Examining Links Between Total Factor Productivity Growth and National Food Supplies: Are there Implications for Food Security and Self-Sufficiency?

by

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Abstract

Total factor productivity (TFP) measures the ratio of aggregate inputs used in agricultural production to agricultural outputs. Given concerns related to food security, including inequality in food access and disparities in food self-sufficiency potential among nations, my research seeks to address whether TFP, an economic measure, can have a more "humanized" dimension through its relationship with food availability. Drawing from national statistics on food production and trade for 48 food items from 1961 to 2013 for 131 countries, I analyze trends in indices of food supply per capita and food self sufficiency and compare these to TFP growth trends to investigate linkages between TFP and food availability. I find that TFP growth shows the closest associations with specific food items, especially animal products. Although my findings suggest that TFP growth may help to maintain self-sufficiency levels in some countries, many high-income countries are moving away from self-sufficiency despite steady TFP growth. Further research is needed to investigate the statistical relationship between these variables based on time-series analysis, including the specific mechanisms that may underpin these associations.

Chapter 1: Introduction

In the context of population increase, shifting diets, and climate change, the rate of change in global food production is under an increased level of scrutiny. In order to match changing demand and address under nutrition, calorie production may need to double by 2050 over levels in the 2000s (Tilman et al., 2011), and sustainable intensification is considered a possible strategy for achieving this while avoiding additional land clearing (Godfray et al., 2010). Plateauing yields on the world's most productive land (Ray et al., 2013) indicate that agricultural expansion on a scale large enough to meet increasing food demand is both an unlikely and unsustainable solution (MacDonald, 2013). Complicating this situation, climate change and rising land scarcity further limit the possibility of agricultural land expansion (Lambin and Meyfroidt, 2011). Beyond the discussion of yields, changing global diets imply a shift in the makeup of global agricultural production, especially towards animal agriculture. Current patterns of yield growth are insufficient to meet this demand (Ray et al., 2013), indicating that productivity must be considered in any analysis of global food supply.

Agricultural total factor productivity (TFP) measures the ratio of aggregate inputs of land, labor, capital, and material resources used in production to output (Fuglie, 2015). This metric uses market value to capture the efficiency with which these inputs are combined to produce output, where TFP growth occurs when outputs change faster than inputs. Growth in TFP has emerged as the clear driving force behind global growth in agricultural output since the Green Revolution: TFP has accounted for 40% of total agricultural output growth, and has overtaken input intensification as the key factor driving output growth since the 1980s (Fuglie and Wang, 2012: 3). The majority of TFP studies suggest that there is large variation in TFP growth within developing countries, even though the rate has risen overall since the 1980s (Fuglie and Wang, 2012). Regional disparities suggest that investment in productivity growth may follow patterns of economic development that already complicate food access.

Complementing the role of productivity growth in sustaining global food supply, global food trade is increasingly seen as a way to overcome country-level inequalities in resource endowment to account for gaps in yields and productivity (i.e Porkka et al., 2013). More than 20% of global calorie production is traded (FAOSTAT, 2013), and 80% of the world's population lives in a country which imports more calories than they export (Porkka et al., 2013:

e82714). Import dependence, however, raises concerns of system resilience and susceptibility to climate and trade shocks (Agarwal, 2014; D'Odorico et al., 2019). Increasingly, global land use patterns indicate an increased focus of global agriculture towards a globalized food trade system, with 13% of global agricultural land allocated to exported commodities (MacDonald et al., 2015: 278). The relationship between productivity growth, trade, and increased food security is clearly defined. For example, Benton and Bailey (2019) identify a joint investment in productivity growth and international trade liberalization throughout the second half of the 20th century, which has led to an increase in food availability worldwide. Given the rise of export-oriented agriculture, it is critical to reflect on the potential for food self-sufficiency and examine its relationship with productivity gains.

1.1: Research Objectives

My overarching aim in this thesis is to investigate whether or not there are links between productivity growth and national level food supply, including food self-sufficiency, across countries over time. By decomposing trends for key food items, I identify an opportunity to understand where productivity gains are allocated in a country's food supply, and whether they contribute to a wide range of nutritional and self-sufficiency considerations.

Complementary to the shifting composition of global agriculture is the well-defined link between diets, health, and environment (Tilman and Clark, 2014). While incidences of hunger and underweight are decreasing worldwide, malnutrition, in all forms is increasing, notably undernourishment, micronutrient deficiencies, and obesity (West et al., 2014; FAO, 2019). From both a health and economic standpoint, current diet trends do not align with the priorities of global agriculture: health costs from poor diet are estimated to be 5% of global GDP, while the added value of global agricultural production is only 3.79% (FAO, 2013: 5). This paradox indicates the need for better integration of food security and agricultural priorities. A shift to healthy diets derived from sustainable food systems is crucial to fulfilling global climate targets (Willet et al., 2019). Given this close relationship between diet, agriculture, and sustainability, I therefore hope to shed light on whether agricultural productivity growth as represented in national TFP indices targets these crucial aspects of the food system. To do so, I focus on simple food systems indicators: national food supplies and national food self-sufficiency.

Current dietary trends themselves limit efficiencies in the global production system. With rising incomes, populations spend less on cereals and more on animal products, refocusing the resource and land requirements for global food production (Delgado, 2003). The shift towards animal agriculture, for example, increases demand for external land and water resources (MacDonald et al., 2015), resulting in increased trade linkages to meet dietary requirements. Acosta and Santos-Montero (2019) find different levels of productivity for ruminants, monogastrics, and plants, indicating that TFP gains may not be evenly allocated across these different components of the food supply. Accordingly, the allocation of more land and resources to animal feed, as well as competing non-food crops such as biofuels, imply that advances in production quantity may not translate directly to increased food availability on a caloric basis (Cassidy et al., 2013). Based on the tenuous relationship between raw agricultural production and how it translates into the food supply, I hypothesize that TFP growth may not always lead to increases in nutritious foods or enhanced self-sufficiency levels due to these production inefficiencies (i.e. growing food crops for non-feed uses or growing luxury crops with low nutritional value).

Because my analysis takes a broad perspective on food security via caloric and quantity values of food supply, it is important to note that these metrics alone only address one pillar of food security: availability. Several considerations arise, notably when comparing caloric and monetary values. MacDonald et al. (2015) find that different metrics for agricultural trade tell different stories of its role in global food availability. Wheat, soybean, and maize, for example, make up half of global caloric trade but only 21% of the monetary value (MacDonald et al., 2015: 277). Even converting mass to dietary energy, which will be performed in my analysis, provides a more nuanced understanding of the role of trade in food security (D'Odorico et al., 2014). The EAT-Lancet Commission recommends that food production systems should reorient their priorities from quantity to health, suggesting that an analysis focused on calories alone may perpetuate a misunderstanding of the actual food security situation (Wilet et al., 2019). In order to not equate food supply with food security, I utilize the concepts of food self-sufficiency and food inequality, and I outline contrasting viewpoints on both trade and productivity growth in circumventing inequalities in global resource allocation.

Many TFP studies indicate that there is large variation in TFP growth within developing countries, even though the rate has risen overall since the 1980s (Fuglie, 2015). Another benefit of my analysis is therefore its global scope. In-depth TFP studies often focus on high-income countries due to data availability (Fuglie and Wang, 2012), indicating the need for further global analysis of TFP growth across income levels. This unequal distribution of advancements presents an avenue for analysis in the context of food availability and access across income levels and geographic regions. I anticipate the relationship between TFP and improved self-sufficiency over time will be most apparent in countries that are major food producers, given their capacity to adopt and invest in productivity strategies. I further hypothesize that the reorientation of global agriculture towards international trade will imply that advances in TFP growth are closely linked with integration into global networks of agricultural trade.

1.2: Thesis Structure

In this thesis, I first introduce the concepts of food inequality and self-sufficiency to develop a conceptual framework linking productivity growth and the composition and source of national-level food supply, and understanding the implications of inequalities in regional patterns of TFP growth. In my methodology, I continue with a discussion of my data sources and the transformations undertaken to create comparable indexes of productivity growth, food supply, and food self-sufficiency ratio (SSR). I then compare relationships between TFP growth and the composition of total food supply over time, and TFP growth and self-sufficiency status, through the use of visual analysis with index plots. I then use these two avenues of analysis to discuss the dynamic relationship between productivity growth and food production. Specifically, I examine how increases in productivity correspond with shifts in the quantity and composition of food supply on the national level. By juxtaposing these trends with those in self-sufficiency status, this analysis will shed light on the applicability of TFP growth to both food supply and integration in global food trade. I identify the implications for a "humanization" of this economic measure, focusing on relevance to food supply over economy, by investigating the allocation of productivity growth within metrics relevant to food security.

Chapter 2: Conceptual Framework

2.1: Total Factor Productivity Growth

Rather than simply analyzing actual TFP values at a point in time, much research focuses on TFP *growth* as an important metric for productivity trends. For example, the mechanisms behind TFP growth could be important for understanding food and agricultural system sustainability and resilience (Coomes et al., 2019). As an aggregate measure, TFP is stronger than single factor productivity in separating the effects of technical change and intensified use of certain inputs. As such, TFP "is a better indicator of technical or efficiency improvements and more closely associated with changes in production costs" (Fuglie, 2015: 200). However, this broad scope implies that "it will tend to reflect not just pure technical change but also economies of scale, improvements in technical and allocative efficiency, and changes in the quality of natural resources like soil, water and climate" (Fuglie, 2015: 200). This implies that TFP is especially sensitive to resource degradation, an important consideration in any analysis of agricultural production in the context of climate change (Fuglie, 2015). Positive TFP growth may indicate that the associated technological and management strategies can overcome the resulting natural resource degradation of increasingly-intensive agriculture or may indicate that shifts in management practices have promoted more efficient use of natural resources (Coomes et al., 2019; Fuglie et al., 2020). TFP growth emerges as a telling metric of the future of food production.

2.2: Considerations in TFP Research

When examining TFP growth, several elements are not explicitly considered or captured. The role of ecosystem services and other forms of natural capital are typically left out of standard TFP calculations because they are not "marketed" (Coomes et al., 2019). TFP accounting also neglects negative environmental externalities, such as greenhouse gas emissions and biodiversity loss (Fuglie et al., 2019). Although global-scale studies of TFP attempt to draw patterns of TFP growth across income levels, investigating the overall rate of TFP growth does not imply anything about the actual drivers of the growth (Fuglie, 2015; Coomes et al., 2019). Without a full understanding of the drivers of TFP growth, it is difficult to pinpoint specific local conditions that facilitate or hinder productivity.

However, the critique most relevant to my research is the lack of a food or nutritional indicator that links TFP growth with food security. TFP is a decidedly economic measure, focusing on monetary value, and previous productivity research also calls for a more human-centric approach to this distinctly economic metric. Coomes et al. (2019) recognize the need to look beyond a simple economic perspective in TFP research, with TFP gains weighed "against societal consideration of the broader value for ecosystem services, biodiversity, food security and social equity" (Coomes et al., 2019: 27). Benton and Bailey (2019) call to refocus from the measure of yields per unit to the number of people that can be fed on this unit area, using food supply as a humanization of TFP growth metrics. To contextualize the complementary roles of TFP and import dependence within a discussion of food security, I draw on the concepts of food inequality and food self-sufficiency.

2.3: Food Self-Sufficiency

While TFP is celebrated for its contribution to global food security, the strengthening of trade networks is also considered a crucial element in increasing food availability. In this context, a country's trade situation is evaluated through the consideration of food self-sufficiency and its converse, import dependency. Clapp (2017) defines food self-sufficiency as domestic production of 100% or more of domestic food consumption. Like TFP growth, it limits a food system's vulnerability by removing it from the liabilities of the global trade system (Carr, 2017). While food security does not differentiate between imported and domestically produced food, food self-sufficiency focuses on the availability dimension of food security and considers the supply (Clapp, 2017). For this key difference, I use the Self-Sufficiency Ratio (SSR, as defined by the Food and Agriculture Organization of the United Nations (FAO)) to examine the interaction between TFP and domestic food supply. The SSR considers a country's production, import, and export values, in one crop or a group of crops, to weigh the magnitude of production against domestic utilization (FAO, 2001).

The complementary concept of food sovereignty weighs the advantages of self-sufficiency over import dependence. Over the past two decades, the definition of food sovereignty has shifted its focus from the "right of self-reliance of nations ...to the rights of people to define domestic production and trade, as well as determine the extent to which they want to be self-reliant" (Agarwal, 2014: 1248). The scale has also shifted increasingly from national to local, recognizing within country inequalities in food availability that self-sufficiency itself may not capture (Clapp, 2017).

It is important to note that a country labeled "self-sufficient" by the SSR and DEP may still engage in trade as an exporter and importer, as this is ultimately a theoretical concept. Indeed, Agarwal (2014) acknowledges that trade cannot be entirely eliminated due to biophysical resource constraints, and that the potential for self-sufficiency is more reliant on a country's domestic capacity for food production rather than a complete rejection of food trade. Highlighting the complementary relationship between dietary energy production and food supply, Porkka et al. (2013) presume that recent yield gains have first been allocated towards domestic food supply, and secondarily for export. However, this does not imply a departure from engaging in trade: between 1965 and 2005, the majority of countries increased their production, while the proportion of the global population living in import-dependent countries remained consistent (Porkka et al., 2013). The use of food imports does not imply food scarcity either, and any analysis that links food insecurity and local limits to growth must identify where scarcity is and isn't the limiting factor in food security challenges (Porkka et al., 2017). The rhetoric of rights and resilience in the discussion of food self-sufficiency and sovereignty highlight its role determining its own food-security future without the influence of the manufactured inequalities in the global system.

2.4: Food Insecurity and Food Inequality

The FAO identifies 4 pillars of food security: physical availability of food, economic and physical access to food, food utilization, and stability of these three dimensions over time. In order to be considered food secure, the population in question must fulfill all four criteria simultaneously (FAO, 2008). Two separate types of food insecurity are defined based on time: chronic and transitory.

The idea of food inequality effectively links the access dimension of food supply with the availability dimension, lending a more comprehensive understanding of the implications of this analysis for food security. The foundations of food (in)equality presented by D'Odorico et al. (2019) restate the view that access to food is considered a human right. Enough food is produced to fulfill this right, however, availability and access are limited through policy decisions and economic constraints. While other human rights cannot be traded, alienated, or sold, food can because it is a commodity (D'Odorico et al., 2019). Access is thereby inhibited through an unjust distribution of food, despite perceived availability from simple food supply indicators, which have universally increased for most countries over time.

2.5: Food Inequality and Biophysical Limitations

D'Odorico et al. (2019) measure how inequality in food availability may arise through the discussion of natural resource endowments available within a country for food production. Uneven resource endowments are key in understanding patterns of import dependence and reduced self-sufficiency. Fader et al. (2013) identify two groups amongst trade-dependant regions. One, with countries mainly in the Andean and Scandinavian region, has reasons outside of resource limits for trade dependency, and could be producing sufficient food to meet its consumption with economic and trade policy changes. The second, largely in North Africa and the Arabian Peninsula, is confined to import dependent by its natural resources and thus has less available policy options when it comes to decreasing reliance on external food trade. For countries approaching their resource boundary, the decision to move towards productivity growth or to increase import dependence, moving away from self-sufficiency, is less a choice than a necessity.

Overall, Fader et al. (2013: 7) found that 66 countries cannot reach food self-sufficiency due to land and water constraints, indicating that their population and consumption patterns force a reliance on trade at current productivity levels). Through these networks, these countries rely on ex-situ land and water resources, embodied in traded agricultural commodities, to meet their food production requirements (Fader et al., 2013). Similar to D'Odorico's examination of the biophysical resource endowment, the natural resource boundary is defined as the land and water available as inputs in food production. Local limitations can be overcome by including land and water resources abroad, outside the scope of domestic agricultural production (Fader et al., 2013; Porkka et al., 2017). From this perspective, import dependence overcomes unjust distribution of resources by substituting one countries' capacity for production with another's.

2.6: Inequality in Global Food Trade

Understanding the biophysical limitations at the level of agricultural production uncovers how much of this inequality is manufactured by socio-economic development and trade. Indeed, perceptions of scarcity and socio-cultural institutions may construct an alternative, culturally influenced carrying capacity that determines food availability beyond biophysical constraints (Porkka et al., 2017). As such, the availability dimension in the context of global food trade is either limited or strengthened based on the access dimension manufactured by trade policies. D'Odorico et al. (2019) identify international food trade as essential to remedying unequal food availability due to natural resource endowments. When trade is accounted for in calculations of food supply distribution, metrics indicating food inequality all but disappear (Carr et al., 2016). Even so, production patterns themselves are heavily influenced by trade policies, encouraging production in exporting countries and limiting it in areas where small farmers cannot match international competitors (D'Odorico et al., 2019). By restricting the productivity of one region at the expense of another, dynamics of food access inequality are further entrenched (Stevens et al., 2003).

Along with the assumption of reducing inequalities, the increased globalization of food trade is accompanied by the goal of increasing system efficiency. Examining globalized patterns of land use, Lambin and Meyfroidt (2011) explore the potential for system efficiency achieved through globalized trade linkage. From a land use perspective, the outsourcing of food production implies that it will be undertaken by areas with higher productivity (Kastner et al., 2014). Even so, the expropriation of land and resources abroad may lead to improvements in food supply in the receiving country, but do not guarantee that could be used to improve food security in the sending country. Furthermore, trade flows do not always occur in the 'correct' direction (Carr et al., 2016). By overcoming unequal distribution of biophysical resources through trade, we see the appearance of global manufactured inequalities with regards to who advances in food production benefit.

The concentration of productivity growth in certain countries may ultimately benefit global rather than domestic consumers. At the subnational scale, TFP growth is often most evident in regions with export-oriented agriculture, such as Brazil's main soy producing regions and palm oil plantations in Indonesia (Fuglie and Wang, 2012). The intensification strategies of the green revolution, conversely, targeted domestically consumed staple crops vital to food security, such as rice (Fuglie and Wang, 2012). I identify this as a key consideration in the discussion of TFP and national level food supply: understanding whether TFP advances are suited to countries that are focused on their own domestic food availability or those that are better integrated into global production networks. TFP growth may therefore be more oriented towards a globalized system of agricultural production rather than domestic level food security and self-sufficiency. Regional concentration of food production for export increases the vulnerability of the food system to price shocks as well (Agarwal, 2014). These considerations circle back to the reinforcement of food system inequalities, cancelling out food system resilience brought on by TFP increases.

