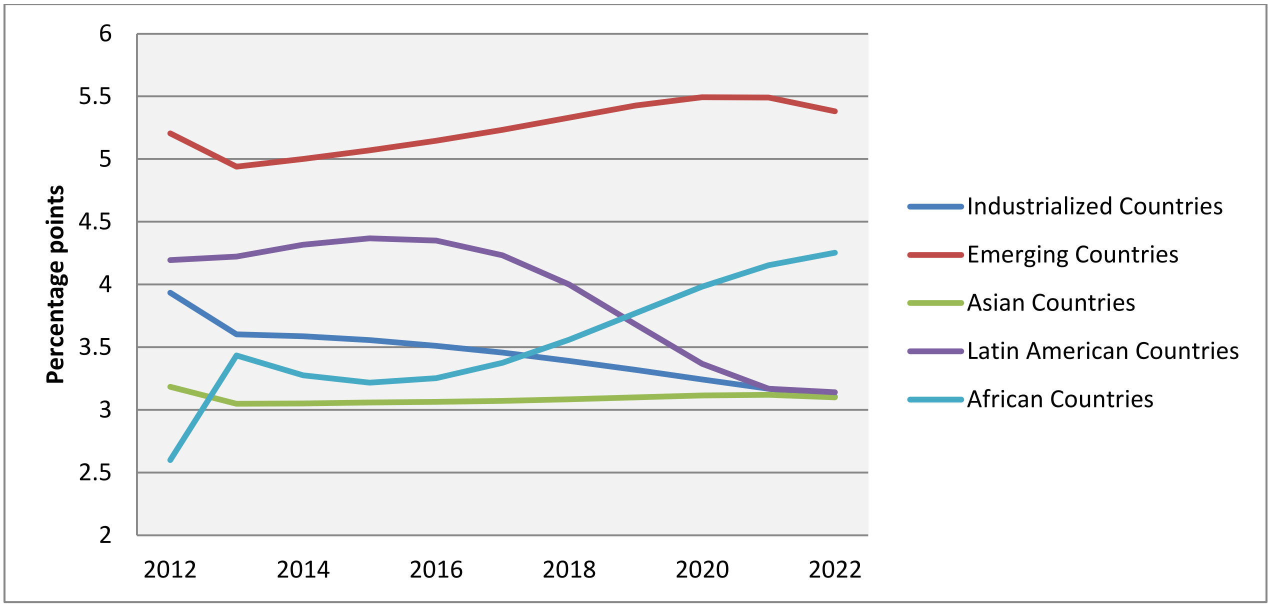


Figure 7. TFP-induced Grain Import Growth Rates from GTAP

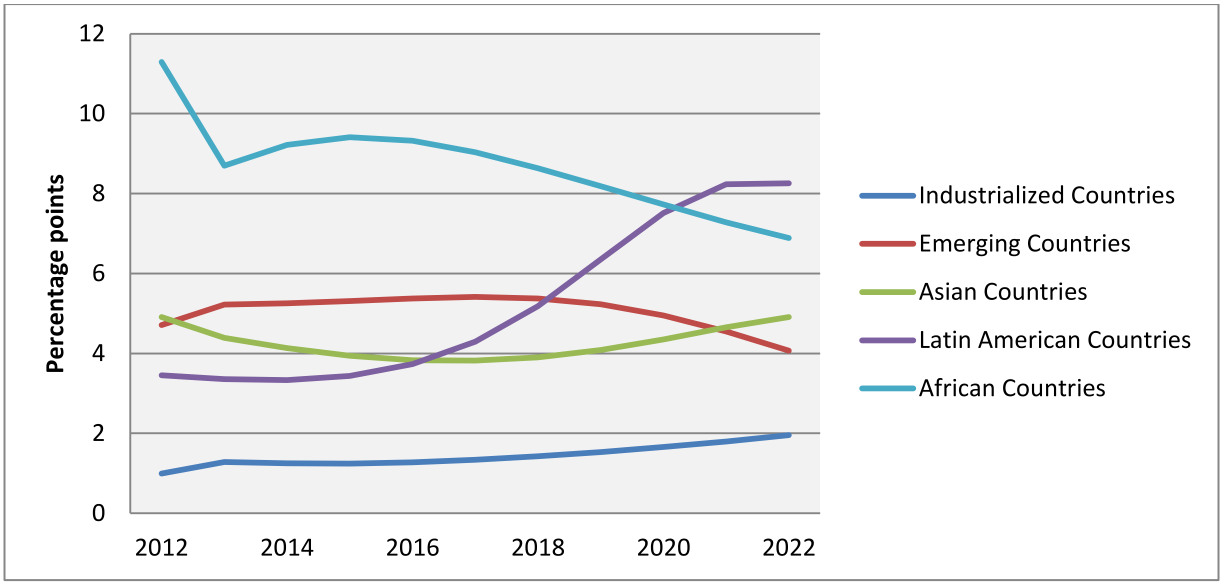


Figure 8. Roots & Tubers Production Growth Rates

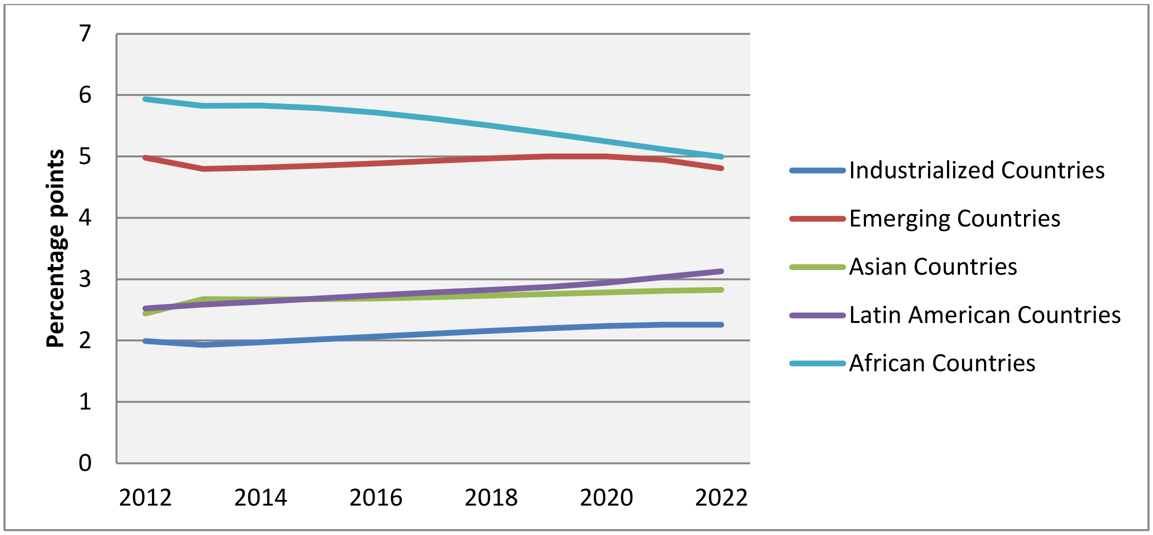


Figure 9. Roots & Tubers Import Growth Rates

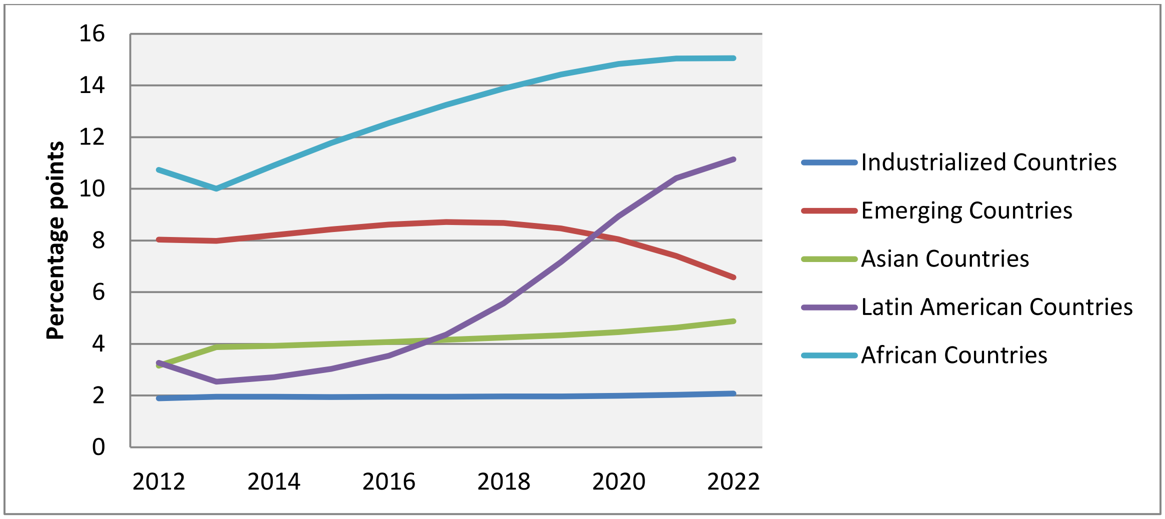


Table 1. Country List

Industrialized Countries	Emerging Economies	Latin American Economies
Australia	China	Bolivia
Japan	India	Colombia
USA	Indonesia	Ecuador
EU*	Brazil	Peru
		Guatemala
		Nicaragua
Asian Economies	**African Countries**	
Cambodia	Egypt	
Laos	Morocco	
Philippines	Tunisia	
Vietnam	Nigeria	
Bangladesh	Senegal	
Pakistan	Ethiopia	
Sri Lanka	Madagascar	
Kyrgyzstan	Malawi	
Armenia	Mozambique	
Azerbaijan	Tanzania	
Georgia	Uganda	
	Zambia	
ROW Countries*	Zimbabwe	

Notes: 1. EU consists of: Austria, Belgium, Luxembourg, Bulgaria, Cyprus, Czechoslovakia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Spain, Sweden, and the United Kingdom.

