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The Impact of COVID-19 and Associated Policy Responses on Global Food Security

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Agricultural Trade Costs

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Abstract: This article tracks the recent evolution of salient trade costs in agricultural and food markets. We review ways to measure costs and conditions for policy prescriptions to reduce them when feasible. We pay attention to transportation costs, border measures, and standard-like nontariff measures. By pointing out limitations in current approaches and recent developments, we hope to improve our understanding of their effects. We suggest promising directions for further research and investigation of agricultural trade costs, including on the emerging debate on gene-editing and trade, transportation costs, and mainstreaming recent approaches in disentangling effects of trade costs on supply, demand, trade, prices, and welfare.

JEL codes: F14, Q17

Keywords: Agricultural trade costs, transportation, tariffs, nontariff measures

1. Introduction and summary

This article looks at trade costs in agriculture and allied food markets and their recent evolution. By trade cost, we mean that a border is present between parties producing, moving, exchanging, and consuming goods. First, we take stock on what we know so far on major trade costs affecting these markets, and what can be done to reduce them, including guidance from international trade theory. Second, we provide practical suggestions for applied economists to account for these trade costs in economic analysis of agricultural and food markets.

We also indicate interesting data sources and suggest recent methodological approaches to capture and measure trade costs in economic analysis. Finally, the article also points out fruitful areas of future inquiry focusing on trade costs affecting these markets. A special emphasis is dedicated to transportation costs. With a few notable exceptions (for example, Blonigen and Wilson; Hummels; Hummels et al.; and Korinek and Sourdin) applied trade

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economists have neglected the wealth of information available on trade costs associated with transportation. We provide this information for agricultural trade with the hope of raising awareness about these data and fruitful future use of them.

Trade in agricultural and food goods is special in the sense that moving agricultural goods across markets is costly (Hummels) relative to farmgate value. These goods tend to be bulky and/or perishable and can affect human and plant health broadly defined if they do not meet quality standards. These trade costs, expressed as a share of the total value of the shipped agricultural good are high. This in contrast to the cost of shipping high-value manufacturing goods, such as a smartphone over the ocean (a few dollars in hundreds of dollars of the phone value landed in most OECD markets). In ad valorem form, agricultural trade costs are substantial but decreasing.

In addition to physical costs, protectionism lurks in these markets, both using traditional tariffs, tariff rate quotas (TRQs), and nontariff measures (NTMs). In contrast, manufacturing trade has been extensively liberalized in the last 70 years. The trade integration in manufacturing was achieved through multiple General Agreement on Tariffs and Trade (GATT) WTO rounds of multilateral negotiations and regional agreements. Agricultural policy and trade distortions were majorly addressed in the WTO's Uruguay Round Agreement on Agriculture (URAA) starting in 1995. A few piecemeal agricultural policy changes came through the GATT before the URAA, but the URAA was the first comprehensive approach to address the many distortions present in these markets. The uncompleted Doha Round has been essentially stuck with no conclusion in sight. Little progress has been made in a multilateral fashion after the implementation period of the URAA, which ended in 2005. WTO negotiations on maritime transport services (used for agriculture trade) are also stalled.

Regional and bilateral trade agreements have significantly substituted for the lack of progress in multilateral liberalization and have provided a patchwork of unevenly lower tariffs, with some TRQs and the usual few remaining bastions of high protection in dairy, sugar, and cotton fiber. TRQs exist under regional and bilateral agreements, providing restricted access to particular U.S. trade partners like Australia and Dominican Republic-Central America Free Trade Agreement (CAFTA-DR) members, among others, and restricting access to other countries. Trade diversion remains. Gains in transparency have also been obtained on NTMs and via the WTO's Sanitary and Phytosanitary Measures (SPS) and Technical Barriers to Trade (TBT) Committees and the trade-concern process (Orden; and Grant and Arita).

In contrast to this secular trend, since 2017, substantial trade policy disruptions have taken place creating substantial trade costs, using aggressive unilateralism, primarily in the United States. Predictably, the unilateralist policies have been followed by retaliations from trade partners targeted by these measures. Manufacturing sectors were targeted by the United States, but retaliatory tariffs hit U.S. agriculture substantially. Similarly, the temperamental renegotiation of NAFTA and hasty withdrawal from the Trans Pacific Partnership (TTP) agreement have had a disruptive effect on complex supply and value chains in agriculture and food markets (Bellora and Fontagné, 2019). The disruptions could lead to hysteresis from trade costs, with permanent loss of some foreign markets, as explained later. The United States has become a less dependable trade partner with new uncertainty-related costs for our trade partners. The topic of agricultural trade costs is timely.

The structure of the paper is as follows. We first set up a simple approach to characterize trade costs. Then the article reviews transportation policies and costs (policies, freight, insurance), and price and quantity-based trade distortions (tariffs, TRQs, export restrictions) and standard-like measures (NTMs, nontariff barriers, and transparency measures). For each of these trade costs, we review prescriptions from economic theory to reduce them. Following the sequence, we provide some directions for fruitful research on agricultural trade cost. Appendix 1 contains detailed data sources for the trade costs covered in the article.