2.7: Inequality in Access

Tied in to the discussion of these globalized systems is the close relationship between TFP growth and access to resources and investment. Headey et al. (2010) identify distance from the nearest OECD country as the only significant factor in their regression analysis of TFP growth rates. The potential for trade and access to technology and investment that arise with geographic proximity may heighten the incentive to pursue TFP improvements. Hindering the export market with too much focus on food self-sufficiency disincentivizes investments in productivity, especially in developing countries (Clapp, 2017). In other words, countries that are better incorporated into the globalized food trade may have better access to and incentive to adopt strategies facilitating TFP growth.

Accordingly, unequal regional patterns of TFP growth may reflect capacity and willingness to invest in productivity. A common theme that emerges amongst global-scale productivity analyses is the disparity between regions, between developed and developing countries and on a country level. Within low-income countries especially, disparities in the magnitude of growth are evident: China and Brazil are noted for their TFP growth rates double the average for developing countries (Fuglie et al., 2012). Growth in these major producers has accounted for much of the global TFP growth (Headey et al., 2010), skewing TFP growth across the Global South.

2.8: Inequality Across Regions and Income Class

Population growth, another contextual factor in food supply, emerges as a key factor at the intersection of productivity and natural resource endowment. The resource boundary presented by Fader et al. (2013) reflects a population-based limitation more than any other factor, one that could be remedied with marginal increases in productivity (MacDonald, 2013). Situations in which productivity increases fail to ease local food supply challenges occur when they cannot match rates of rapid population growth, even when coupled with trade. In many cases where the implementation of an import strategy failed to take hold, notably in South Asia and Sub-Saharan Africa, the approximated productivity advances could not match population growth (Porkka et al., 2017). Similarly, D'Odorico et al. (2019) find that increases in food supply inequality occur when population growth occurs in a context with low biophysical resource endowment, which provides an insufficient basis to build upon for productivity growth.

When examining the components of TFP growth, Headey et al. (2010) find the largest source of TFP growth is technical, not efficiency, change, indicating that access to research and development, and capital are crucial starting points. Under this assumption, TFP growth that would be able to surpass population pressure and resource boundaries would closely follow income levels. Similarly, Fuglie and Wang (2012) contend that uneven access to resources and technology are the largest challenges to global food supply. Patterns of TFP growth since the green revolution exemplify the importance of investment in agricultural research: China and Brazil make conscious policy and investment decisions, while Sub-Saharan Africa lacks the economic resources to pursue investment in agricultural technology to stimulate comparable growth. This showcases the challenge of measuring productivity growth in the Global South without regard for the large disparity in income level and resources between regions.

This lack of access to food security strategies extends beyond productivity. Import dependence is seen as an option for high-income countries. Developed countries are suited to withstand the price shocks of volatile global markets, while lower income countries could do well to reduce their reliance on global markets, boosting their own resilience (Chang, 2009; Clapp, 2017). Lack of economic development may not allow for an import, productivity, nor expansion strategy, heightening the risk of food insecurity for over a billion people by 2050 (Fader et al., 2013). A country's income level may constrain its strategies to secure food access.

By comparing productivity growth in economic terms to food availability, I seek to 'humanize' the measurement of TFP growth and understand its potential implications for food security. My conceptual framework for this research (Figure 2.8.1) therefore takes into consideration whether TFP growth remedies food inequality or follows global patterns of inequality that continue to limit food availability.

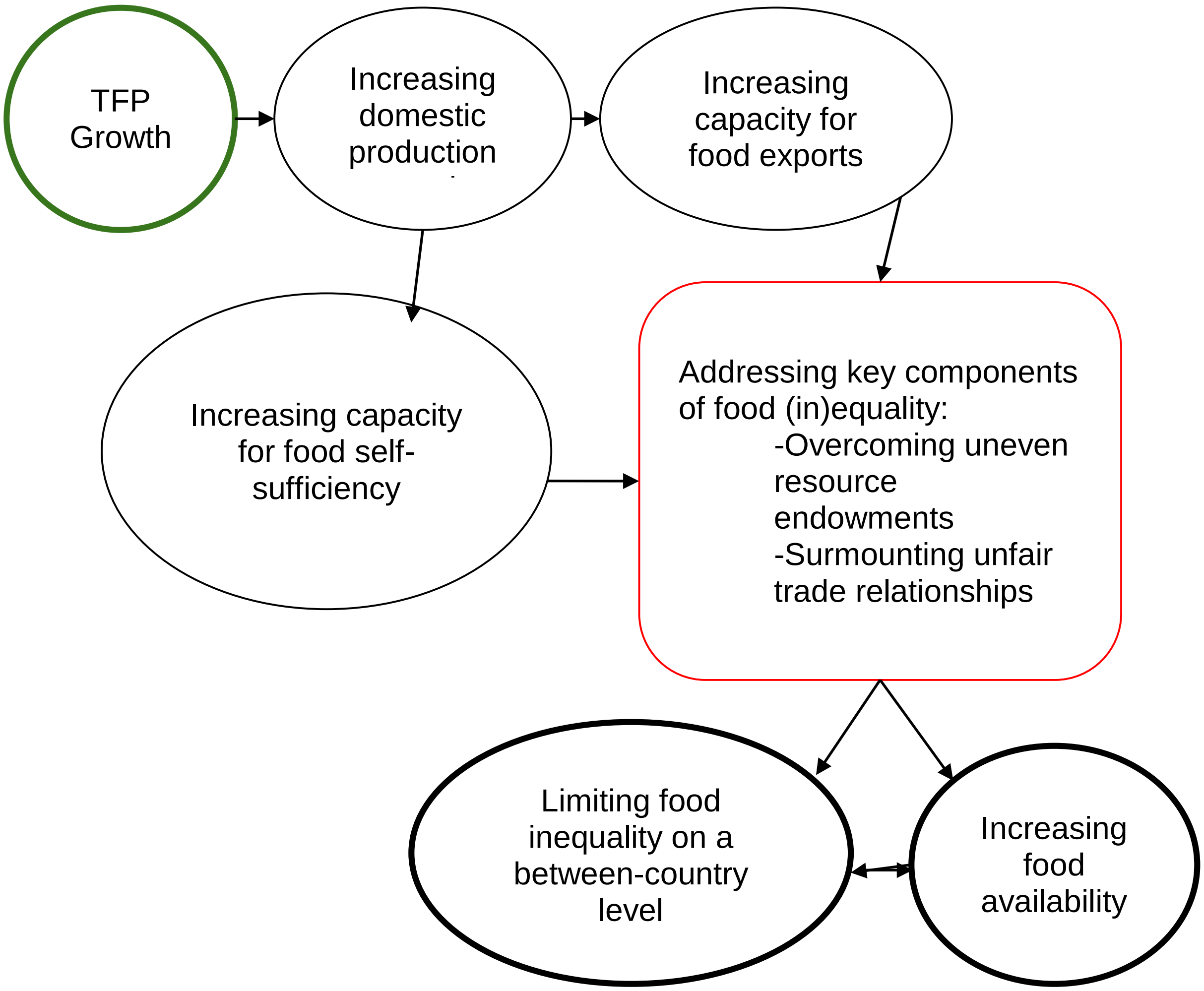


Figure 2.8.1: In my conceptual framework, TFP growth contributes to an increase in domestic production capacity, which increases a country's ability to produce food both for domestic consumption and export. By increasing export capacity and decreasing reliance of food imports, countries are able to enter trade relationships on fairer terms and minimize vulnerability to trade shocks. The interplay with food availability on the country level thus limits inequality in access to food, enabling countries to keep up with population growth and changing patterns in food demand. In this way, TFP growth, focused on economic value, has a humanitarian aspect in addressing the access dimension of food insecurity.

Chapter 3: Methodology

3.1: Data Sources

The TFP growth index data I use here is from the United States Department of Agriculture Economic Research Service (USDA-ERS), which represents an index of continuous TFP values for 172 countries between 1961 and 2015. These were calculated using data from the FAOSTAT database and other national statistical sources, and are index values with a base year of 2005 (i.e. the value of every country in 2005 is 100). I took all region, sub-region, and income class information that was not already included from the World Bank country database. The crop data I use are from the FAOSTAT Food Balance Sheets (FBS) database. These standardized sheets are designed to "illustrate long-term trends in national food supplies", including trade, as well as the national-level characteristics and utilization of both primary and processed commodities (FAO, 2001). The FBS items used in my analysis are: production, imports, exports, and total food supply.

A fair amount of data cleaning was needed to standardize the two major datasets. As the FBS database was only available from 1961 until 2013 at the time of my research, TPF index values from 2014 and 2015 were not considered in my analysis. In order to overcome discrepancies in country labels between the USDA and FAO data, a country "master list" was created, enabling me to join countries across both databases by FAO code. Income classifications, region, and sub-region labels from the TFP dataset were joined with the country master list.

The TFP dataset combines several small island nations into three composite countries: Micronesia, Polynesia, and the Lesser Antilles. As these countries are all small nations in both geographic size and population, I assumed that the TFP growth rates would not vary significantly between the islands. The aggregate TFP index value was inputted for each individual country that had its own FBS table, based on their geographic position in reference to the island group.

For the portion of the analysis comparing total food supply and TFP growth, 151 countries, which had continuous TFP and FBS data, were analysed. For analyses concerning trade and self-sufficiency, only 131 countries were analysed based on data availability for production, import, and export values (Appendix Table 1). Several countries had to be dropped from my analysis due to missing values in either the TFP or FBS datasets. For consistency in my

1961-2013 analysis, the 22 former Soviet Union countries were removed due to the limited data period in the FBS (these were not reported individually before the 1990s), even though several had continuous TFP data from 1961. Although an area of considerable size that limits the geographic scope of this analysis, I decided that the inconsistent time frame would not match the goals of my analysis.

3.2: Total Food Supply Analysis

Although the FBS includes an aggregate total food supply value in calories per capita per day for each country, I decided to recalculate this value using my own selection of 48 food items to provide more nuance (Appendix Table 2). As this analysis is grounded in a food security perspective, I considered the importance of each item in the food supply and its potential relationship with TFP. The calculation of the total food supply value in the FBS is such that food available for consumption is separated from seed, animal feed, waste, and other non-food uses. All twelve seafood and marine products were excluded because TFP calculations do not account for fishing and aquaculture. This may skew the total food supply value for nations that rely on fishing for a large portion of their food supply, or orient production towards fish farming for export. However, including production not considered in TFP would limit the effectiveness of comparing TFP and total food supply growth patterns. As the unit of total food supply is total calories per capita per day, several items were excluded for the total food supply calculation to avoid inflated values. Demerau et al. (2019) find that sugar crops, refined and vegetable oils have exceptionally low vitamin and micronutrient contents despite their high caloric value; I therefore excluded 23 vegetable oils, oil crops, and sugar crops on the basis of high caloric density compared to low nutritional value. Given the call for a more nuanced view of the actual composition of the food supply in global food security literature (e.g., De Fries et al., 2015), I decided the high caloric/low nutrient values of sugars and oil crops could disproportionately affect the question of whether food availability improves with TFP. Finally, 12 other items, including spices, stimulants, and alcohol, were excluded from the total food supply calculation on the basis of their assumed minimal contribution to nutrition and food security (Appendix Table 3).

The remaining 48 food items were divided into *cereals*, *animal products*, and *vegetal products* groupings (Appendix Table 2). The total food supply value was then calculated for these three groups by summing the individual item total food supply values for each year, and these three were summed to get an aggregate total food supply per capita per day value. TFS values were indexed relative to 2005 in order to directly compare with TFP index values. The logic of "growth accounting" focuses on the relative patterns of TFP growth (rather than raw TFP values, providing consistency and comparable across countries (Fuglie, 2019). Comparing indexes examines the speed at which the value is growing in each country, but does not show where the value itself is lower or higher. A similar analysis of yields of staple crops focusing on growth rates is conducted by Ray et al. (2012). Given the vast differences in production capabilities between countries and regions, this ensures the scale of growth would be more evident, without the sheer difference in values distracting from the importance of growth.

3.3: Self-Sufficiency Analysis

In order to analyze the role of TFP in food self-sufficiency, the self-sufficiency ratio (SSR) was calculated for each group of items, including total food supply. The SSR is interpreted as the percentage of food consumed in a country that is produced domestically, in calories, production volume, or monetary value (FAO, 2016). It is calculated using the following formula provided by the FAO:

$$Production\ /\ (Production + Imports - Exports) * 100$$

Production, import, and export values were taken from the FBS in units of 1000 tonnes. Many of the FBS values in production, import, and export categories were 0. As these are measured in units of 1000 tonnes, I assumed these to represent a quantity of especially small size, or nonexistent, rather than missing or inconsistent data. This was done in order to have a continuous SSR ratio throughout the study period with the most data points possible. Calorie conversion factors did not need to be applied because of the nature of the ratio calculation. The SSR values for each year were not converted into index values like the TFS values: since the SSR value is a ratio, the product would be a value relative to itself without the need for further standardization. Index values would also obscure which countries are more self-sufficient than others, which I wanted to consider when examining complimentary patterns of TFP and SSR change.

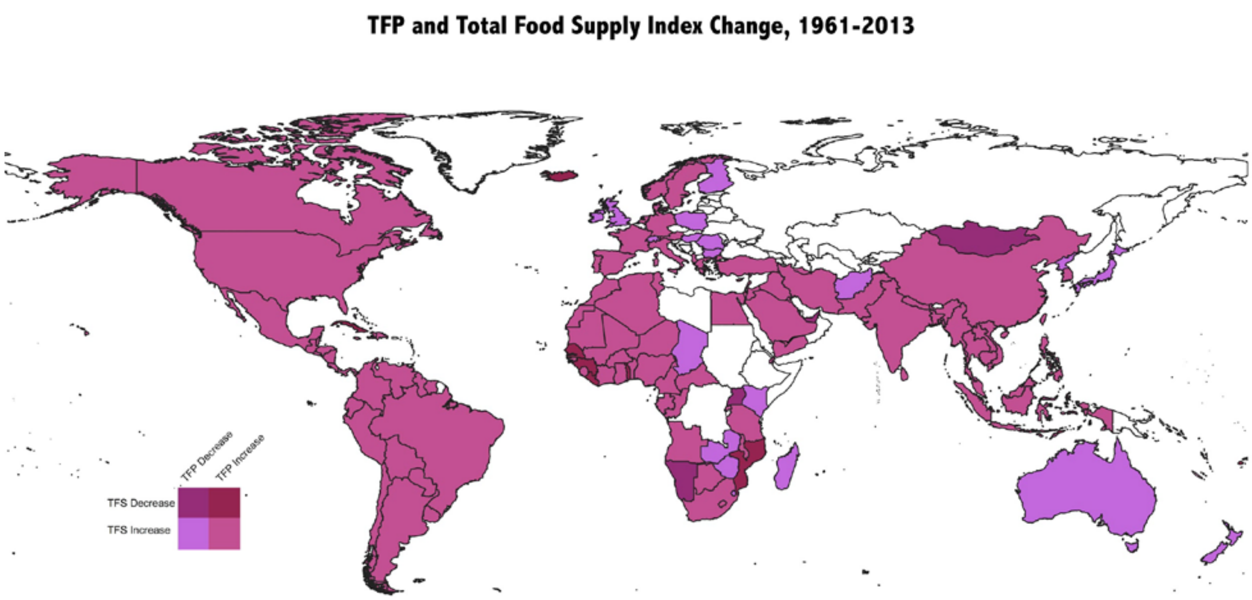
SSR values can become distorted when aggregated across total food supply, since a country that produced a large amount of one crop for export might have a high SSR value despite overall reliance on food imports (FAO, 2012; Clapp, 2017). For more nuance in the self-sufficiency analysis, SSR values were also calculated individually for wheat, maize, rice, and soybean. These four crops make up a significant portion of diet globally and are often analysed separately in self-sufficiency analyses (Clapp, 2017), implying they would be the most intuitive in a comparison of TFP and food security. Ray et al. (2013) also chose to analyze maize, rice, wheat, and soybeans in their analysis of global yield trends, indicating their importance in the realm of global calorie production (approximately 60%).

3.4: Classification and Visual Interpretation of Trends

For exploratory purposes, I classified the countries into 3 sets of quartiles based on TFP, TFS, and SSR change over the study period, serving as a preliminary analysis of patterns across region and income level. I considered formal statistical analysis, such as panel regressions and time series analysis, beyond the scope of this project. In order to visualize trends in TFP growth in relation to TFS and SSR, Index plots were created using the ggplot2 package in R version 3.6.2 (R Core Team, 2019) Various plots were created for each country according to data availability, as some countries with total food supply data did not have enough data to compute and SSR ratio. One set compared TFP index values with those for the four groups of total food supply. I identified patterns in how closely each food category followed the TFP growth rate, and whether the composition of the total food supply changed over the study period. The other set compared trends in TFP and the SSR values for each item category, following the same pattern of visual analysis. Bivariate choropleth maps of TFP and TFS growth and TFP and SSR growth were created using QGIS version 3.4. This style of map was chosen to highlight positive and negative trends in each metric in reference to TFP patterns.

Chapter 4: Relationship between TFP Growth and Total Food Supply

In this chapter, I examine trends in total food supply indices, as well as the components indices of animal products, vegetable products, and cereals. Total food supply values are standardized to daily, per capita values to present a proxy for national diet. I identify those patterns notable for their relationship with patterns of TFP growth. I find that very few countries (noticeably only a few in Sub-Saharan Africa and Northern Asia) had a net decrease in TFS during the study period (Map 4.1). Cereal values, which most closely matched those of TFS, showed the least net change over the study period, and had the least noticeable relationship with TFP change. Most increases in TFP, especially after 2000, were buoyed by increases in animal product index values.