2. ROW Countries consists of: Mexico, Canada, New Zealand, Fiji, Micronesia, New Caledonia, Papua New Guinea, Polynesia, Soloman Islands, Vanuatu, Korea (Republic), Korea (D.P.R.), Malaysia, Singapore, Thailand, Brunei Darussalam, Myanmar, Timor Leste, Afghanistan, Bhutan, Argentina, Chile, Paraguay, Uruguay, Venezuela, French Guiana, Guyana, Suriname, Costa Rice, Panama, Belize, Bahamas, Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, Trinidad and Tobago, Switzerland, Albania, Belarus, Croatia, Russian Federation, Ukraine, Moldova, Kazakhstan, Tajikistan, Turkmenistan, Uzbekistan, Bahrain, Iran, Israel, Kuwait, Oman, Qatar, Saudi Arabia, Turkey, UAE, Iraq, Jordan, Lebanon, Syria, Yemen, Algeria, Libya, Cote d'Ivoire, Burkina Faso, Cape Verde, Gambia, Mali, Mauritania, Niger, Benin Guinea, Guinea-Bassau, Liberia, Sierra Leone, Togo, Central African Republic, Congo, Equitorial Guinea, Gabon, Sao Tome and Principe, Chad, Angola, Congo (D.R.), Mauritius, Burundi, Rwanda Seychelles, Djibouti, Somalia, Sudan, Comoros, Eritrea, Botswana, South Africa, Lesotho, and Swaziland.

3. The industrialized countries, emerging, and ROW countries are excluded from the food security analysis.

Table 2. Comparing 2000-2009 Average Gross Output (GO) and Value-added (VA) TFP Growth Rates

	VA TFP	GO TFP		VA TFP	GO TFP		VA TFP	GO TFP
Industrialized Countries			Emerging Countries			Latin American Countries		
Australia	0.41%	0.33%	Brazil	6.09%	3.96%	Bolivia	-1.54%	-1.00%
Japan	3.76%	2.41%	China	3.54%	2.96%	Colombia	4.54%	2.96%
USA	4.34%	2.09%	India	2.00%	1.87%	Ecuador	5.01%	3.26%
EU*	3.15%	1.97%	Indonesia	3.74%	3.57%	Peru	4.89%	3.18%
						Guatemala	2.75%	2.38%
						Nicaragua	3.62%	3.13%
Asian Countries			African Countries					
Cambodia	5.64%	5.38%	Egypt	3.80%	2.48%	ROW Countries*	2.32%	1.97%
Laos	2.33%	2.22%	Morocco	6.22%	4.05%			
Philippines	2.77%	2.64%	Tunisia	2.31%	1.51%			
Vietnam	2.56%	2.44%	Nigeria	0.88%	0.83%			
Bangladesh	3.46%	3.23%	Senegal	2.04%	1.93%			
Pakistan	0.52%	0.48%	Ethiopia	1.32%	1.24%			
Sri Lanka	1.13%	1.05%	Madagascar	1.26%	1.19%			
Kyrgyzstan	1.54%	1.43%	Malawi	1.28%	1.21%			
Armenia	5.49%	5.11%	Mozambique	0.09%	0.08%			
Azerbaijan	2.77%	2.57%	Tanzania	1.19%	1.12%			
Georgia	-2.81%	-2.62%	Uganda	-1.75%	-1.65%			
			Zambia	2.34%	2.21%			
			Zimbabwe	-1.56%	-1.47%			

Note: EU and ROW countries are aggregates. See Table 1 for their included countries.

Table 3. Pair-wise Correlations Between FAO Grain Production Growth and Gross Output- and Value-added-induced GTAP Production Growth

	Gross Output TFP	Value-added TFP	Number of Countries
Sample Total	0.3139	0.4514	39
Industrialized Countries	0.8065	0.8923	4
Emerging Countries	-0.7616	-0.4044	4
Developing Countries	0.2600	0.4158	30
Africa Countries	0.0198	0.241	13
Asian Countries	0.0667	0.2642	15
Latin American Countries	0.0094	0.0334	7

Note: The Industrialized, Emerging, and Developing Countries do not sum to the Sample Total because of the exclusion of ROW countries. Developing countries include the Africa, Asia, and Latin America aggregations detailed in Table 1.

Table 4. Aggregate Number of Food Insecure (millions), 2012-2022

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
(Baseline)	Asian Countries	21	45	46	30	31	31	42	43	44	44	34
	Latin American Countries	32	29	27	25	24	19.5	18	17	21	18	18
	African Countries	105	96	63	52	43	31	21	12	7	7	3
	Aggregate Number of Food Insecure	**158**	**170**	**136**	**107**	**98**	**81.5**	**81**	**72**	**72**	**69**	**55**
(TFP-induced)	Asian Countries	20	35.5	20	20	21	10	11	11	11	11	0
	Latin American Countries	29	24	23	18	17	16	13	6	5	5	3
	African Countries	103	82	63	57	45	33	24	12	6	6	4
	Aggregate Number of Food Insecure	**152**	**142**	**106**	**95**	**83**	**59**	**48**	**29**	**22**	**22**	**7**

Table 5. Aggregate Food Distribution Gaps (thousand tons)

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
(Baseline)	Asian Countries	150	325	327	302	315	329	344	351	356	354	354
	Latin American Countries	611	588	528	484	432	385	346	311	289	276	263
	African Countries	1,409	1,046	789	588	408	262	162	88	62	39	22
	Aggregate Distribution Gap	**2,170**	**1,959**	**1,644**	**1,374**	**1,155**	**976**	**852**	**750**	**707**	**669**	**639**
(TFP-induced)	Asian Countries	98	164	123	104	84	71	61	50	34	1	0
	Latin American Countries	544	478	384	309	246	188	136	100	76	53	32
	African Countries	1,342	1,069	826	609	418	270	155	76	38	17	1
	Aggregate Distribution Gap	**1,984**	**1,711**	**1,333**	**1,022**	**748**	**529**	**352**	**226**	**148**	**71**	**33**

Table 6. Average Annual Food Production and Import Growth Rates in Asia, Africa, and Latin America, 2012-2022.