2. A simple approach

To set the stage, we start with a simple approach, paralleling Calvin and Krissoff, using a simple price transmission equation to express the law of one price between two locations (*A* and *B*) across a border. We account for the exchange rate (*ER*) between the two currencies, per unit transportation costs (broadly defined) between the two locations (*TC*), price-based market-access impediments in both countries (*Tariffs*)[2] , nontariff measures (*NTM*), cost of uncertainty (hedging and insurance for exchange rate, transportation, and other risk), corruption and red tape cost in both countries, subsumed into an aggregate other trade cost (*OTC*). We have:

$$p_B = ER*(p_A + TC_{AB}) + Tariffs_{AB} + NTM_B + OTC_{AB}\,. \qquad (1)$$

This simple approach is elaborated by incorporating imperfect substitution between the goods in origin (*I*) and destination (*D*) countries (Yue et al.; and Liu and Yue) with a simple CES approach of the form $\underset{D,I}{Max} \quad U(D,I,AOG) = (\alpha D^{\rho} + (1-\alpha)I^{\rho})^{1/\rho} + AOG$, with AOG being an aggregate all other good, and parameters α and ρ expressing preferences and the substitution between *I* and *D* ($\sigma = \dfrac{1}{1-\rho}$). This leads to the following price transmission between the source country (good *I* from *A* to *B*) and the close substitute in the destination country (good *D* in *B*) priced at price p_D:

$$p_D \frac{1-\alpha}{\alpha}\left(\frac{D}{I}\right)^{\frac{1}{\sigma}} = ER*(p_A + TC_{AB}) + Tariffs_{AB} + NTM_B + OTC_{AB}\,. \qquad (2)$$

[2] Border duties and other price based distortions can be expressed in ad valorem equivalent (in percent of the border price) or in specific form (in local currency units per physical unit added to the border price). Trade bans (import or export) have a tariff equivalent.

This approach allows us to derive trade and welfare implications, using the resulting demand and expenditure function from the CES structure in a consistent manner. One recovers the law of one price in (2) when σ goes to infinity and α=1/2. The CES structure also lends itself to the gravity framework used in many investigations of trade costs and their impact on trade and welfare. The price p_A itself could be affected by policies in *B*, say, some SPS requirements. Equation (1) and (2) can be amended to reflect these additional costs to export to destination *B,* and then p_A would reflect a general export price to any destination plus the additional cost to the specific destination *B*.

Note that this approach focuses on variable trade costs and does not address fixed costs or prohibitive cost, such as those involved in the extensive margin of trade with new products or new partners (Scoppola et al.; Hejazi et al.). An average fixed cost can be added to the average variable trade costs, and it is scale dependent (Scoppola et al.). This addition is especially relevant for shipping cost as explained below and when thinking of the extensive margin of trade in new markets. Prohibitive trade costs can be accommodated econometrically applying the Kuhn-Tucker approach of Wales and Woodland to corner solution (Yue and Beghin).We briefly mention more elaborate approaches when needed.

Each component of these trade costs in equations (1) and (2) can incorporate a policy subcomponent. As we cover extensive ground already, we stay away from approaches using co-integration methods and thresholds to estimate "non-observable" trade costs, which obfuscate arbitrage between markets (Goodwin and Piggott; Lence et al.; and others). We also abstract from trade cost induced by distortions associated with domestic support via farm programs. We refer readers to the analyses of Smith et al., Orden and Brink, and Orden to learn of distortive effects of these programs and compliance with WTO commitments to reduce these distortions.

3. Transportation costs

It is well established that bilateral trade decreases as geographic distance increases, and distance is a common independent variable within gravity models (Disdier and Head 2008). However, the circumstances where geographic distance is a good proxy for transportation costs (TC_{AB}) is less understood and not straightforward (see Martinez-Zarzoso et al.; and Halaszovich and Krina). Given knowledge of transportation systems, it is possible to be more precise about the transportation costs both captured and uncaptured by geographic distance - even when direct transportation cost data are unavailable.[3] The main components of transportation systems and costs are mode, infrastructure, technology, and policy, which are explained in sequence.

3.1. Transportation Mode

For measuring transportation costs, it is important to identify the transportation mode when more than one mode is probable. For example, ocean freight is the only relevant cost for shipping bulk grains from the United States to Europe or Asia (we need not consider air travel). Bulk shipping from the United States to Mexico or Canada may take place with any of the 3 primary modes (truck, rail, boat). Generally, economies of scale are captured with greater distances because the fixed cost of shipping via truck is less than rail, and shipping via rail is less than boat. Depending on data availability, mode choice is possible to assess though aggregate demand (modal split and behavioral) and disaggregate demand (behavioral and inventory) models.