Map 4.1: TFP and Total Food Supply Index Change in 131 countries, 1961-2013

4.1: North America, Europe, and Oceania

Northwest Europe, North America, and Oceania showed negligible change in TFS value despite consistent TFP growth. Some growth appeared when looking at individual components, such as cereals in Norway, Denmark, and Sweden, and vegetables in the United Kingdom, Australia, New Zealand, and Canada. Animal products rose with TFP in every Southern European country except for Malta (Appendix Figure 1). Given that TFS patterns deviated from those of cereal crops, the decrease in cereals did not lead to a decrease in TFS, at least not to the same magnitude. In Transition Europe, TFP did not match patterns in any aspect of food supply: overall TFP growth was negligible and TFS declined in this region. The only transition European country to experience a noticeable spike in TFP, Albania shows the same patterns Southern Europe: consistent TFP growth is associated with the increasing replacement of cereals by animal and vegetable products (Appendix Figure 2).

4.2: Asia

Outside of these regions, I observed the most noticeable association between TFP with the role of animal products in total food supply. In Developed Asia, animal products rise accordingly with TFP, while cereal values fall (Figure 4.2.1). Mainland China shows a different pattern, in which TFS, animal products, and cereal values all rise consistently (Figure 4.2.2).

In Southeast Asia, another especially cereal-dependent region, TFP and TFS indices were largely unrelated. Animal producers were the only group that rose consistently across the region, but only in Myanmar and Laos do we see TFP patterns reflected in these patterns of growth (Appendix Figure 3). Only in the Philippines did cereals and TFS rise alongside TFP (Figure 4.2.3).

In South Asia, animal products matched TFP patterns especially well. In India and Pakistan, TFP patterns aligned with growth in animal products throughout the study period, which is also the case in Bangladesh after 1990. Even so, cereals and TFS did not rise as impressively in this region (Figure 4.2.4). Given the reliance on cereals in food supply, it is possible that TFP growth has done more for secondary crops rather than primary food sources. In this region at least, TFP growth has been accompanied by diversification of food sources, but not necessarily an increase in total food availability.

The extent of TFS value and change in composition in Western Asia was more varied. With the exception of vegetable product index in Iran, Lebanon, Jordan, and Turkey, I observed little overall change in TFS. What change there is was associated with cereals, which do not match TFP at all.

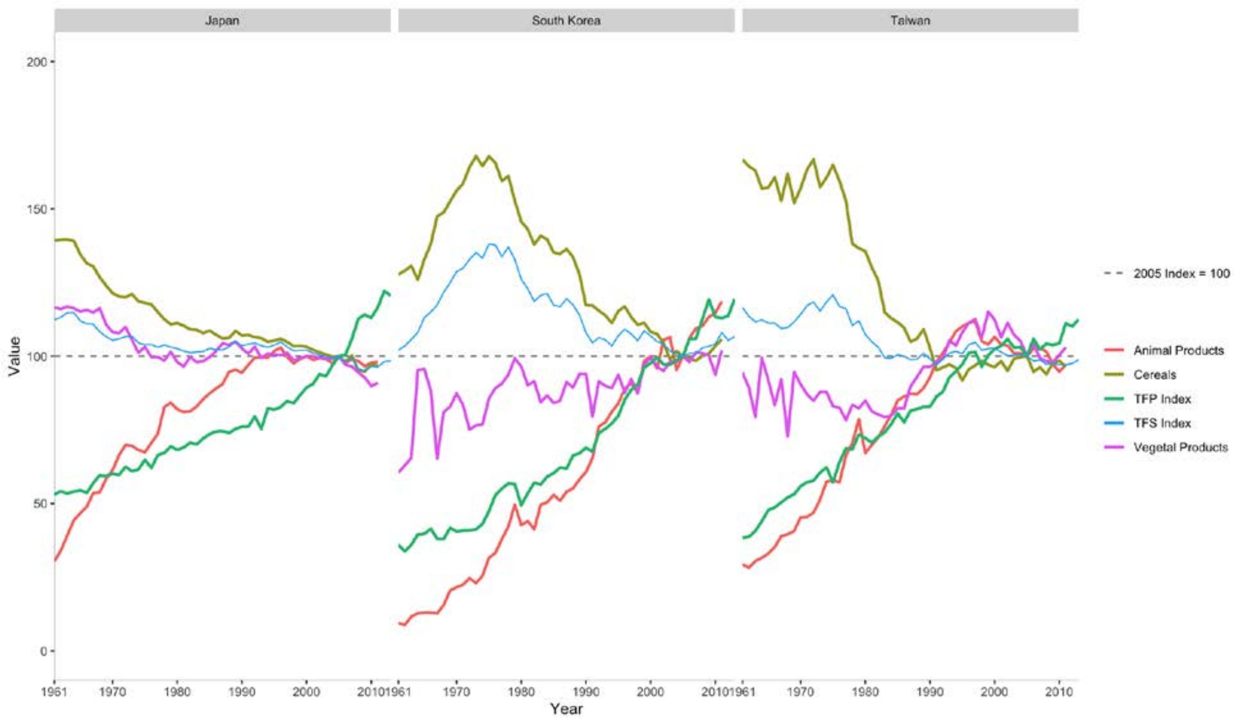


Figure 4.2.1: Shifting composition of total food supply in Developed Asia, showing a tendency away from cereals towards animal products. South Korea and Taiwan experience a small net decrease in TFS, all despite steady TFP growth.

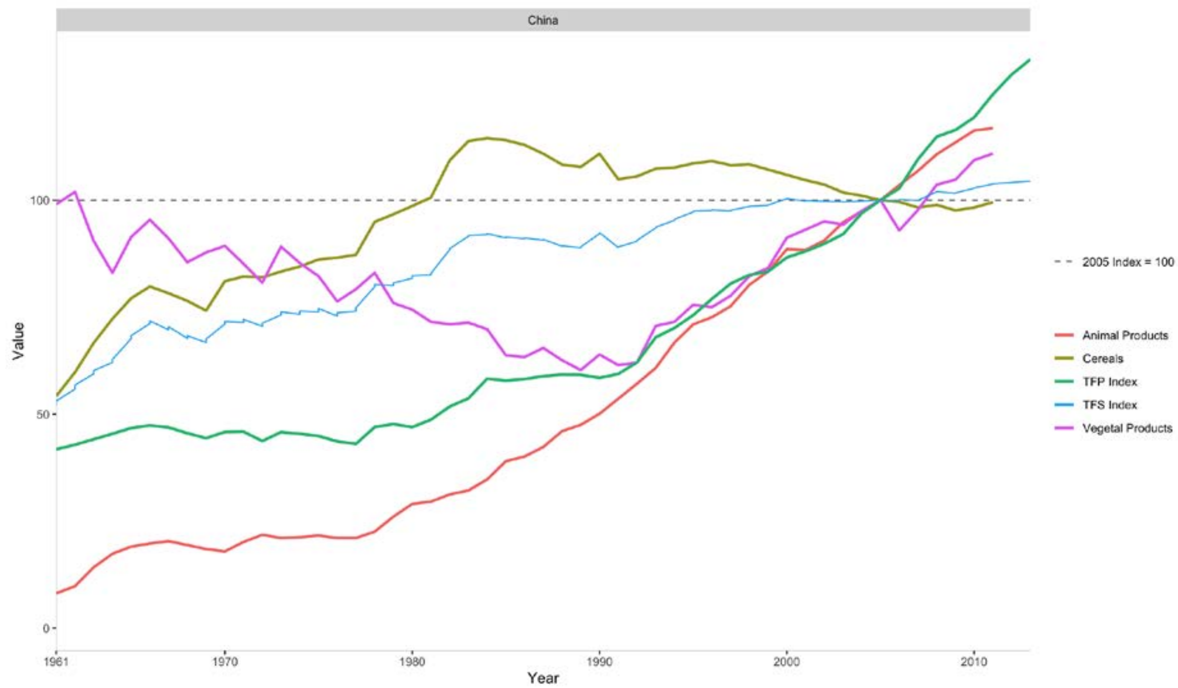


Figure 4.2.2: The consistent rise in all categories of food supply in Mainland China: animal (orange) and vegetable (purple) products are exceptionally well aligned with TFP growth (green) after 1990.

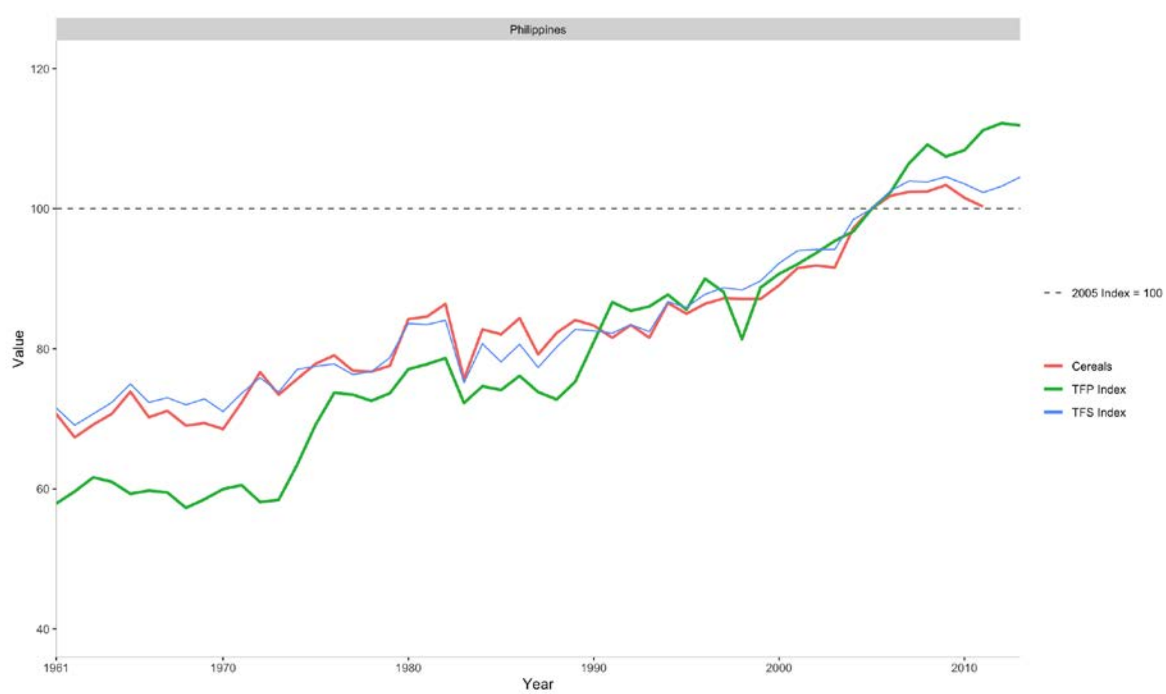


Figure 4.2.3: Cereal and TFS values in the Philippines, which rise in line with TFP growth. This is one of the only cases in Asia in which TFP growth reflects cereal product increase, which is closely associated with TFS value given the importance of cereals in food supply.

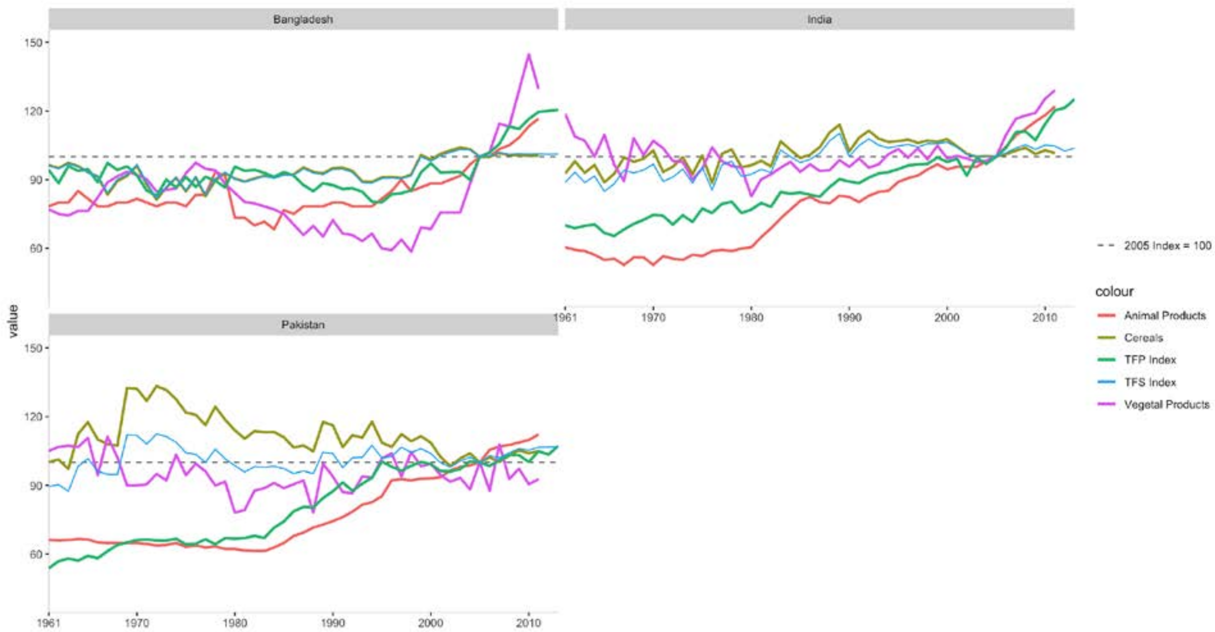


Figure 4.2.4: TFP, total food supply and categorical indices in India, Bangladesh and Pakistan. Notice the close relationship between animal products (orange) and TFP (green). Cereals and TFS, which are closely related, do not follow the upward trend of TFP to the same extent.

4.3: Latin America

The clearest relationships in South America between TFP and TFS growth occurred in animal products, while cereal and TFS values remained consistent in countries that experienced steady rises in TFP growth. A similar pattern of food supply diversification to South and Southeast Asia was apparent in Central America (Figure 4.3.1). The Andean countries are as equally cereally-dependent as Central America and Asia, but show less of a movement towards diversification of their food supply (i.e. growth of animal and vegetable product index) over the study period. Only in Colombia, which has the steadiest TFP growth in the Andean region, is TFP growth mirrored by a steady increase in animal products after 1970. TFP growth is better aligned with cereals than other regions, but it is a tenuous relationship at best (Appendix Figure 4). Brazil's animal products index reflects TFP growth with the same dramatic upward slope from 1980 onwards.

Similarly, Chile had an especially close relationship between animal food supply and TFP growth after 1970 (Figure 4.3.2). This pattern is an outlier in the Southern Cone region, as is Chile's steady pattern of TFP growth: in the rest of the region, TFS, cereals, and TFP values change very little, with the exception of vegetable product fluctuations.

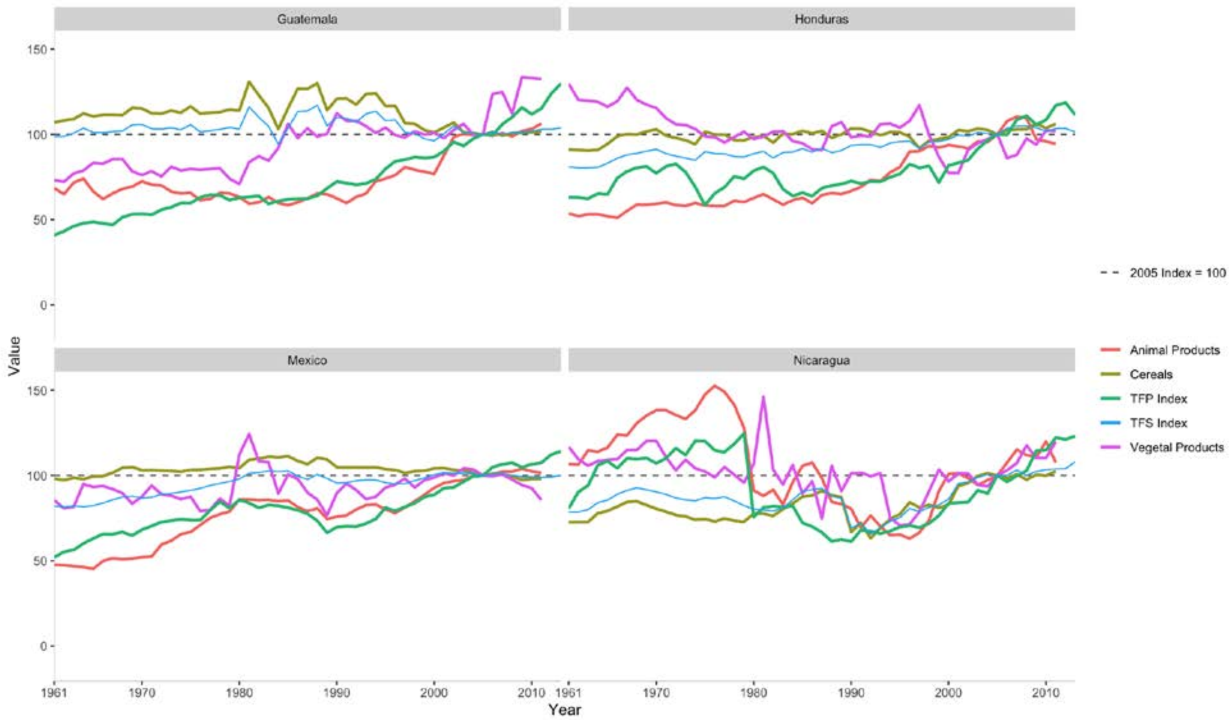


Figure 4.3.1: Guatemala, Honduras, Mexico, and Nicaragua show consistency between animal product index (orange) and TFP growth (green). Even so, TFS (blue) is clearly best tied to cereal (yellow) index value, which has stayed consistent regardless of TFP growth.

Figure 4.3.2: TFS and animal product index values in Brazil and Chile. Animal product index has a much closer relationship with TFP growth than TFS. Notice Chile's impressive rate of TFP growth, which is unique in the Southern Cone Region.