	Asia		Africa		Latin America	
	Production	Imports	Production	Imports	Production	Imports
Baseline	1.93%	4.25%	4.40%	3.85%	1.56%	4.61%
TFP-induced	3.31%	3.02%	2.82%	13.18%	4.21%	4.78%

Notes:

1. Asia here excludes Armenia and Azerbaijan and Africa excludes the North African countries Egypt, Tunisia, and Morocco.
2. Food Production here consists only of grains and root crops, specified in grain equivalents.

Appendix A. Equating Gross Output and Value-added TFP Growth Measures

The basis for deriving a value-added measure of total factor productivity growth (TFP) from one defined in terms of gross output was developed in the seminal work by Domar (1961). There Domar defines value-added TFP as the gross output TFP measure scaled by the sum of each factor's cost share less that of intermediate inputs. Here we define the relationship between gross output and value-added TFP growth. Below we show, following Balk (2003), that because both measures of productivity growth may be derived from the profit function, they both equally reflect technological progress.

We first define the technology set $S(t)$ in time period *t* as all feasible output and input combinations such that

(1) $$S(t) \equiv \{(x, y) \mid x \text{ can produce } y \text{ at period } t\}$$

where vectors *x* represent input quantities, *y* represent output quantities, and *t* represents time. One representation of the technology set (1) is given by the value-added function

(2) $$VA(x_{KL}, w_M, p, t) \equiv \max_{x_M, y}\{py - w_M x_M \mid (x_{KL}, x_M, y) \in S(t)\}$$

with subscripts *KL* referring to capital and labor and *M* referring to intermediate inputs. Vector *p* represent output prices and *w* represents input prices. Equation (2) provides the maximum value added at given output and intermediate input prices, conditional on value-added (capital-labor) input quantities.

Under weak regularity conditions, the technology set (1) may also be represented by the cost function

(3) $$C(w, y, t) \equiv \min_{x}\{wx \mid (x, y) \in S(t)\}.$$

Equation (3) provides the minimum cost for producing the output quantities (*y*) when input prices are given *w*.

Duality theory tells us that the cost function and the value-added function are related by way of the profit function:

$$
\begin{aligned}
\Pi(w, p, t) &\equiv \max_{x, y}\{py - wx \mid (x, y) \in S(t)\} \\
&= \max_{y}\{py - C(w, y, t)\} \\
&= \max_{x_{KL}}\{VA(x_{KL}, w_M, p, t) - w_{KL}x_{KL}\}.
\end{aligned} \tag{4}
$$

That is, profit may be defined as the difference between gross revenues and total costs or by value-added revenues and capital-labor costs. Balk notes that by applying the Envelope Theorem we may show that the two measures of productivity are linked:

$$
\begin{aligned}
\frac{\partial \Pi(w, p, t)}{\partial t} &= -\frac{\partial C(w, y^*, t)}{\partial t} \\
&= \frac{\partial VA(x^*_{KL}, w_M, p, t)}{\partial t}
\end{aligned} \tag{5}
$$

where y^* is the solution to the second maximization problem in (4) and x^*_{KL} is the solution to the third maximization problem in (4). By setting the two right-hand side terms in (5) equal to each other we have

$$
-\frac{\partial C(w, y^*, t)}{\partial t} = \frac{\partial VA(x^*_{KL}, w_M, p, t)}{\partial t}. \tag{6}
$$

Taking logs gives

$$
-\frac{\partial C(w, y^*, t)}{\partial t}\frac{C(w, y^*, t)}{VA(x^*_{KL}, w_M, p, t)}\frac{1}{C(w, y^*, t)} = \frac{\partial VA(x^*_{KL}, w_M, p, t)}{\partial t}\frac{1}{VA(x^*_{KL}, w_M, p, t)} \tag{7}
$$

which equals

$$
-\frac{C(w, y^*, t)}{VA(x^*_{KL}, w_M, p, t)}\frac{\partial \ln C(w, y^*, t)}{\partial t} = \frac{\partial \ln VA(x^*_{KL}, w_M, p, t)}{\partial t} \tag{8}
$$

Expression (8) now equals Balk's equation (55):

(9) $$\frac{\partial \ln VA(x^*_{KL},\ w_M,\ p,\ t)}{\partial t} = -\frac{C(w,\ y^*,\ t)}{VA(x^*_{KL},\ w_M,\ p,\ t)}\frac{\partial \ln C(w,\ y^*,\ t)}{\partial t}.$$

Equation (9) states that value-added TFP growth rate is equal to a dual version of the Domar factor multiplied by the negative of the cost function's rate of technological progress. This result is consistent with the result shown by Morrison Paul (1999), that the primal rate of productivity growth is equal to the negative of the dual rate of productivity growth, or $\frac{\partial Y}{\partial t} = -\frac{\partial C}{\partial t}$ (Morrison Paul, 1999).

Appendix B. Food Security Estimates

Appendix Table B1. Baseline Number of Food Insecure, by Country, 2012-2022 (in millions).