4.4: Africa

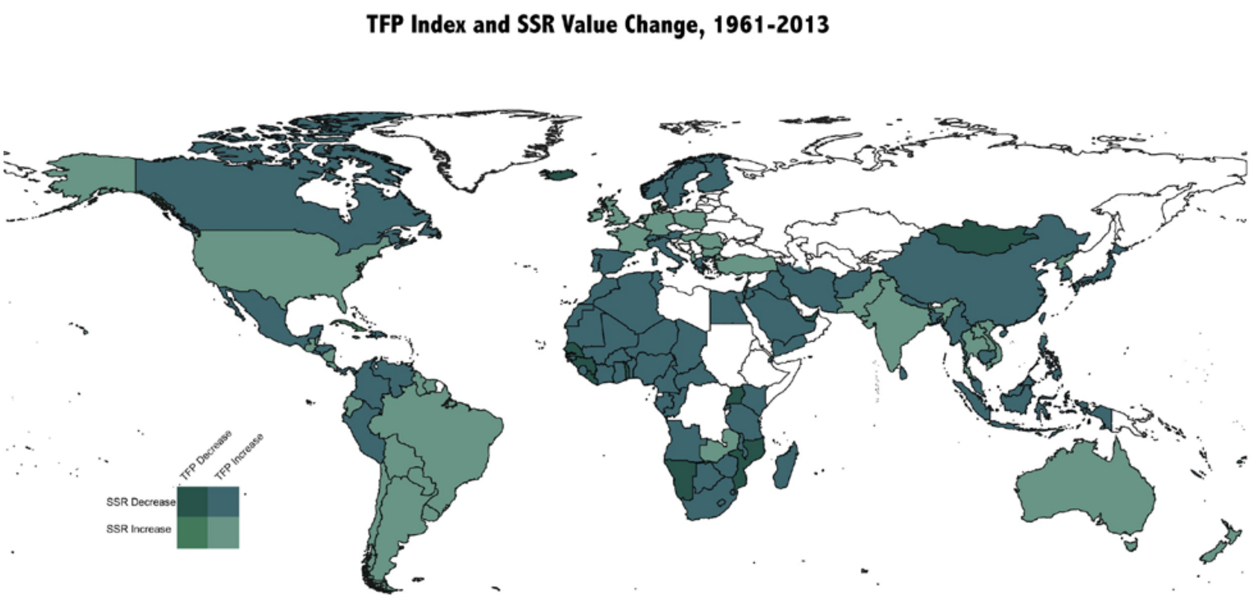
Like South and Southeast Asia, North Africa shows a more diverse pattern of TFS growth, including consistent growth in animal products. North Africa is an incredibly cereal dependent region, and one of the only regions to experience consistent TFS and cereal growth. Although TFS does not diverge from the pattern of cereal crops, TFP growth patterns are matched closely by those in vegetable products. Animal product TFS also follows similar patterns to TFP, to a much closer extent in Tunisia and Morocco (Appendix Figure 4).

Sub-Saharan Africa had the least steady periods of TFP growth, but overall consistency in TFS values around the index value of 100. Only in Benin and Ghana, the TFS index matches TFP growth well, especially after 1980 (Appendix Figure 5). South Africa, the only country classified by Fuglie as Developed Africa, has steady TFP growth after 1985, but almost no overall change in TFS value, which appears to be closely related to cereal value. Nigeria, on the other hand, experiences a TFS spike in the 1980s exactly in line with a TFP spike, which seems tied to growth in cereals (Figure 4.4.1).

Figure 4.4.1: Comparing TFS and TFP patterns in South Africa and Nigeria. We see that a TFP spike in Nigeria in the 1980s reflects a corresponding spike in cereal and TFS indices, while steady TFP growth in South Africa does not seem related to either value.

Chapter 5: Relationship between TFP Growth and Self-Sufficiency

In this chapter, I outline trends in food self-sufficiency as they relate to TFP change. I find a global shift away from self-sufficiency (Map 5.1), but several countries that experience strong TFP growth are able to maintain consistent SSR values throughout the study period.



Map 5.1: TFP Index and all-food SSR Value Change in 131 countries, 1961-2013. Note that TFP change is derived from an index valued pegged to the TFP value of a country in 2005, while the SSR change is derived from empirical value derived from the SSR equation (see page 15).

5.1: Europe, North America, and Oceania

High-income countries in Europe showed little regional homogeneity in their SSR patterns. In Northwest Europe, several countries displayed a flipped pattern of TFP growth and SSR calculated from all foods (all-food SSR), in which SSR values fall while TFP index grows. However, self-sufficiency gains in some crops matched TFP increases in certain time periods, such as animal product SSR in the Netherlands, Denmark, and Germany (Appendix Figure 6). Individual crop analyses show a highly fluctuating staple crop SSR. Only in two cases (United

Kingdom and Germany) does the wheat SSR rise above 100, and only in Germany did wheat SSR increase alongside TFP (Appendix Figure 7).

In Southern Europe, Spain, Italy, Greece, and Cyprus have a consistent pattern of TFP growth, and vegetable product SSR values over 100. (Appendix Figure 8) Transition Europe shows a better positive trend in SSR values, despite varying rates of TFP growth. Wheat SSRs in Poland, Hungary, and post-2000 Bulgaria have an especially close relationship with TFP growth, indicating that it has become a significant producer of diet staples (Appendix Figure 9). This region is one with the most consistent levels of self-sufficiency above 100. Compared to other regions, however, TFP growth is not occurring at as high a rate and shows some fluctuations.

North America and Oceania show high SSR values consistent with their high production capacity, albeit with intense fluctuations in cereal and animal product SSR values (Figure 5.1.1). Inflated SSR values suggest the production system has an already high capacity and is geared towards food exports.

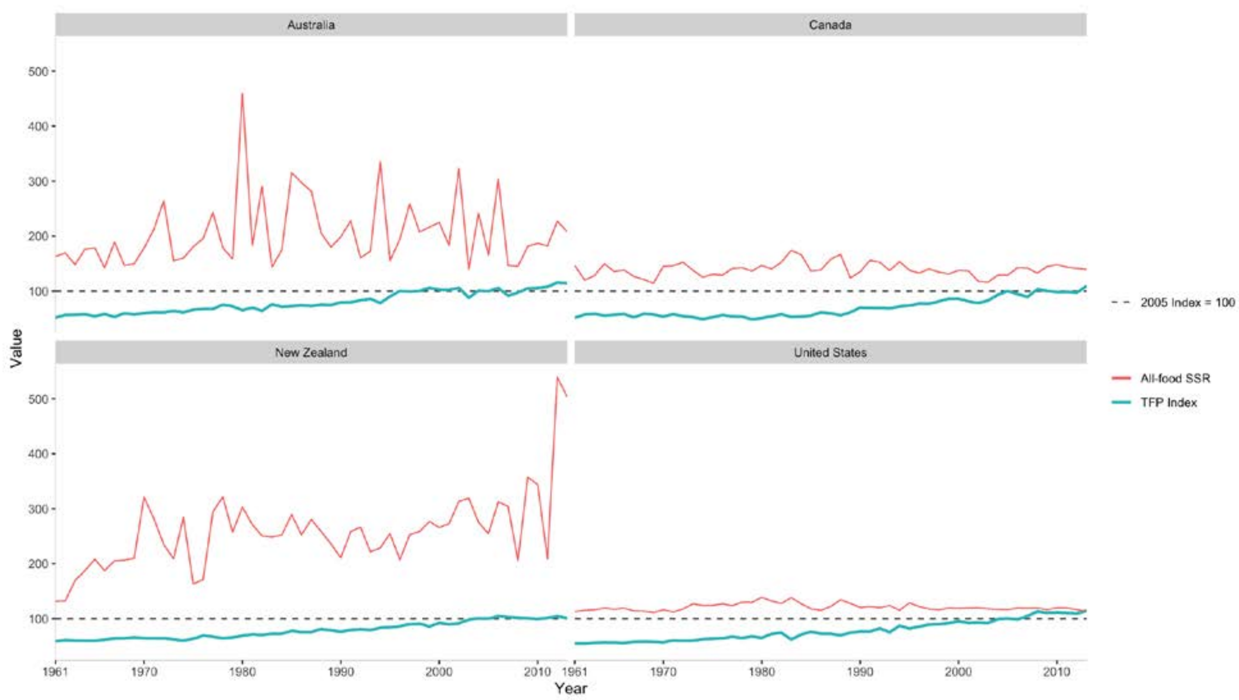


Figure 5.1.1: Australia, New Zealand, Canada, and the United States have exceptionally high SSR values, suggesting strong capacity for domestic food production and food exports, which could be heightened by TFP growth.

5.2: Asia

Developed Asia showed the clearest relationship, albeit a negative one, between TFP growth and SSR value. Taiwan, South Korea, and Japan had very similar decreasing trends in SS despite some of the most consistent and impressive TFP growth in the world (Figure 5.2.1). While rice SSR in this region rests around 100, wheat, maize, and soy quickly drop to 0 after 1970 (Appendix Figure 10). In Mainland China, SSR values only began to drop under 100 for the first time in the 2000s (Figure 5.2.2). Although it experiences the same level and pattern of TFP growth, mainland China starts at a higher SSR level for all categories, including staple crops, than Japan, Korea, and Taiwan.

Malaysia and Brunei follow the same trend of developing Asia: incredible TFP growth with minimal fluctuations, while SSR values begin to drop in the 1970s (Figure 5.2.1). The Philippines and Myanmar follow a similar steady pattern, maintaining the same SSR values for the duration of the study period after initial drops in the 1970s (Figure 5.2.1). In the rest of Southeast Asia, we see very little change in self-sufficiency status in response to steady TFP growth.

The South Asian countries are more consistent in their patterns of self-sufficiency. In Bangladesh, India, Nepal, and Pakistan, SSR values remain at or slightly below 100 with remarkable consistency, despite TFP growth occurring in the 1980s and 1990s (Figure 5.2.3). Afghanistan, which has fluctuating TFP growth, provides another example of TFP fluctuations that aligns with shifts and fluctuations in SSR value (Appendix Figure 11).

All countries in West Asia, except for Kuwait and the United Arab Emirates experience steady TFP growth, but self-sufficiency status is highly variable. Turkey and Iran have consistently high all-food SSR, but cereal and staple SSR is well below all-food SSR in many countries, often nearing 0 (Appendix Figure 12).

Figure 5.2.1: SSR values in Developed Asia and Southeast Asia. Developed Asia and Malaysia show substantial drops in self-sufficiency levels despite strong TFP growth, while the Philippines and Myanmar show consistency in SSR values in light of TFP growth. Cereal SSR is lower in the first group, while animal product SSR is lowest in the second.

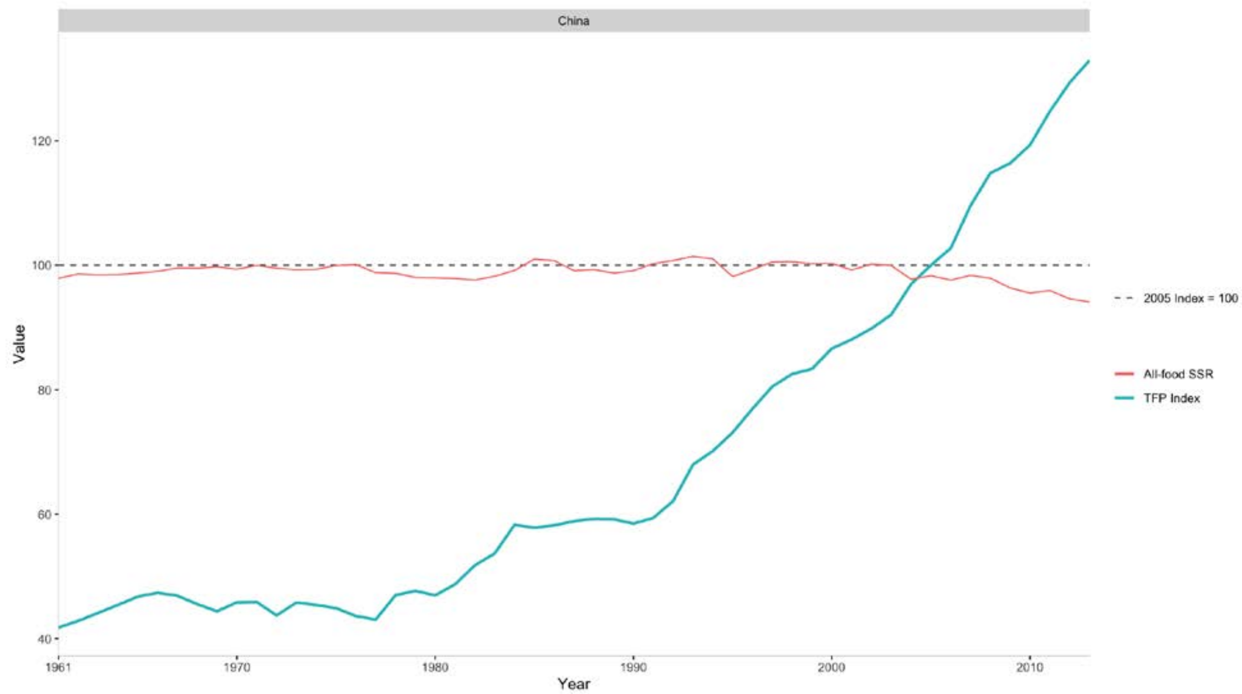


Figure 5.2.2: Unlike the Developed Asia countries, Mainland China maintains self-sufficiency levels in all categories around 100, complemented by very steady TFP growth after 1980.

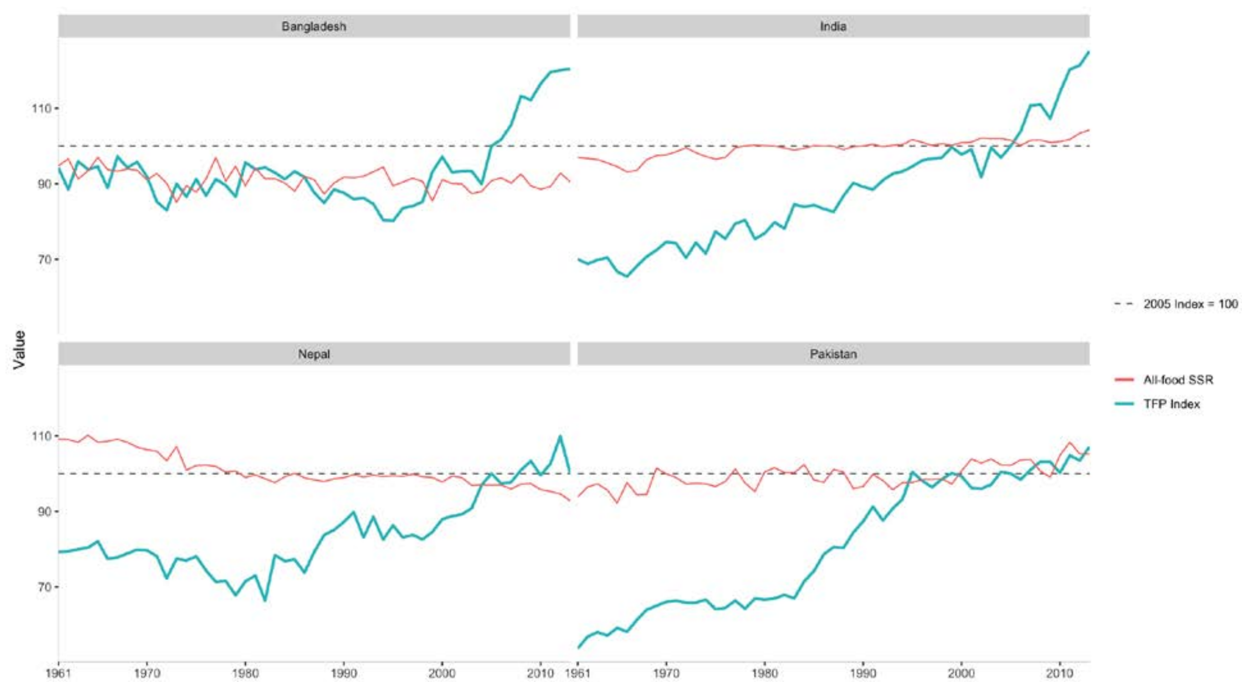


Figure 5.2.3: SSR values in South Asia, at or slightly below 100, maintain consistency with TFP growth.

5.3: Latin America

In Latin America, large spikes in SSR are present based on regional specialization. Andean and Central American countries maintain vegetable SSRs slightly above or below 100 (Appendix Figure 13). Similarly, Southern Cone countries have SSR values well above 100, mainly in cereals (Appendix Figure 14). Conversely, the Andean region is noticeably weak in cereal self-sufficiency, and has very little overall change in staple SSRs despite large fluctuations (Appendix Figure 15). Within South America, Brazil is unique for its wholly positive relationship between TFP and SSR, although all-food SSR does not increase impressively (Figure 5.3.4). In Central America, regardless of regional variance in TFP growth, no country consistently improves their SSR value in line with TFP, except for animal products in Nicaragua (figure 5.3.5).