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Asian Countries	**21**	**45**	**46**	**30**	**31**	**31**	**42**	**43**	**44**	**44**	**34**
Cambodia	0	0	0	0	0	0	0	0	0	0	0
Laos	1	0	0	0	0	0	0	0	0	0	0
Philippines	19	29	30	30	31	31	42	43	44	44	34
Vietnam	0	0	0	0	0	0	0	0	0	0	0
Bangladesh	0	15	16	0	0	0	0	0	0	0	0
Pakistan	0	0	0	0	0	0	0	0	0	0	0
Sri Lanka	0	0	0	0	0	0	0	0	0	0	0
Kyrgyzstan	1	1	0	0	0	0	0	0	0	0	0
Armenia	0	0	0	0	0	0	0	0	0	0	0
Azerbaijan	0	0	0	0	0	0	0	0	0	0	0
Georgia	0	0	0	0	0	0	0	0	0	0	0
Latin American Countries	**32**	**29**	**27**	**25**	**24**	**19.5**	**18**	**17**	**21**	**18**	**18.4**
Bolivia	6	5	5	4	4	3.3	2	2	1	1	1.2
Colombia	5	5	5	5	5	4.9	5	5	10	10	10.3
Ecuador	9	9	8	8	8	6.2	6	6	6	5	5
Peru	0	0	0	0	0	0	0	0	0	0	0
Guatemala	11	9	8	8	7	5.1	5	4	4	2	1.9
Nicaragua	1	1	1	0	0	0	0	0	0	0	0
African Countries	**105**	**96**	**63**	**52**	**43**	**31**	**21**	**12**	**7**	**7**	**3**
Egypt	0	0	0	0	0	0	0	0	0	0	0
Morocco	0	0	0	0	0	0	0	0	0	0	0
Tunisia	0	0	0	0	0	0	0	0	0	0	0
Nigeria	17	17	0	0	0	0	0	0	0	0	0
Senegal	7	5	5	4	5	3	3	3	2	2	0
Madagascar	13	13	11	12	10	10	8	5	5	5	3
Malawi	0	0	0	0	0	0	0	0	0	0	0
Mozambique	10	7	5	3	3	3	0	0	0	0	0
Tanzania	38	34	25	21	16	11	6	0	0	0	0
Uganda	18	18	15	11	8	4	4	4	0	0	0
Zambia	1	1	1	0	0	0	0	0	0	0	0
Zimbabwe	1	1	1	1	1	0	0	0	0	0	0

Appendix Table B2. TFP-induced Number of Food Insecure, by Country, 2012-2022 (in millions).

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Asian Countries	**20**	**35.5**	**20**	**20**	**21**	**10**	**11**	**11**	**11**	**11**	**0**
Cambodia	0	0	0	0	0	0	0	0	0	0	0
Laos	0	0	0	0	0	0	0	0	0	0	0
Philippines	19	20	20	20	21	10	11	11	11	11	0
Vietnam	0	0	0	0	0	0	0	0	0	0	0
Bangladesh	0	15	0	0	0	0	0	0	0	0	0
Pakistan	0	0	0	0	0	0	0	0	0	0	0
Sri Lanka	0	0	0	0	0	0	0	0	0	0	0
Kyrgyzstan	1	0.54	0	0	0	0	0	0	0	0	0
Armenia	0	0	0	0	0	0	0	0	0	0	0
Azerbaijan	0	0	0	0	0	0	0	0	0	0	0
Georgia	0	0	0	0	0	0	0	0	0	0	0
Latin American Countries	**29**	**24**	**23**	**18**	**17**	**16**	**13**	**6**	**5**	**5**	**3**
Bolivia	5	4	3	2	2	2	1	1	1	1	1
Colombia	5	5	5	5	5	5	5	0	0	0	0
Ecuador	7	6	5	3	2	2	2	0	0	0	0
Peru	0	0	0	0	0	0	0	0	0	0	0
Guatemala	11	9	10	8	8	7	5	5	4	4	2
Nicaragua	1	0	0	0	0	0	0	0	0	0	0
African Countries	**103**	**82**	**63**	**57**	**45**	**33**	**24**	**12**	**6**	**6**	**4**
Egypt	0	0	0	0	0	0	0	0	0	0	0
Morocco	0	0	0	0	0	0	0	0	0	0	0
Tunisia	0	0	0	0	0	0	0	0	0	0	0
Nigeria	17	0	0	0	0	0	0	0	0	0	0
Senegal	7	7	5	6	4	5	3	2	2	2	0
Madagascar	13	11	9	9	7	5	3	3	0	0	0
Malawi	0	0	0	0	0	0	0	0	0	0	0
Mozambique	10	10	8	5	5	3	3	3	0	0	0
Tanzania	33	34	25	21	16	11	6	0	0	0	0
Uganda	21	18	15	15	12	8	8	4	4	4	4
Zambia	1	1	0	0	0	0	0	0	0	0	0
Zimbabwe	1	1	1	1	1	1	1	0	0	0	0

Appendix Table B3. Baseline Food Distribution Gap, by Country, 2012-2022 (thousand tons).