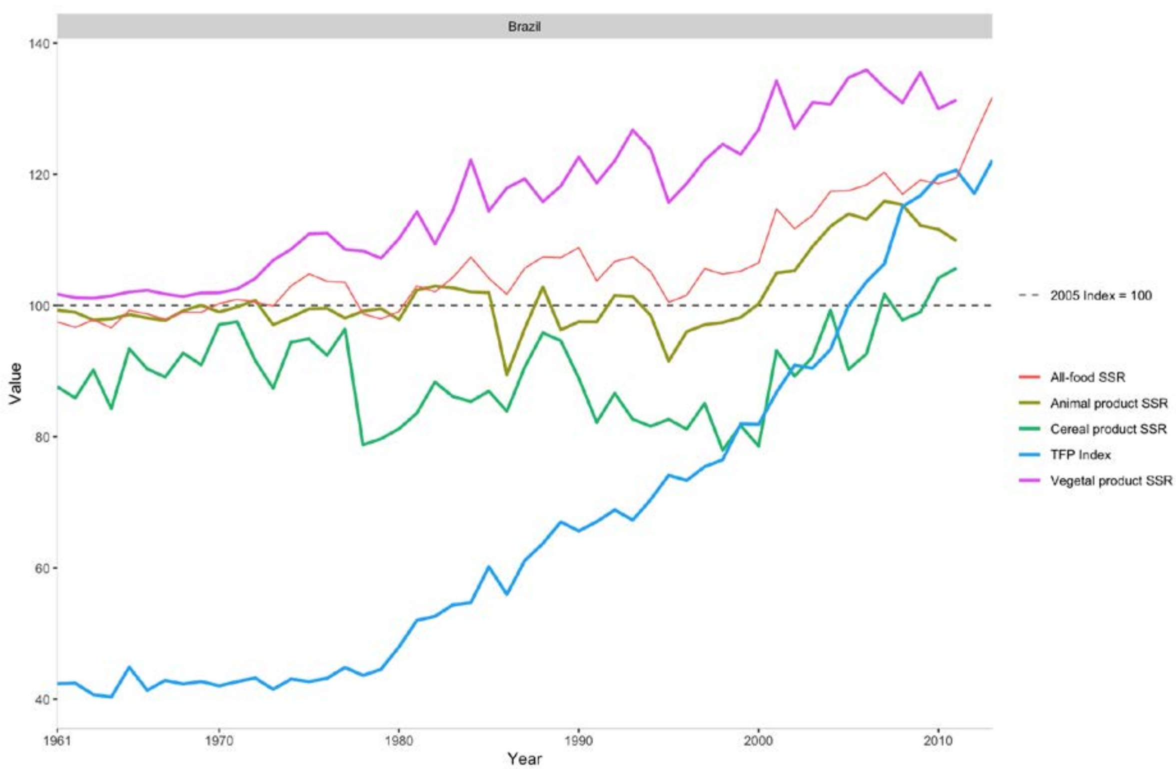


Figure 5.3.1: Brazil shows increasing SSRs well over 100 in animal and vegetal product SSR in line with TFP take-off around 1980, suggesting that TFP growth has helped both Brazil's domestic food supply and export capacity.

Figure 5.3.2: The close relationship between animal product SSR and TFP growth in Nicaragua, one of the most pronounced in Latin America.

5.4: Africa

Flatlining SSR values in Sub-Saharan Africa indicate that TFP growth has perhaps allowed countries to maintain a certain level of SS, rather than improve it overall. In almost all countries in Africa, vegetable product SSR was consistently around 100. In the Eastern region, all-food SSR stayed consistently around 100, despite variation in the magnitude of TFP growth in the region and fluctuations in staple SSR (Appendix Figure 16). In the Central, Sahel and Western regions, slight TFP growth is reflected by consistent SSR values. South Africa and Nigeria both have fluctuations despite relative consistency in TFP growth, although Nigeria does maintain its all-food SSR just below 100 for the entirety of the study period, despite large fluctuations in cereal and livestock SSR (Appendix Figure 17). North Africa had SSR fluctuations rather than overall improvements, especially in cereal SSR values (Appendix Figure 18).

Chapter 6: Discussion of Results

In this section, I identify major patterns and their connection to the existing literature. Specifically, I observe how these reflect former predictions for self-sufficiency status, as well as the shift towards animal products in the global food supply. I also re-address the potential for TFP growth in surmounting inequality in food access in the context of my results.

6.1: Food Supply Implications of Global Patterns of TFP Investment and Growth

Sustained TFP growth shows that the country has focused on TFP growth as a priority. I observe that many lower income countries experience large fluctuations or drops in TFP, indicating that certain regions have not been able to fund the agricultural research and development necessary to sustain long-term productivity growth. Brazil and China, however, have invested heavily in research and development and instituted reforms that promote this sustained growth (Fuglie and Wang, 2012). In Brunei, which has the highest TFP growth in the world during the study period, the government has focused on national agricultural development, especially in the animal sector (FAO, 2011). Even so, it is important to remember that the actual level of TFP in the country might be low, which would not be captured by the index value and implies this level of TFP growth is an outlier. Compared to Asia, Africa experienced technical regression between 1961 and 1991, and a decline in productivity caused by lack of investment (Suhariyanto et al., 2001). Even so, the increased consistency past 2000 observed in this study indicates that regions such as Sub-Saharan Africa may have recognized that investment in TFP and trade infrastructure is needed to combat population pressures. Lack of TFP growth may contribute towards falling SSR values, when countries lack the physical, economic, and political infrastructure to rely on food imports. According to Fader et al. (2013), the Middle East and Sub-Saharan Africa will be faced with a trade-off between productivity increases, cropland expansion, and food imports. However, this will require significant investments in trade infrastructure and overall economic growth to afford food imports.

Participation in the global agricultural system has mixed implications for the results of TFP growth. TFP investments are often concentrated in areas producing crops for export, such as palm oil, rather than areas that specialize in domestic staple crops like rice (Fuglie and Wang, 2012). Indeed, incredibly high SSR values and high TFP growth in Latin America (Appendix

Figure 13, Appendix Figure 14) may be indicative of this phenomenon, in which investment is concentrated in an export food crop. Even so, involvement in global trade or even aid networks may improve productivity and capacity for SS through infusions of technology. High maize yields may be the result of productivity investments sponsored by aid programs during the Green Revolution (Suhariyanto et al., 2001), which may be the cause of high maize SSRs in East and Southern Sub Saharan Africa (Appendix Figure 16). Heady et al. (2010) finds that proximity to an OECD country is a significant factor in TFP growth, identifying a geographic benefit to TFP. Despite the impetus to channel TFP investment towards the more high-value export sector, the impacts of TFP growth may be felt beyond the target area throughout the whole production system.

6.2: Implications of Regional Disparities in TFP Growth for Self-Sufficiency

Despite relative consistency in global patterns of TFS growth, evidence of disparities in TFP growth were reflected in patterns of self-sufficiency (SSR) between regions. The lack of consistency in TFP growth may therefore be a reflection of their diminished capacity for consistent improvements in self-sufficiency.

Prahan et al. (2014) find that only major producers, namely India, Brazil, Argentina, Nigeria, the United States, Germany, and Australia, can achieve national-level food self-sufficiency. Indeed, these are some of the only countries where I see consistent increases in TFP and SSR values above 100 for the duration of the study period. For these major producers, however, it is important to note that exceptionally high SSR values are most likely caused by the over-emphasis on one crop or crop group produced for export in a given country (FAO, 2019). This phenomenon is especially evident in regions with very high cereal SSR, such as France, Argentina, Australia, and Canada (Figure 5.1.1, Appendix Figure 14), and vegetable product SSR values in Central America and Southern Europe (Appendix Figure 8, Appendix Figure 13).

Of the countries I identify with especially consistent SS levels (SSR value over 100 for over 50 years), France, Costa Rica, Denmark, and Thailand, Guatemala, and Germany, are in the top quartile of TFP growth (Appendix Table 4). Germany is one of the only high-income countries with a clearly defined upward tendency in SSR values, although at middling ranks of TFP growth amongst high-income countries (Appendix Figure 7). In fact, Germany's TFP grows on par with Brazil, and along with India, is one of the only other countries that are able to shift their all-food SSR from below to above 100. Germany, Denmark and the Netherlands, incidentally, have made the highest European investments in TFP (Fuglie, Wang, and Ball, 2012), showing positive results in sustaining self-sufficiency (Appendix Figure 6) The relationship between TFP investment and SSR growth in these high income countries indicates that a push for self-sufficiency is possible, and still attractive, in a high income setting, assuming they are not limited by geographic constraints. Even so, many of these high-income countries can attribute their self-sufficiency to the high ratio of arable land to population density (Baer-Nawrocka and Sadowski, 2019).

TFP growth in these countries may therefore be contributing to the regional SS in Western Europe predicted by Prahdan et al. (2014). The majority of EU agricultural exports, which make up 41% of global agricultural export value, are consumed by other EU countries. Despite this, only 10% of global cropland is located in the European Union (MacDonald et al., 2015: 278), indicating a crucial combination of a high-productivity production system and a high percentage of arable land for cementing regional self-sufficiency. According to Mueller et al. (2012), Eastern Europe will be a significant source of new food production in upcoming years, along with Sub-Saharan Africa. Although the majority of Eastern European region included in the Mueller study is not included in mine, those countries included in Transition Europe, such as Bulgaria, Romania, and Poland showed consistently high SSRs, despite comparatively small TFP growth (Appendix Figure 9). TFP growth in these areas may be supplanting traditional producers in the region, such as France, a major cereal production region that has experienced stagnating yields (Ramankuty et al., 2018). Trends in TFS and SSR at the category level also hint at the pattern of trade specialization within the European Union. Southern Europe has especially high vegetable SSR, while Northwestern Europe has higher cereal SSR values (Appendix Figure 7, Appendix Figure 8). Such high SSR values in these respective categories are again indicative of the propensity of SSR calculation to reflect export-oriented agriculture in a given crop.

Similar to the self-sufficiency situations for Europe, Prahdan et al. (2014) find that South America is another region with the potential for continental self-sufficiency. Steady overall-increase in TFS index coupled with some SSR decline could indicate that the Andean region is relying on higher-production regions such as Northeast South America and the Southern Cone for staple crops. In the Southern Cone, high levels of SS in staple crops (often well above 100) imply that this area produces for trade, be it regional or global, more than enough to satisfy domestic demand. Argentina, for example, a highly food self-sufficient country, shows little increase in TFS over time, indicating that the majority of its agricultural growth has gone towards exports-oriented agriculture (Appendix Figure 14). Brazil and the Southern Cone countries are especially prominent exporters towards China, the United States Europe, but are also major cereals and livestock producers for consumption within South America (OECD & FAO, 2019). Decreases in SSR in one region, such as the low cereal values in the Andean region, could thereby be offset regionally with imports in areas with high TFP growth, such as Brazil and Chile.

The attractiveness of self-sufficiency, and perhaps with it the impetus for TFP development, could depend on income level. In Developed Asia, the fact that such steady TFP and SSR change has occurred in opposite directions indicates that self-sufficiency is less and less appealing to countries as they transition to higher incomes (Figure 5.2.1). Clapp (2016) contends that higher income countries can rely on food imports without worrying about supply shocks and market fluctuations, implying more food supply security. Indeed, Luan et al. (2013) find a negative relationship between SSR and per capita income. By coincidence of resource endowment, these low SSR countries often have low production capacity and will be thus more susceptible to population growth and climate change shocks (Luan et al., 2013). Beyond inequalities in productivity level, global trade policies may contribute to this disparity in agricultural investment. Protectionism by developed countries against imports from developing countries may reinforce inequality in self-sufficiency (Fuglie, Wang and Ball, 2012), as lower income countries cannot develop their agricultural sectors without the opportunity for integration in global agricultural trade.

Contextual factors of economic development seem to contribute to the likelihood of applying TFP growth to SS. Comparing SSR patterns in North and South Korea (Appendix Figure 19) we see that different contexts of economic development could have implications for the relationship between TFP and SSR: while both increase TFP, South Korea’s SSR values drop more and earlier, presumably with its higher level of integration into the global economy.

6.3: Limits to Self-Sufficiency

Productivity growth is often seen as an alternative, or at least a complement, to agricultural expansion in the context of population growth. Given that very few countries shifted from SSRs below to above 100 (Map 5.1), it became clear that the role of TFP in SS would be sustaining self-sufficiency, rather than promoting or improving it. In middle-income countries, especially in South and Southeast Asia, we see that TFP growth might have allowed the possibility of food self-sufficiency to remain viable in the face of population pressures (Figure 5.2.4). In these regions, SSR patterns could demonstrate how TFP has kept pace with population growth and allows countries to avoid resource constraints to food SS. South Asia already devotes over 90% of their cropland to food production for direct human consumption (Foley et al., 2011: 338), suggesting that the types of crops produced by domestic agricultural lands likely play a role in maintaining relatively high levels of self-sufficiency.

Nigeria, which quadruples in population over the study period, shows steady SSR values with steady TFP increase (Appendix Figure 17). Rising TFS values in Nigeria (Figure 4.4.1) compared to rising TFP indices suggest that TFP growth has helped domestic production keep up with population growth. Although Sub-Saharan Africa is continuously highlighted as a region that will face extraordinary population pressure in the coming years, the limited change in the SSR values, which are at 100 in many countries in this region, is another indication that TFP may have helped sustain SSR in the context of population growth. It is possible, however, that these consistent SSR values reflect a shift towards export-agriculture, a danger in SSR calculations mentioned earlier in the context of incredibly high SSRs in South America and Europe (FAO, 2012). Even so, the fact that these SSR values do not spike above 100 (e.g. in South Asia, Figure 5.2.3) suggests that these areas are producing to meet domestic demand, not in excess for export.

Regardless of productivity growth, Pradhan et al. (2014) find that the unit of self-sufficiency that is possible varies depending on the region. Regional resource constraints may limit this potential notwithstanding the scale of population growth. In Developed Asia, strong TFP growth has acted in contrast to that in Southeast Asia with regards to SS, while TFS index values have remained stable. Pradhan et al. (2014) identify Northeast Asia as a region incapable of SS below the global level, for reasons including climate change, dietary patterns, and land availability, not population size. Along with North Africa and the Arabian Peninsula, and much of Sub-Saharan Africa, this group hints that productivity advances are not feasible remedies to climate change and lack of land availability. These regions are also highlighted by Fader et al. (2013) and Porkka et al. (2017) as areas where the reality of resource boundaries overshadows productivity advances. Compounding this, I find that the Middle East (Western Asia) and North Africa were well represented in the highest quartile of TFP growth rates (11 countries out of 15 in the region, see Appendix Table 4). Despite this, their SSR values continuously drop, especially in West Asia, indicating limited capacity for self-sufficiency (Appendix Figure 12, Appendix Figure 18).

Small island nations are another context where geographic limitations to self-sufficiency seem obvious, with self-sufficiency nearly unattainable given natural resource limits (Luan et al., 2013). Small island developing states have one of the highest trade imbalances in the world, and agricultural investment has been limited due to budget deficits (FAO, 1994). The lack of relationship between TFP growth, SS, and TFS patterns in these islands I find may therefore be linked to their low capacity for production. It is questionable as to what extent TFP growth is actually meaningful to these areas, in which agricultural production is limited by land and water resource constraints.

In low-income countries, the drop in self-sufficiency despite TFP and TFS growth (Maps 1 and 2) reflects the global pattern away from SS, which may not be as vital to food security as previously thought. Indeed, it is important to stress that drops in self sufficiency are not definitely associated with inequality: Carr et al. (2016: 4) find that international food trade diminishes inequality relative to production by up to 33%. It may not harm food supply in low-income countries to stay at lower levels of SS and focus TFP advances towards other production goals. Lower levels of self-sufficiency may not be a failure to limit inequality in access but rather a fact of geography (Agarwal, 2014; D'Odorico et al., 2019). Examining TFP growth as an improvement in a country's capacity to find a medium between food self-sufficiency and trade thereby acknowledges the realities of resource endowments.

6.4: Animal Product Growth

The link between animal products and TFP uncovered in this analysis reemphasizes the link between livestock production and development. Despite implications for climate and trade imbalances, this pattern does imply benefits to food supply beyond a caloric basis. A rise in animal product consumption has been linked to nutritional indicators, such as increased micronutrient status and cognitive performance (Willet et al., 2019). This indicates that any contribution of TFP to animal agriculture has been a success with regards to quality of food supply.

The consistent rise of animal products and drop in cereals in economies in transition is wholly unsurprising. Increasing dietary variety is a trademark of areas with rising incomes and urbanizations (Delgado, 2003). It is assumed that TFP increases in these regions, such as Asia and Latin America, would be allocated to the expansion of animal agriculture. Examining food supply indices, consistent increases in animal product index values in country food supply are evident in much of Developed Asia, Central America and South Asia. Although it is evident that cereals still make up a large share of the food supply in these areas, the animal product index reflects the magnitude of TFP change far better than TFS and cereal indices do (Figure 4.2.1, Figure 4.2.4, Figure 4.3.1).

Increased reliance on animal products in national diet exacerbates dependence on external land and water resources (MacDonald et al., 2015). The resource-intensive method of supplying calories from animal products might imply a need for resources that TFP growth cannot overcome. Decreases in animal SSR elsewhere are unsurprising: Acosta and de Los Montero (2019) find livestock productivity growth to be highly variable between regions. I found that SSR values for animal products decreased in most countries, with the exceptions of Brazil, Denmark, the Netherlands, Bolivia, Poland, and Nicaragua. Excluding Bolivia, however, I find steady TFP growth after 1990 in all of these countries.

The rising importance of animal products in diet may reinforce between-country inequalities in food security. Certain key regions in this analysis underline this phenomenon. Brazil and Chile are unique in the South America region for the close relationship between animal product index and TFP growth (Figure 4.3.2), and have had some of the highest TFP growth for ruminants and monogastrics in the world (Acosta and Montero, 2019). Indeed, Latin America, along with Asia, has increased yields in animal agriculture in line with increasing overall productivity, rather than simple input intensification commonplace in other regions (Ramankutty et al., 2018). I find a consistent level of animal product self-sufficiency at 100 for India, Pakistan, and Nepal, indicating they have focused TFP investment into animal agriculture. Coincidentally, Acosta and Montero (2019) identify the highest TFP growth in animal agriculture in the world in India and Pakistan, which is evident in growth of the animal product food supply values (Figure 4.2.4). We see that channelling TFP investment in line with diet shifts towards animal products enables sufficiency maintenance while their demand rises.

Conversely, Sub-Saharan Africa lags behind global levels of growth in numerous TFP studies, especially in animal agriculture. Acosta and Montero (2019) find this to be the only region with net TFP decrease in animal products, of particular importance when considering the population growth and climate change pressures expected for the region in coming years. Animal TFS does not increase here in the same positive trend as it does in Latin America and Asia. I find animal SSR values are generally high around the region, even though they may not be as important in diet here as in other regions (Willet et al., 2019). This further supports the idea that animal agriculture is the focal point of TFP investment.

The staple crop values used in the SSR calculations may reflect increased production and trade for animal feed. China's soy SSR drops from over 100 to 0 between 1990 and 2013, a marked drop for the timespan (Appendix Figure 10) at the same time that its animal product index rises (Figure 4.2.2). While TFS value reflects only that used for human consumption, SSR values, such as soybean, can reflect feed uses. Although TFP continues to grow in China during this time, the scale of demand for animal products may limit the impact of TFP growth.