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Asian Countries	**150**	**325**	**327**	**302**	**315**	**329**	**344**	**351**	**356**	**354**	**354**
Cambodia	0	0	0	0	0	0	0	0	0	0	0
Laos	2	0	0	0	0	0	0	0	0	0	0
Philippines	142	270	307	302	315	329	344	351	356	354	354
Vietnam	0	0	0	0	0	0	0	0	0	0	0
Bangladesh	0	55	20	0	0	0	0	0	0	0	0
Pakistan	0	0	0	0	0	0	0	0	0	0	0
Sri Lanka	0	0	0	0	0	0	0	0	0	0	0
Kyrgyzstan	6	0.4	0	0	0	0	0	0	0	0	0
Armenia	0	0	0	0	0	0	0	0	0	0	0
Azerbaijan	0	0	0	0	0	0	0	0	0	0	0
Georgia	0	0	0	0	0	0	0	0	0	0	0
Latin American Countries	**611**	**588**	**528**	**484**	**432**	**385**	**346**	**311**	**289**	**276**	**263**
Bolivia	152	139	125	112	95	79	67	51	39	27	12
Colombia	80	114	111	116	118	120	123	129	144	162	183
Ecuador	162	147	133	125	114	104	95	86	76	67	58
Peru	0	0	0	0	0	0	0	0	0	0	0
Guatemala	214	186	158	131	105	82	61	45	30	20	10
Nicaragua	3	2	1	0	0	0	0	0	0	0	0
African Countries	**1,409**	**1,046**	**789**	**588**	**408**	**262**	**162**	**88**	**62**	**39**	**22**
Egypt	0	0	0	0	0	0	0	0	0	0	0
Morocco	0	0	0	0	0	0	0	0	0	0	0
Tunisia	0	0	0	0	0	0	0	0	0	0	0
Nigeria	97	11	0	0	0	0	0	0	0	0	0
Senegal	92	81	71	57	46	36	27	18	13	6	0
Madagascar	218	191	164	151	126	101	80	62	49	33	22
Malawi	0	0	0	0	0	0	0	0	0	0	0
Mozambique	141	98	68	42	26	9	0	0	0	0	0
Tanzania	549	433	324	222	135	72	29	0	0	0	0
Uganda	282	211	151	110	74	44	26	8	0	0	0
Zambia	11	6	1	0	0	0	0	0	0	0	0
Zimbabwe	19	15	10	6	1	0	0	0	0	0	0

Appendix Table B4. TFP-induced Food Distribution Gap, by Country, 2012-2022 (thousand tons).

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Asian Countries	**98**	**164**	**123**	**104**	**84**	**71**	**61**	**50**	**34**	**1**	**0**
Cambodia	0	0	0	0	0	0	0	0	0	0	0
Laos	0	0	0	0	0	0	0	0	0	0	0
Philippines	91	144	123	104	84	71	61	50	34	1	0
Vietnam	0	0	0	0	0	0	0	0	0	0	0
Bangladesh	0	18	0	0	0	0	0	0	0	0	0
Pakistan	0	0	0	0	0	0	0	0	0	0	0
Sri Lanka	0	0	0	0	0	0	0	0	0	0	0
Kyrgyzstan	7	1.73	0	0	0	0	0	0	0	0	0
Armenia	0	0	0	0	0	0	0	0	0	0	0
Azerbaijan	0	0	0	0	0	0	0	0	0	0	0
Georgia	0	0	0	0	0	0	0	0	0	0	0
Latin American Countries	**544**	**478**	**384**	**309**	**246**	**188**	**136**	**100**	**76**	**53**	**32**
Bolivia	130	109	87	72	59	46	39	32	25	17	9
Colombia	66	86	69	52	36	20	4	0	0	0	0
Ecuador	128	90	58	37	25	16	6	0	0	0	0
Peru	0	0	0	0	0	0	0	0	0	0	0
Guatemala	218	193	170	148	126	106	87	68	51	36	23
Nicaragua	2	0	0	0	0	0	0	0	0	0	0
African Countries	**1,342**	**1,069**	**826**	**609**	**418**	**270**	**155**	**76**	**38**	**17**	**1**
Egypt	0	0	0	0	0	0	0	0	0	0	0
Morocco	0	0	0	0	0	0	0	0	0	0	0
Tunisia	0	0	0	0	0	0	0	0	0	0	0
Nigeria	10	0	0	0	0	0	0	0	0	0	0
Senegal	93	85	77	66	55	42	30	18	10	2	0
Madagascar	204	164	126	92	62	40	21	7	0	0	0
Malawi	0	0	0	0	0	0	0	0	0	0	0
Mozambique	154	119	91	70	48	35	23	9	0	0	0
Tanzania	542	421	309	207	120	55	14	0	0	0	0
Uganda	307	255	202	155	117	86	61	42	28	15	1
Zambia	9	3	0	0	0	0	0	0	0	0	0
Zimbabwe	23	22	21	19	16	12	6	0	0	0	0

Appendix C. Value-added TFP-induced GTAP Production and Trade Estimates

Appendix Table C1. TFP-induced Average Production and Trade Growth Rates, 2012-2022.