6.5: Limitations

It is also important to recognize that using TFP index values, rather than concrete numerical ones, distracts from the level of TFP in a country. Spain, for example, still has some of the lowest actual TFP values in Europe in spite of its impressive growth since 1961 (Fuglie, Wang, and Ball, 2012). The way that TFP is calculated, as a ratio of inputs to outputs, may not reflect investment in agriculture so much as trends of development. For middle-income countries in Europe, for example, TFP growth has largely been driven by an exit of workers from agriculture, leaving more resources per worker (Fuglie, Wang, and Ball, 2012). TFP growth may therefore not reflect investment and political will to improve productivity, but be just another facet of shifting economies.

A key trend that appeared across regions amongst lower income countries was a characteristic "spike" in TFP growth around the year 2000. This pattern may have impacts beyond the timeframe of this analysis: in the high-income group, countries starting with lower levels of TFP often show more impressive growth rates. In Europe, for example, Spain has the highest TFP growth exhibiting the “catch up” affect consistent with a low starting point (Fuglie, Wang, and Ball, 2012). Extrapolating from high-growth cases in Asia and Europe and following the logic of “catching up”, it is probable that these spikes could have implications for TFS and SSR that are not evident in my study time frame.

Other issues arise from my selection of crops. Defining my selection of “staples” is difficult given regional diet and capacity to grow a certain crop. SSR values are therefore skewed based on geography rather than productivity. Recalling the call for increasing consideration of food supply content in food security research, I aimed not to conflate supply values with nutrition. However, excluding such export-oriented crops such as palm oil and sugarcane leaves out a large portion of production systems (Carlson, 2018). Further analysis in this topic would be well served to compare production of luxury crops to food supply.

Chapter 7: Conclusions

The main goal of my research was to assess how well TFP growth could be applied to addressing food global food security, by examining its relationship with food-availability (total food supply index) and self-sufficiency (SSR value). Particularly, I sought to gauge how investment in TFP could overcome key facets of food inequality. I conclude that TFP growth is a notable option in overcoming local limits to growth imposed by land restraints in the context of population growth and shifting diets. The combination of consistent TFP growth and stable SSR value, even if it is below 100, is prevalent in countries around the world and the total daily per capita caloric value is either consistent or increasing. In many areas, I notice a trend towards animal products that often tracks TFP increases more closely than cereal or vegetable improvements. In comparing TFP growth with SSR values, I attempted to gauge the potential for applying TFP growth to food self-sufficiency. Observing the trends of each measure, however, often showed the opposite trend, especially for countries that had undergone a significant level of development over the study period. This was in line with my expectations for self-sufficiency patterns, given the complexity of factors that vary across region and income level. The inability to translate TFP gains into self-sufficiency, especially in staple crops, is apparent across many regions. I observe very few shifts from trade dependent to self-sufficient. Accounting for the general positive trend of TFS indices, however, it is possible that TFP growth has allowed countries to sustain levels of self-sufficiency with increasing population. Mainland China, South and Southeast Asia, and parts of Sub-Saharan Africa exemplify this possibility. By comparing TFP and SSR patterns on the country scale, I notice opportunities for self-sufficiency on the regional or continental scale that is buoyed by TFP growth. Differences in categorical SSR values show potential for regional synergies based on specialization in each crop category. Furthermore, the growth of SSR values over 100 in the presence of steady TFP growth (such as in Brazil) confirm my prediction that TFP growth could be instrumental in promoting integration in the global food trade system. This works to overcome inequality in access, increasingly export capacity in the production country and overcoming limits to food production elsewhere.

I interpret the consistency in self-sufficiency measures to imply a stabilizing effect of TFP growth, enabling each country to minimize uncertainty in food supply and to strike a comfortable balance between import dependence and self-sufficiency. TFP growth may thereby allow countries with high population growth countries to maintain the same level of sufficiency, even if below a self-sufficient level. I sought to uncover a more human-centric dimension to TFP, to understand how TFP impacts food supply beyond an aggregate caloric value. Recalling D'Odorico et al.'s (2019) argument that biophysical resource boundary compounds food inequality, the ability of TFP growth to transcend current limitations, to whatever extent, indicates that it is effective in improving a country's overall capacity to feed its population. Furthermore, TFP growth could work to combat inequality between countries by enabling populations to enjoy increased diversification of food supply, standardizing global diets beyond traditional staples. Despite these clear benefits, however, it is important to remember that disparities in TFP investment may be another facet of inequality in food production systems.

With variables so susceptible to climatic variation, political conflict, and economic development, it is nearly impossible to define a truly causal relationship between TFP and self-sufficiency, and TFP and the characteristics of food supply. Even so, it is clear that investment in TFP has resulted in quality improvements and diversification around the world. Although by no means a clear causal relationship, the similarity in trends defines a clear association between food supply improvements and TFP improvements, enabling consistency in sufficiency status and addressing issues of food access on a country scale.

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Appendix A: Tables

Appendix Table 1: Countries included in analysis with associated region, sub-region, and income level.

Country	Region	Sub-region	Income Level
Afghanistan	Asia	South Asia	LI
Albania	Europe	Europe, Transition	MI-U
Algeria	West Asia and North Africa	North Africa	MI-U
Angola	Africa, Sub-Sahara	SSA, Southern	MI-L
Argentina	Latin America and Caribbean	SA, Southern Cone	MI-U
Australia	Oceania	Oceania	HI
Austria	Europe	Europe, Northwest	HI
Bahamas	Latin America and Caribbean	Caribbean	HI
Bangladesh	Asia	South Asia	MI-L
Belize	Latin America and Caribbean	Central America	MI-U
Benin	Africa, Sub-Sahara	SSA, Western	LI
Bolivia	Latin America and Caribbean	SA, Andean	MI-L
Botswana	Africa, Sub-Sahara	SSA, Southern	MI-U
Brazil	Latin America and Caribbean	SA, NE	MI-U
Brunei Darussalam	Asia	West Asia	HI
Bulgaria	Europe	Europe, Transition	MI-U
Burkina Faso	Africa, Sub-Sahara	SSA, Sahel	LI
Cabo Verde	Africa, Sub-Sahara	SSA, Sahel	MI-L
Cambodia	Asia	SE Asia	MI-L

Cameroon	Africa, Sub-Sahara	SSA, Central	MI-L
Canada	North America	North America	HI
Central African Republic	Africa, Sub-Sahara	SSA, Central	LI
Chad	Africa, Sub-Sahara	SSA, Sahel	LI
Chile	Latin America and Caribbean	SA, Southern Cone	HI
China (mainland)	Asia	NE Asia	MI-U
Colombia	Latin America and Caribbean	SA, Andean	MI-U
Congo	Africa, Sub-Sahara	SSA, Central	MI-L
Costa Rica	Latin America and Caribbean	Central America	MI-U
Cote d'Ivoire	Africa, Sub-Sahara	SSA, Western	MI-L
Cuba	Latin America and Caribbean	Caribbean	MI-U
Cyprus	Europe	Europe, Southern	HI
Denmark	Europe	Europe, Northwest	HI
Djibouti	Africa, Sub-Sahara	SSA, Horn	MI-L
Dominican Republic	Latin America and Caribbean	Caribbean	MI-U
Ecuador	Latin America and Caribbean	SA, Andean	MI-U
Egypt	West Asia and North Africa	North Africa	MI-L
El Salvador	Latin America and Caribbean	Central America	MI-L
Eswatini	Africa, Sub-Sahara	SSA, Southern	MI-L
Fiji	Asia	Pacific	MI-U
Finland	Europe	Europe, Northwest	HI
France	Europe	Europe, Northwest	HI
Gabon	Africa, Sub-Sahara	SSA, Central	MI-U
Gambia	Africa, Sub-Sahara	SSA, Sahel	LI

Germany	Europe	Europe, Northwest	HI
Ghana	Africa, Sub-Sahara	SSA, Western	MI-L
Greece	Europe	Europe, Southern	HI
Guatemala	Latin America and Caribbean	Central America	MI-L
Guinea	Africa, Sub-Sahara	SSA, Western	LI
Guinea-Bissau	Africa, Sub-Sahara	SSA, Western	LI
Guyana	Latin America and Caribbean	SA, NE	MI-U
Haiti	Latin America and Caribbean	Caribbean	LI
Honduras	Latin America and Caribbean	Central America	MI-L
Hungary	Europe	Europe, Transition	HI
Iceland	Europe	Europe, Northwest	HI
India	Asia	South Asia	MI-L
Indonesia	Asia	SE Asia	MI-L
Iran	West Asia and North Africa	West Asia	MI-U
Iraq	West Asia and North Africa	West Asia	MI-U
Ireland	Europe	Europe, Northwest	HI
Israel	West Asia and North Africa	West Asia	HI
Italy	Europe	Europe, Southern	HI
Jamaica	Latin America and Caribbean	Caribbean	MI-U
Japan	Asia	Asia, Developed	HI
Jordan	West Asia and North Africa	West Asia	MI-L
Kenya	Africa, Sub-Sahara	SSA, Eastern	MI-L
Kuwait	West Asia and North Africa	West Asia	HI
Laos	Asia	SE Asia	MI-L

Lebanon	West Asia and North Africa	West Asia	MI-U
Lesotho	Africa, Sub-Sahara	SSA, Southern	MI-L
Liberia	Africa, Sub-Sahara	SSA, Western	LI
Madagascar	Africa, Sub-Sahara	SSA, Southern	LI
Malawi	Africa, Sub-Sahara	SSA, Southern	LI
Malaysia	Asia	SE Asia	MI-U
Mali	Africa, Sub-Sahara	SSA, Sahel	LI
Malta	Europe	Europe, Southern	HI
Mauritania	Africa, Sub-Sahara	SSA, Sahel	MI-L
Mauritius	Africa, Sub-Sahara	SSA, Southern	MI-U
Mexico	Latin America and Caribbean	Central America	MI-U
Mongolia	Asia	NE Asia	MI-L
Morocco	West Asia and North Africa	North Africa	MI-L
Mozambique	Africa, Sub-Sahara	SSA, Southern	LI
Myanmar	Asia	SE Asia	MI-L
Namibia	Africa, Sub-Sahara	SSA, Southern	MI-U
Nepal	Asia	South Asia	LI
Netherlands	Europe	Europe, Northwest	HI
New Zealand	Oceania	Oceania	HI
Nicaragua	Latin America and Caribbean	Central America	MI-L
Niger	Africa, Sub-Sahara	SSA, Sahel	LI
Nigeria	Africa, Sub-Sahara	SSA, Nigeria	MI-L
North Korea	Asia	NE Asia	LI
Norway	Europe	Europe, Northwest	HI

Pakistan	Asia	South Asia	MI-L
Panama	Latin America and Caribbean	Central America	MI-U
Paraguay	Latin America and Caribbean	SA, Southern Cone	MI-U
Peru	Latin America and Caribbean	SA, Andean	MI-U
Philippines	Asia	SE Asia	MI-L
Poland	Europe	Europe, Transition	HI
Portugal	Europe	Europe, Southern	HI
Romania	Europe	Europe, Transition	MI-U
Rwanda	Africa, Sub-Sahara	SSA, Eastern	LI
Sao Tome and Principe	Africa, Sub-Sahara	SSA, Central	MI-L
Saudi Arabia	West Asia and North Africa	West Asia	HI
Senegal	Africa, Sub-Sahara	SSA, Sahel	LI
Sierra Leone	Africa, Sub-Sahara	SSA, Western	LI
Solomon Islands	Asia	Pacific	MI-L
South Africa	Africa, Developed	South Africa	MI-U
South Korea	Asia	Asia, Developed	HI
Spain	Europe	Europe, Southern	HI
Sri Lanka	Asia	South Asia	MI-L
Suriname	Latin America and Caribbean	SA, NE	MI-U
Sweden	Europe	Europe, Northwest	HI
Switzerland	Europe	Europe, Northwest	HI
Taiwan	Asia	Asia, Developed	HI
Tanzania	Africa, Sub-Sahara	SSA, Eastern	LI
Thailand	Asia	SE Asia	MI-U

Timor-Leste	Asia	SE Asia	MI-L
Togo	Africa, Sub-Sahara	SSA, Western	LI
Trinidad and Tobago	Latin America and Caribbean	Caribbean	HI
Tunisia	West Asia and North Africa	North Africa	MI-L
Turkey	West Asia and North Africa	West Asia	MI-U
Uganda	Africa, Sub-Sahara	SSA, Eastern	LI
United Arab Emirates	West Asia and North Africa	West Asia	HI
United Kingdom	Europe	Europe, Northwest	HI
United States of America	North America	North America	HI
Uruguay	Latin America and Caribbean	SA, Southern Cone	HI
Vanuatu	Asia	Pacific	MI-L
Venezuela	Latin America and Caribbean	SA, Andean	MI-U
Vietnam	Asia	SE Asia	MI-L
Yemen	West Asia and North Africa	West Asia	MI-L
Zambia	Africa, Sub-Sahara	SSA, Southern	MI-L
Zimbabwe	Africa, Sub-Sahara	SSA, Southern	LI

Appendix Table 2: Crops included in the analysis

Item Group	Item	Item Group	Item
Animal Products	Bovine Meat	Vegetal Products	Yams
Animal Products	Mutton & Goat Meat	Vegetal Products	Beans
Animal Products	Pigmeat	Vegetal Products	Peas
Animal Products	Poultry Meat	Vegetal Products	Pulses, Other and products
Animal Products	Meat, Other	Vegetal Products	Nuts and products
Animal Products	Offals, Edible	Vegetal Products	Soybeans
Animal Products	Fats, Animals, Raw	Vegetal Products	Groundnuts (Shelled Equivalent)
Animal Products	Butter, Ghee	Vegetal Products	Coconuts - Incl Copra
Animal Products	Cream	Vegetal Products	Olives (including preserved)
Animal Products	Eggs	Vegetal Products	Tomatoes and products
Animal Products	Milk - Excluding Butter	Vegetal Products	Onions
Cereals	Wheat and products	Vegetal Products	Vegetables, Other
Cereals	Barley and products	Vegetal Products	Oranges, Mandarines
Cereals	Maize and products	Vegetal Products	Lemons, Limes and products
Cereals	Oats	Vegetal Products	Grapefruit and products
Cereals	Millet and products	Vegetal Products	Citrus, Other
Cereals	Sorghum and products	Vegetal Products	Bananas
Cereals	Cereals, Other	Vegetal Products	Plantains
Cereals	Rice (Milled Equivalent)	Vegetal Products	Apples and products
Vegetal Products	Rye and products	Vegetal Products	Pineapples and products
Vegetal Products	Potatoes and products	Vegetal Products	Dates

Vegetal Products	Cassava and products
Vegetal Products	Sweet potatoes
Vegetal Products	Roots, Other

Vegetal Products	Grapes and products (excluding wine)
Vegetal Products	Fruits, Other
Vegetal Products	Miscellaneous

Appendix Table 3: Crops excluded from total food supply calculation and therefore omitted in my analysis due to their assumed low contribution to healthy diets and balanced nutrition.

Item Group	Item	Item Group	Item
Luxury Crops	Alcohol, Non-Food	Oil Crops	Oil crops, Other
Luxury Crops	Beer	Oil Crops	Rice bran Oil
Luxury Crops	Beverages, Alcoholic	Oil Crops	Rape and Mustardseed
Luxury Crops	Beverages, Fermented	Oil Crops	Sesame seed
Luxury Crops	Cloves	Oil Crops	Sunflower seed
Luxury Crops	Cocoa Beans and products	Oil Crops	Palm kernels
Luxury Crops	Coffee and products	Oil Crops	Cottonseed
Luxury Crops	Pepper	Sugar Crops	Sugar (Raw Equivalent)
Luxury Crops	Pimento	Sugar Crops	Sugar beet
Luxury Crops	Spices, Other	Sugar Crops	Sugar cane
Luxury Crops	Wine	Sugar Crops	Sugar non-centrifugal
Luxury Crops	Tea (including mate)	Sugar Crops	Sweeteners, Other
Oil Crops	Vegetable Oil	Aquatic	Fish, Body Oil
Oil Crops	Soybean oil	Aquatic	Fish, Liver Oil
Oil Crops	Groundnut oil	Aquatic	Freshwater Fish
Oil Crops	Sunflower Seed Oil	Aquatic	Marine Fish, Other
Oil Crops	Rape and Mustard Oil	Aquatic	Meat, Aquatic Mammals
Oil Crops	Cottonseed Oil	Aquatic	Pelagic Fish
Oil Crops	Palm Kernel Oil	Aquatic	Molluscs, Other
Oil Crops	Palm Oil	Aquatic	Cephalopods
Oil Crops	Coconut Oil	Aquatic	Crustaceans

Oil Crops	Olive Oil	Aquatic	Demersal Fish
Oil Crops	Maize Germ Oil	Aquatic	Aquatic Animals, Others
Oil Crops	Oil Crops Oil, Other	Aquatic	Aquatic Plants

Appendix Table 4: TFP Growth Rankings by quartile (Countries listed by total TFP change, 1961-2013 - 1 is least growth, 4 is most)

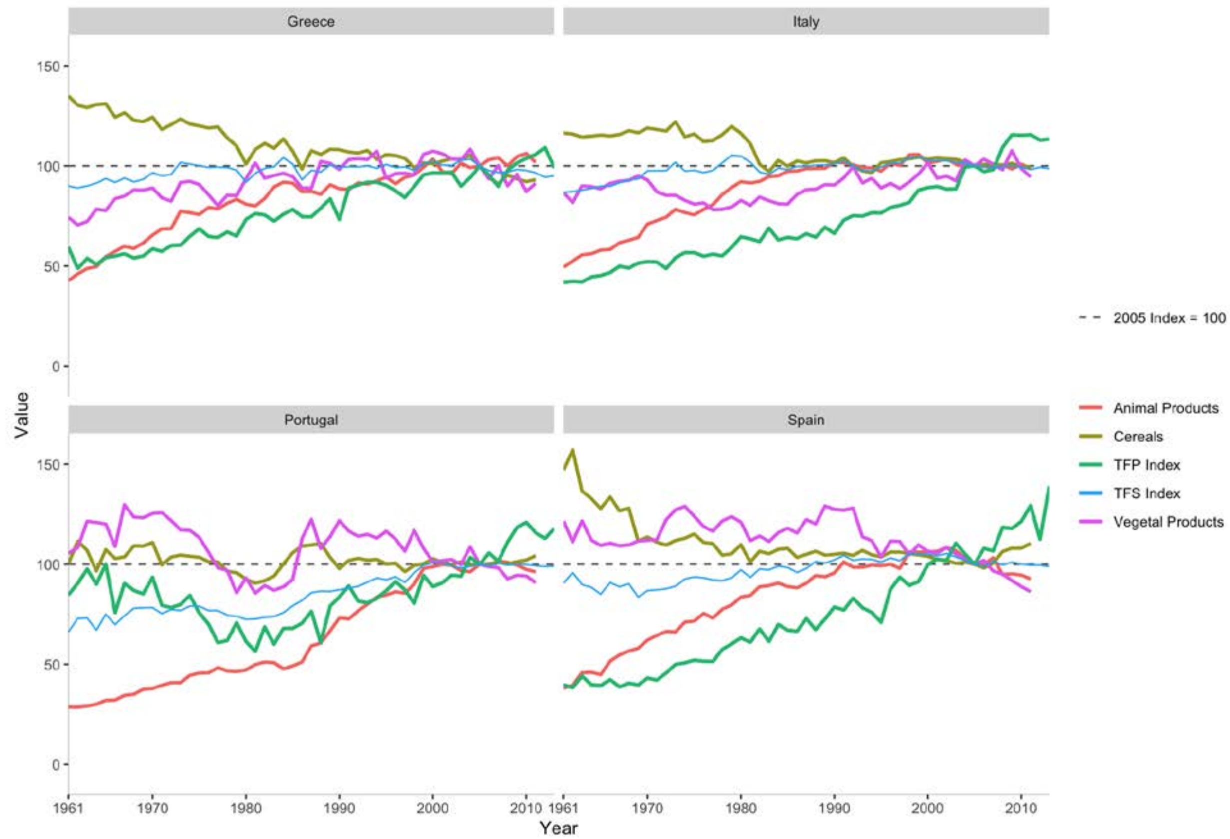
Quartile 1	
Timor-Leste	Iceland
Gambia	Mozambique
Trinidad and Tobago	Niger
Vanuatu	Gabon
Cuba	Congo, Republic
Fiji	Burkina Faso
Liberia	Paraguay
Senegal	Romania
Solomon Islands	Kuwait
Guinea	Afghanistan
Sao Tome and Principe	Madagascar
United Arab Emirates	Zimbabwe
Togo	Nigeria
Uganda	Ghana
Mongolia	Poland
Namibia	Panama
Mauritius	

Quartile 2	
Ecuador	Portugal
Nepal	Chad
Central African Republic	Angola
Côte d'Ivoire	Cambodia
Yemen	El Salvador
Bangladesh	Belize
Bolivia	Argentina
Kenya	Sri Lanka
Norway	Greece
Jamaica	United Kingdom
Mauritania	Sierra Leone
Tanzania	Sweden
Hungary	New Zealand
Ireland	Nicaragua
Switzerland	Cape Verde
Mali	Malta
Guinea-Bissau	

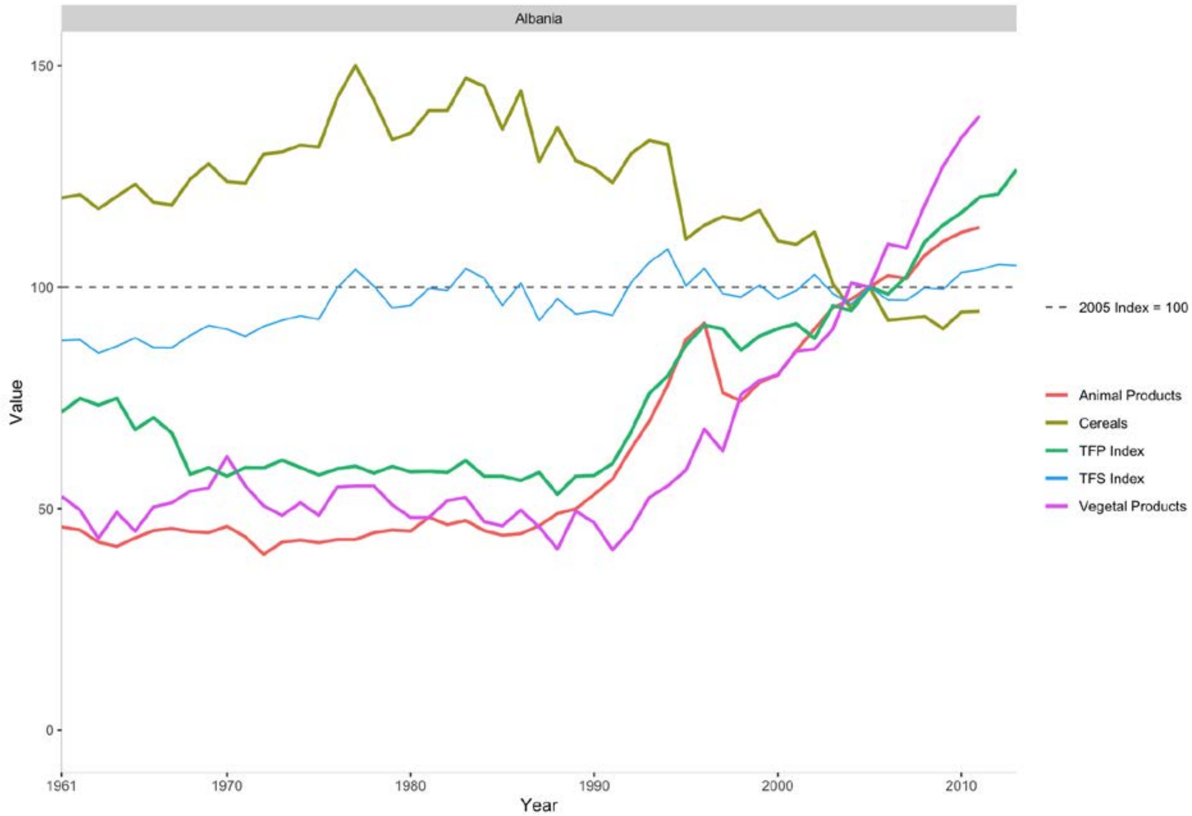
Quartile 3	
Jordan	Albania
Uruguay	India
North Korea	Zambia
Austria	Bulgaria
Honduras	South Africa
Benin	Myanmar
Dominican Republic	Canada
Finland	Bahamas
Peru	Cameroon
Laos	Turkey
Rwanda	United States
Haiti	Iraq
Pakistan	Mexico
Cyprus	Australia
Lesotho	Swaziland
Philippines	Tunisia
Djibouti	

Quartile 4	
Guyana	Netherlands
Indonesia	Iran
Botswana	Brazil
Malawi	Lebanon
France	Morocco
Colombia	South Korea
Japan	Saudi Arabia
Vietnam	Malaysia
Egypt	Guatemala
Germany	Costa Rica
Italy	China
Thailand	Suriname
Chile	Israel
Taiwan	Spain
Venezuela	Brunei Darussalam
Denmark	
Algeria	

Appendix B: Figures

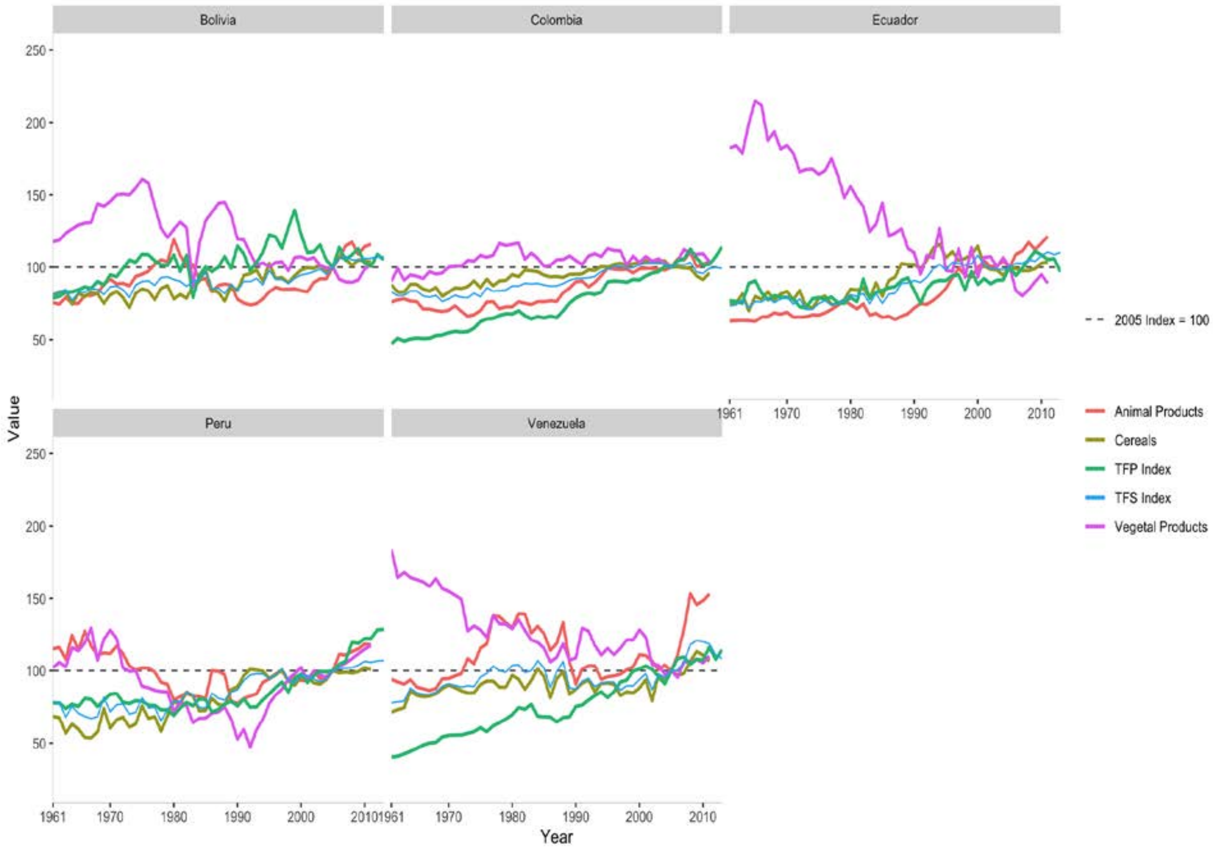


Appendix Figure 1: In Southern Europe, animal product index grows in line TFP better than any other category. A relationship is also evident between vegetal products and TFP in Greece and Italy.



Appendix Figure 2: Albania had a TFP spike in the 1990s corresponding with a rise in animal and vegetable products values, and a drop in cereal TFS.

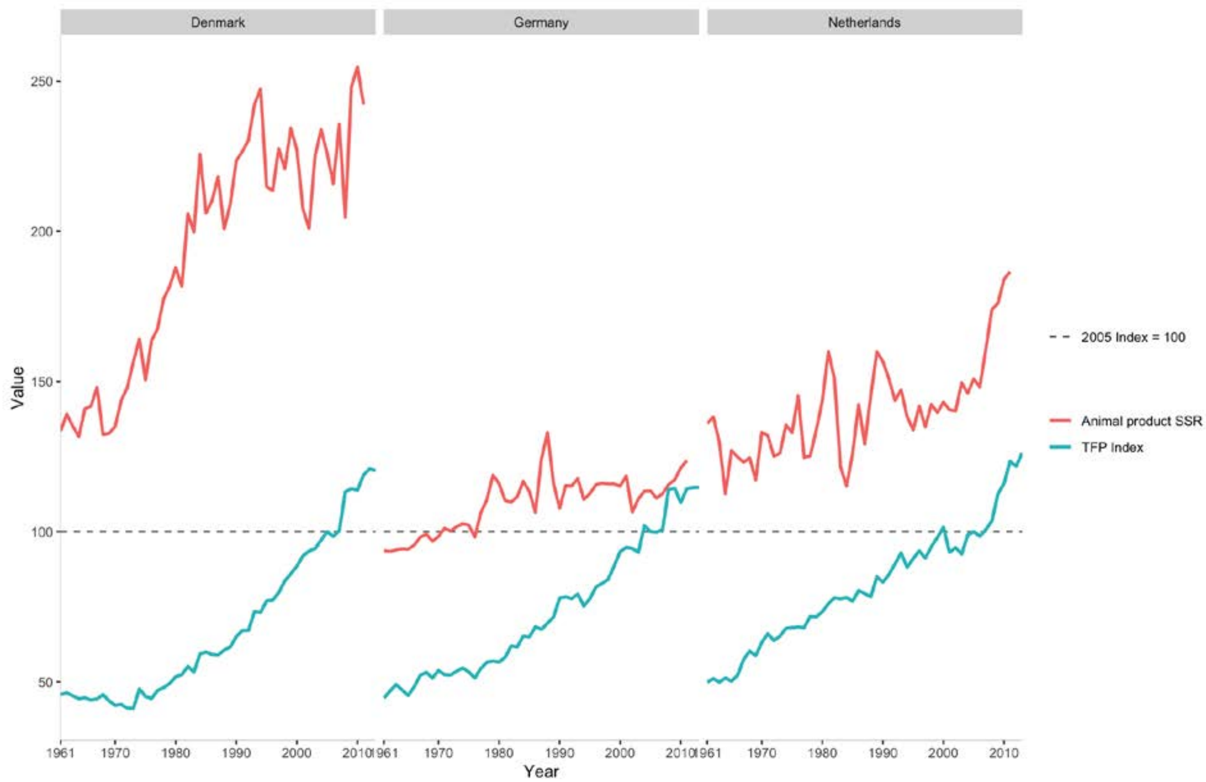
Appendix Figure 3: In Myanmar and Laos, TFP growth patterns betweer align with vegetable and animal product indicies. Even so, it seems that food supply is heavily dependent on cereals, which do not change much over the study period with TFP.



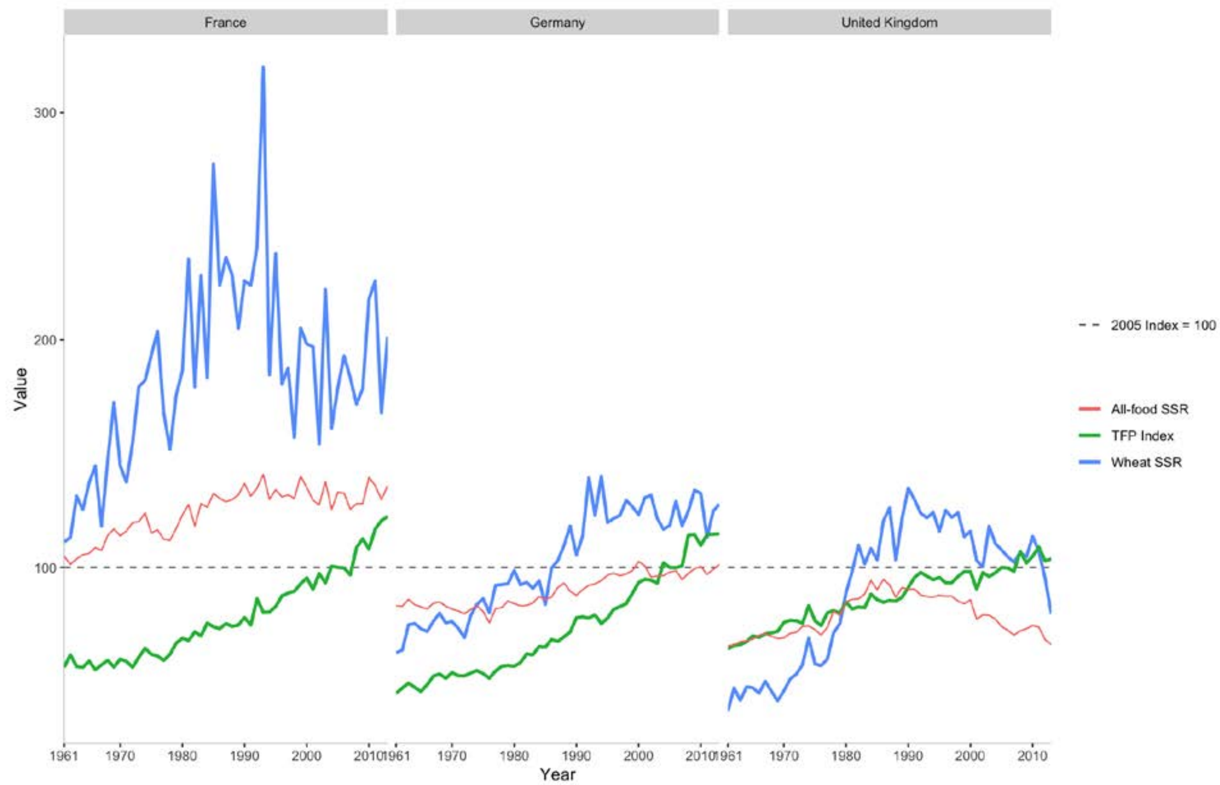
Appendix Figure 4: TFS indices and TFP growth in the Andean Region. Unlike in Central America, TFP growth does not generally reflect any rise in animal or vegetal product indices. Only Colombia shows a consistent rise in animal products that reflects TFP growth well.

Appendix Figure 4: TFS indices in North Africa. Despite consistent cereal product and TFS index growth, TFP growth better aligns with animal and vegetable products.