	Grains			Roots & Tubers			Horticultural & Livestock Products		
	Production	Imports	Exports	Production	Imports	Exports	Production	Imports	Exports
Industrialized Countries	**3.4%**	**1.4%**	**4.0%**	**2.1%**	**2.0%**	**6.3%**	**2.3%**	**1.6%**	**4.7%**
Australia	1.6%	5.5%	1.9%	1.0%	4.4%	0.7%	-0.3%	13.6%	-12.9%
Japan	3.7%	-7.4%	38.9%	0.7%	-2.6%	13.3%	0.8%	-1.5%	11.7%
USA	3.8%	4.8%	3.1%	2.5%	2.0%	5.8%	2.1%	2.7%	4.0%
EU	3.3%	3.0%	4.7%	2.1%	0.3%	3.6%	2.7%	1.5%	5.5%
Emerging Countries	**5.2%**	**5.0%**	**9.1%**	**4.9%**	**8.1%**	**-0.8%**	**4.6%**	**8.6%**	**2.2%**
China	6.1%	9.4%	-1.9%	5.3%	11.5%	-3.1%	5.4%	9.2%	-1.2%
India	4.0%	1.0%	10.9%	3.4%	4.7%	0.6%	3.7%	6.3%	4.3%
Indonesia	4.1%	5.1%	4.8%	3.8%	6.3%	-0.5%	5.2%	5.6%	2.5%
Brazil	5.8%	1.1%	10.4%	3.8%	1.8%	2.3%	2.9%	4.3%	2.3%
Asian Countries	**3.1%**	**4.3%**	**4.5%**	**2.7%**	**4.2%**	**1.4%**	**3.2%**	**6.4%**	**14.4%**
Cambodia	4.2%	-3.3%	17.4%	5.0%	2.8%	10.4%	4.5%	3.4%	4.8%
Laos	3.2%	38.0%	-27.4%	3.7%	19.2%	-22.5%	-8.4%	27.3%	-49.1%
Philippines	1.9%	4.0%	-0.1%	2.8%	4.7%	0.2%	1.3%	2.9%	2.0%
Vietnam	3.8%	3.9%	4.6%	2.7%	3.8%	3.0%	4.0%	5.7%	4.1%
Bangladesh	3.6%	-0.6%	19.3%	3.5%	0.4%	5.7%	6.1%	3.6%	12.9%
Pakistan	3.1%	5.4%	3.9%	2.4%	7.3%	-5.3%	6.5%	-4.1%	23.8%
Sri Lanka	1.7%	1.5%	9.0%	1.6%	1.7%	1.0%	5.0%	-1.9%	16.7%
Kyrgyzstan	0.7%	2.9%	-2.1%	2.2%	4.5%	-6.0%	-1.0%	12.9%	-17.0%
Armenia	5.9%	-2.4%	19.2%	3.6%	-1.3%	14.7%	4.8%	0.1%	13.8%
Azerbaijan	-0.9%	9.2%	-12.8%	3.1%	12.9%	-11.9%	-3.2%	16.6%	-28.7%
Georgia	-1.7%	2.4%	-7.5%	-0.6%	4.2%	-8.2%	-0.9%	6.8%	-7.3%

Appendix Table C1. TFP-induced Average Production and Trade Growth Rates, 2012-2022, Continued.

	Grains			Roots & Tubers			Horticultural & Livestock Products		
	Production	Imports	Exports	Production	Imports	Exports	Production	Imports	Exports
Latin American Countries	**3.9%**	**5.2%**	**7.3%**	**2.8%**	**5.7%**	**-0.9%**	**4.2%**	**10.3%**	**1.9%**
Bolivia	1.5%	13.9%	-12.6%	2.0%	15.2%	-19.5%	4.7%	13.5%	-2.3%
Columbia	4.1%	2.9%	7.5%	2.2%	1.3%	1.4%	3.3%	7.4%	-1.4%
Ecuador	4.6%	1.9%	10.0%	3.6%	3.5%	2.7%	5.0%	6.1%	2.0%
Peru	3.6%	8.8%	-6.7%	3.6%	9.4%	-5.7%	5.3%	18.1%	-12.7%
Guatemala	4.1%	2.9%	6.1%	3.1%	4.7%	1.7%	4.2%	4.3%	3.6%
Nicaragua	4.2%	0.4%	12.0%	2.7%	0.8%	6.4%	6.1%	-1.2%	10.2%
African Countries	**3.5%**	**8.7%**	**10.1%**	**5.5%**	**12.9%**	**0.5%**	**8.5%**	**9.1%**	**29.6%**
Egypt	6.2%	3.1%	11.6%	4.4%	5.5%	4.8%	10.1%	0.5%	29.8%
Morocco	5.4%	-1.7%	18.0%	4.1%	1.6%	5.9%	12.4%	-7.2%	36.3%
Tunisia	4.6%	1.4%	11.0%	3.7%	4.7%	5.9%	3.9%	5.7%	5.1%
Nigeria	0.1%	19.0%	-21.5%	5.7%	22.9%	-23.3%	-8.1%	15.7%	-31.2%
Senegal	5.2%	1.8%	14.4%	3.1%	3.7%	3.6%	2.2%	6.2%	3.4%
Madagascar	5.1%	2.9%	10.4%	2.9%	5.8%	-2.4%	4.5%	16.2%	-14.8%
Malawi	3.7%	4.1%	4.8%	2.7%	6.7%	-1.0%	6.8%	10.0%	2.0%
Mozambique	1.7%	8.9%	-5.2%	4.1%	12.1%	-7.4%	-1.1%	15.0%	-22.1%
Tanzania	4.8%	12.6%	-8.8%	5.3%	17.4%	-12.1%	9.8%	10.3%	5.9%
Uganda	1.8%	7.8%	-4.3%	4.5%	11.1%	-9.3%	5.0%	19.1%	-18.6%
Zambia	5.2%	6.6%	4.8%	4.4%	8.6%	-6.9%	4.7%	19.0%	-18.8%
Zimbabwe	1.8%	6.1%	-2.3%	0.7%	7.4%	-5.1%	6.5%	14.3%	-3.0%

Appendix Table C2. TFP-induced Average Annual Changes in Production and Trade Growth Rates, 2012-2022.

	Grains			Roots & Tubers			Horticultural & Livestock Products		
	Production	Imports	Exports	Production	Imports	Exports	Production	Imports	Exports
Industrialized Countries	**-7%**	**8%**	**-16%**	**4%**	**1%**	**-17%**	**4%**	**14%**	**0%**
Australia	-42%	42%	-104%	-10%	34%	-59%	6%	149%	-197%
Japan	14%	-32%	-126%	-2%	12%	-36%	-14%	10%	-99%
USA	-17%	23%	-35%	2%	-2%	-4%	1%	29%	-62%
EU	1%	-4%	4%	5%	3%	7%	7%	5%	9%
Emerging Countries	**5%**	**-6%**	**-16%**	**1%**	**-9%**	**47%**	**6%**	**-128%**	**-99%**
China	5%	-121%	189%	-2%	-80%	126%	15%	-161%	263%
India	3%	22%	-39%	1%	33%	-49%	0%	43%	-63%
Indonesia	6%	23%	-93%	10%	58%	-52%	7%	45%	-74%
Brazil	-13%	38%	-74%	0%	20%	-11%	-19%	79%	-132%
Asian Countries	**0%**	**2%**	**-11%**	**3%**	**13%**	**13%**	**4%**	**11%**	**-53%**
Cambodia	13%	-4%	-5%	7%	9%	-55%	10%	-2%	18%
Laos	-19%	-24%	13%	5%	-15%	-1%	-126%	-219%	33%
Philippines	11%	-35%	84%	3%	-1%	37%	0%	-13%	29%
Vietnam	2%	5%	7%	1%	-5%	9%	-19%	4%	-118%
Bangladesh	-1%	-13%	-7%	0%	-4%	1%	-23%	23%	-174%
Pakistan	-8%	30%	-48%	5%	32%	-48%	15%	74%	-188%
Sri Lanka	1%	11%	-73%	3%	19%	-31%	-26%	71%	-216%
Kyrgyzstan	-53%	73%	-227%	5%	159%	-180%	-28%	189%	-294%
Armenia	-7%	78%	-193%	12%	82%	-127%	20%	112%	-207%
Azerbaijan	24%	-97%	201%	-5%	-115%	127%	8%	-219%	274%
Georgia	-40%	24%	-12%	-11%	-18%	-57%	-26%	106%	-259%

Appendix Table C2. TFP-induced Average Annual Changes in Production and Trade Growth Rates, 2012-2022, Continued.

	Grains			Roots & Tubers			Horticultural & Livestock Products		
	Production	Imports	Exports	Production	Imports	Exports	Production	Imports	Exports
Latin American Countries	**-13%**	**58%**	**-17%**	**6%**	**91%**	**-54%**	**5%**	**204%**	**-115%**
Bolivia	-10%	215%	-264%	18%	175%	-247%	28%	290%	-152%
Colombia	12%	-21%	56%	4%	-15%	34%	3%	-57%	77%
Ecuador	4%	-6%	-5%	3%	-5%	6%	-6%	-40%	44%
Peru	-48%	147%	-284%	3%	180%	-227%	9%	442%	-557%
Guatemala	3%	15%	-73%	3%	28%	-40%	8%	46%	-92%
Nicaragua	-3%	-9%	-51%	0%	11%	-27%	-52%	61%	-133%
African Countries	**13%**	**-32%**	**-63%**	**-9%**	**55%**	**-15%**	**53%**	**-9%**	**-92%**
Egypt	-13%	13%	-82%	-2%	20%	-53%	42%	6%	-92%
Morocco	-7%	64%	-161%	-12%	63%	-65%	93%	94%	-182%
Tunisia	17%	-14%	47%	5%	-13%	64%	2%	-14%	37%
Nigeria	52%	-306%	386%	-12%	-198%	228%	93%	-184%	355%
Senegal	-13%	38%	-162%	-6%	55%	-74%	-27%	100%	-213%
Madagascar	13%	-62%	133%	20%	-25%	51%	-6%	-17%	20%
Malawi	11%	21%	68%	-3%	17%	9%	-13%	13%	2%
Mozambique	-19%	51%	-69%	11%	85%	-99%	-67%	41%	-122%
Tanzania	7%	166%	-240%	15%	133%	-186%	25%	258%	-329%
Uganda	-13%	19%	-63%	-4%	51%	-92%	-18%	78%	-125%
Zambia	6%	145%	-127%	12%	134%	-180%	-5%	246%	-319%
Zimbabwe	24%	55%	-59%	42%	86%	-15%	93%	222%	-66%

Endnotes

[1] A separate GTAP category including oilseeds, sugarcane, and fibers was omitted from the analysis.

[2] The model further accounts for total food aid (cereal and non-cereal food commodities), information obtained from the World Food Program (WFP).

[3] The method is similar to that used by Shlomo Reutlinger and Marcelo Selowsky in "Malnutrition and Poverty," World Bank, 1978.

[4] The grain production and import growth rates presented in this paragraph are unpublished, but available upon request.