Appendix Figure 5: The relationship between TFS and TFP indices in Benin, Ghana, and Guinea (after 1980) are well aligned



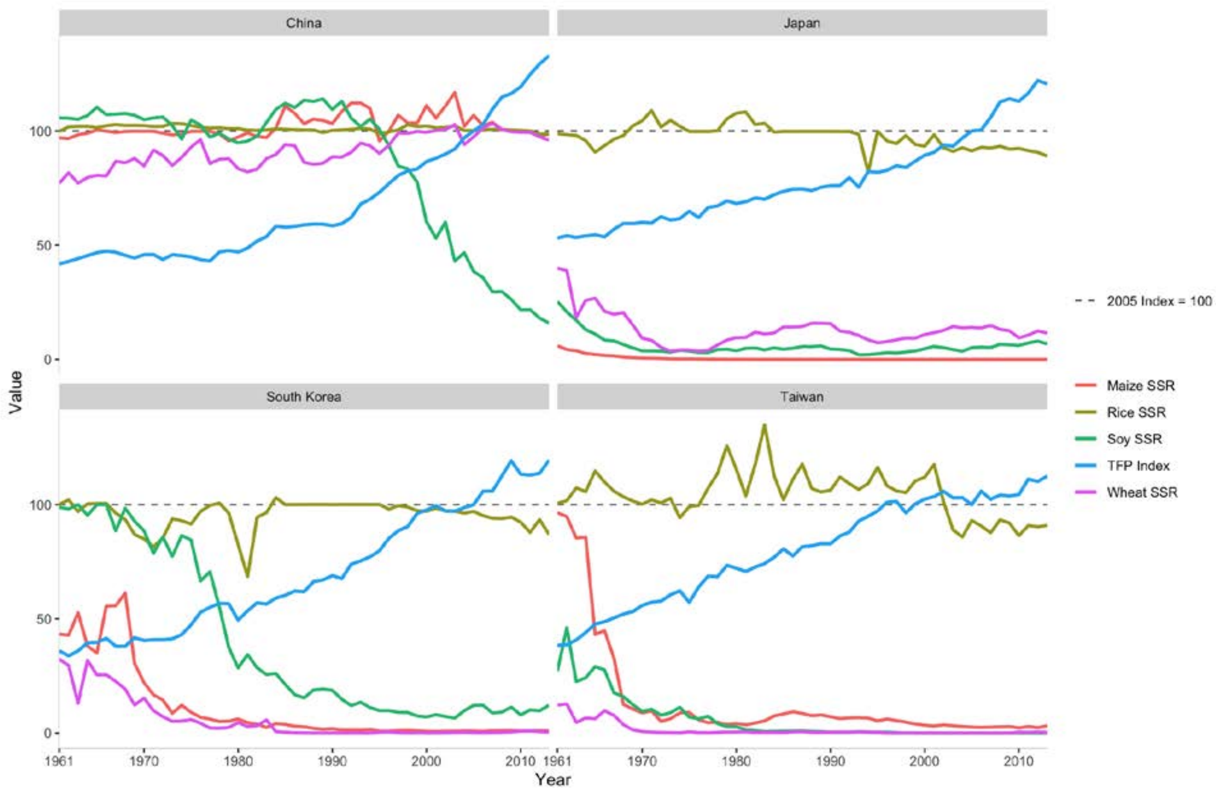
Appendix Figure 6: Animal product SSR values in Northwest Europe compared to TFP growth. SSR increases in the same trend as TFP, indicating increased capacity for animal agriculture brought about by TFP growth.



Appendix Figure 7: Wheat and all-food SSR values in the United Kingdom, Germany, and France compared with TFP growth. In Germany especially, we see a close relationship between the rise of TFP and wheat SSR, indicating increased production capacity. All food SSRs have kept a semblance of a relation with TFP growth in all countries (until 1990 in the UK).

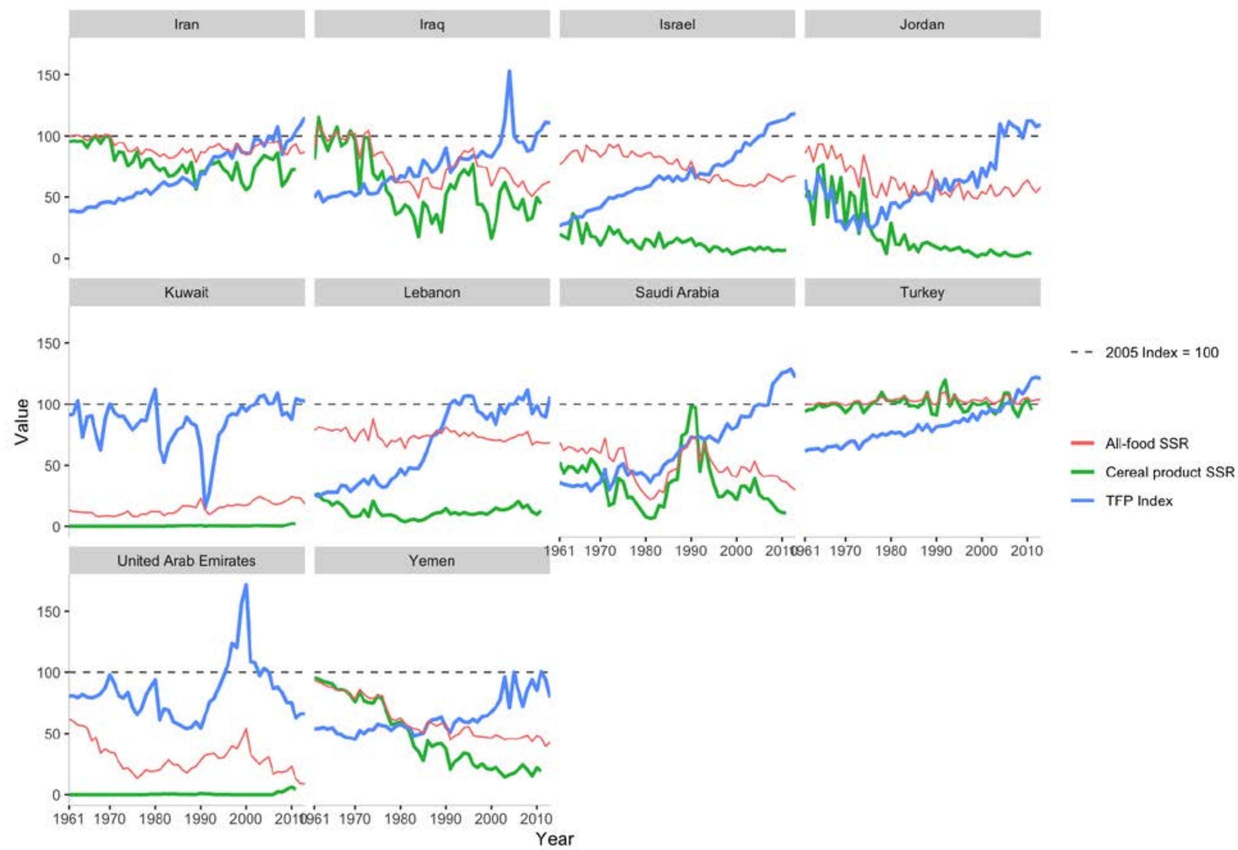
Appendix Figure 8: Consistently high vegetable SSR values in Southern Europe compared to steady TFP growth.

Appendix Figure 9: Wheat, cereal, and all-food SSR in Poland, Romania, and Bulgaria, following the general trend of growth and fluctuations in TFP growth (exlcuding spikes). High SSR values in these categories indicate that these countries have become major producers.



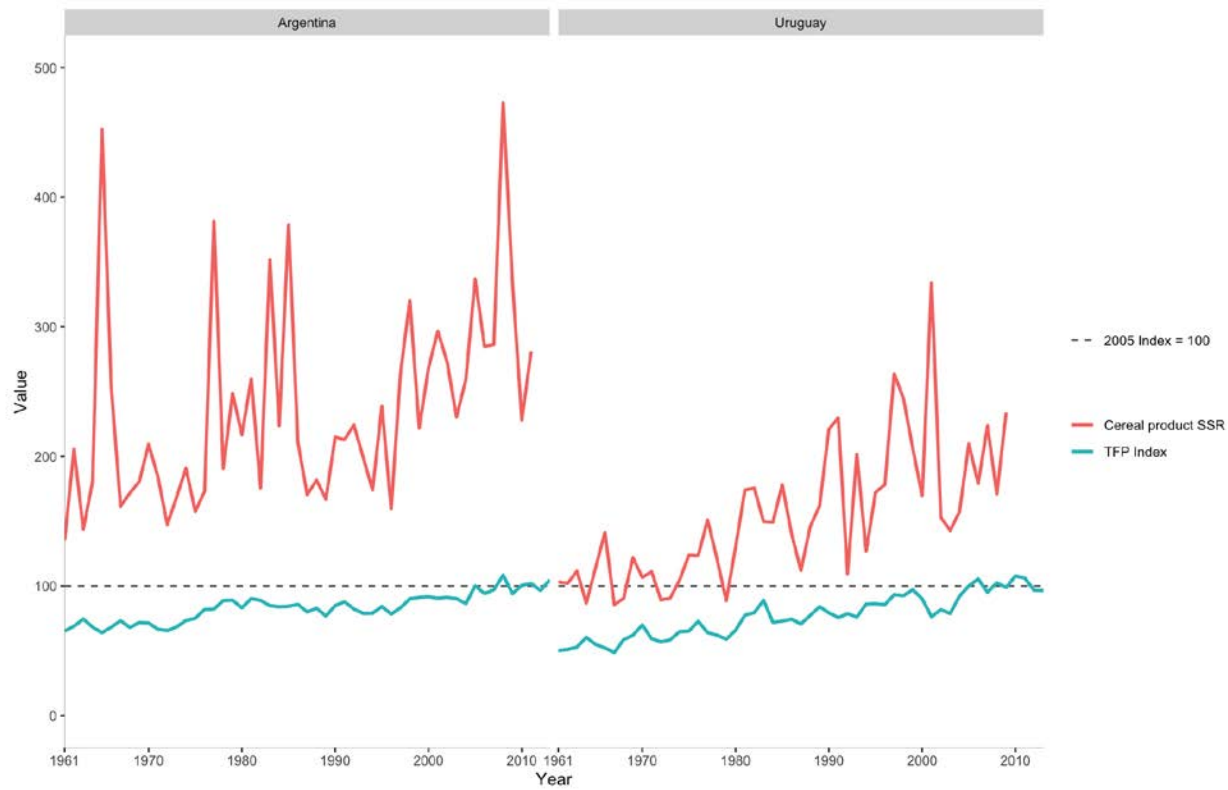
Appendix Figure 10: Staples crop SSR values in Developed Asia and Mainland China. Although all countries maintain rice SSR around 100, China holds self-sufficiency in other staples that Developed Asia has practically ceased to produce. China does experience an incredible drop in soy SSR: this could be an implication of increased livestock consumption in the country, since soy is a common animal feed.

Appendix Figure 11: SSR values in Afghanistan. Notice that drops in SSR value correspond with drops in SSR value, indicating that inconsistent TFP growth leads to inconsistent self-sufficiency status.



Appendix Figure 12: The diversity of self-sufficiency status in Western Asia. Despite steady TFP growth in most countries, only Turkey and Iran have steady all-food and cereal SSR near 100. Cereal values are some of the lowest in the world: even Lebanon and Israel, which have relatively high all-food SSR, is around 0 for cereal SSR.

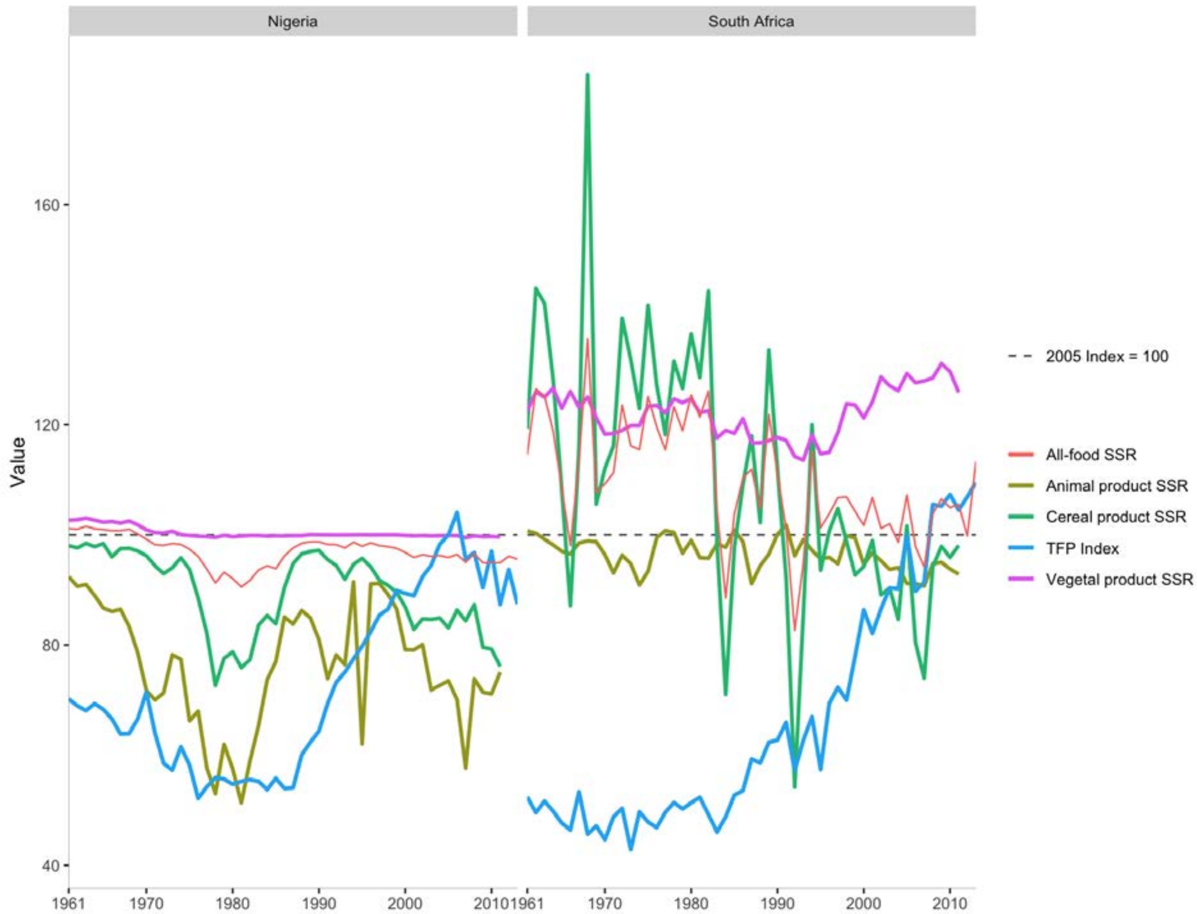
Appendix Figure 13: Exceptionally high vegetal product SSRs in Central America and Ecuador (note that Belize is cropped at 500 to preserve graph scale). This shows a high capacity for production, satisfying both domestic and export needs.



Appendix Figure 14: Cereal product SSR values in Argentina and Uruguay. These incredibly high values over 100 indicate that these countries produce well over the national demand for export rather than domestic food supply.

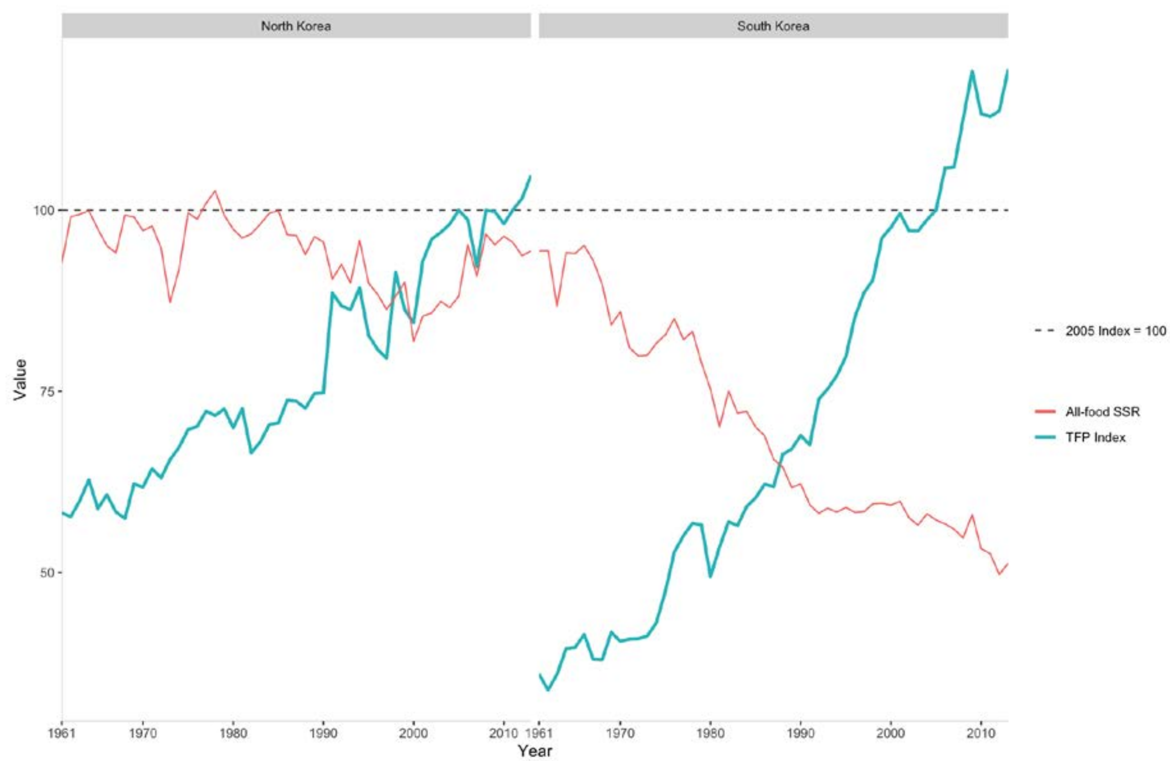
Appendix Figure 15: In Colombia and Venezuela, cereals SSR values are well below all-food values, suggesting that TFP growth likely has not resulted from staple crop production.

Appendix Figure 16: Differing patterns of maize and all-food SSR values in Eastern and Southern Sub-Saharan Africa. It is interesting to note that the sample countries with less TFP growth, Tanzania and Uganda, have less volatility in staple SSR. Vegetal product SSRs stay consistently around 100 throughout the region, regardless of the different levels of TFP growth between countries.



Appendix Figure 17: Comparing SSRs value and TFP growth between South Africa and Nigeria. Both experience steady TFP growth, and manage to keep all-food SSR above or around 100 despite categorical fluctuations.

Appendix Figure 18: Despite TFP growth, North Africa shows fluctuating SSR values, especially in cereal values.



Appendix Figure 19: SSR values in North Korea and South Korea. Note how South Korea's SS level drops steadily, while North Korea experiences fluctuations despite similar TFP growth.