Freight Analysis Framework data from 2012 - 2018 allows us to compare a bulk versus a perishable refrigerated commodity, and internal versus external transportation mode choices.[4]

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[3] Sources of direct transportation costs are listed in the appendix.

[4] The Freight Analysis Framework is a database that provides estimated historical flows and forecasted future flows of U.S. freight movements. Origin and destination, commodity, and transportation modes are specified. The primary data source is the Commodity Flow Survey, but agricultural movements are estimated using supplemental data (from USDA and Bureau of Census) since agricultural shipments are out-of-scope of the survey. See https://faf.ornl.gov/fafweb/

Figure 3.1 compares cereal grain and meat transportation modes of U.S. exports to exit zones, showing that rail and water transportation is more often used to transport cereal grains. Although the trucking may be more expensive than water or rail transportation of bulk commodities, trucking offers higher transportation service quality in terms of speed and reliability, which bears greater importance for meat. Also, the fact that meat needs to be refrigerated means that capturing economies of scale occurs differently.[5]

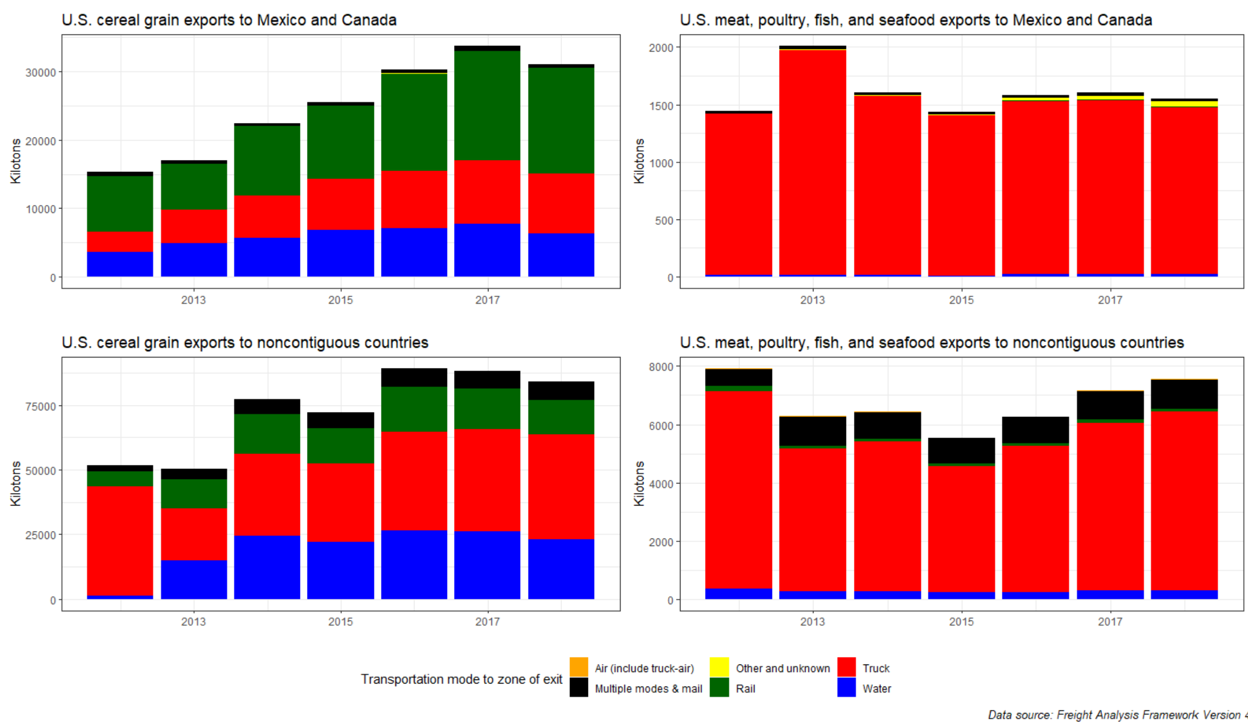

Figure 3.1: Cereal grain and meat internal movements to U.S. exit zones by mode 2012-18

Figure 3.2 compares cereal grain and meat transportation modes of exports from the United States also using data from the Freight Analysis Framework. Both products destined for countries non-contiguous to the United States are almost always exported via boat.[6] However,

[5] Reefer ships with meat in breakbulk are now obsolete, in the modern era meat is containerized and refrigeration occurs at the level of the container. Reefer containers have their own cooling system but need access to the ship power supply. Insulated units do not have their own cooling system, and must be plugged into the ship cooler system. This allows the environmental requirements to be different for each container depending on whether it needs to be frozen, chilled, or controlled (fruit).

[6] Low volumes of higher value meats (such as fish) can be shipped via air to ensure freshness.

most meat exports to Mexico and Canada are shipped via truck, while most cereal grains are exported to Mexico and Canada via water or rail. These graphs illustrate that (1) transportation mode shares for each good vary over time internally and externally, and (2) transportation modes vary based on country-pairs.

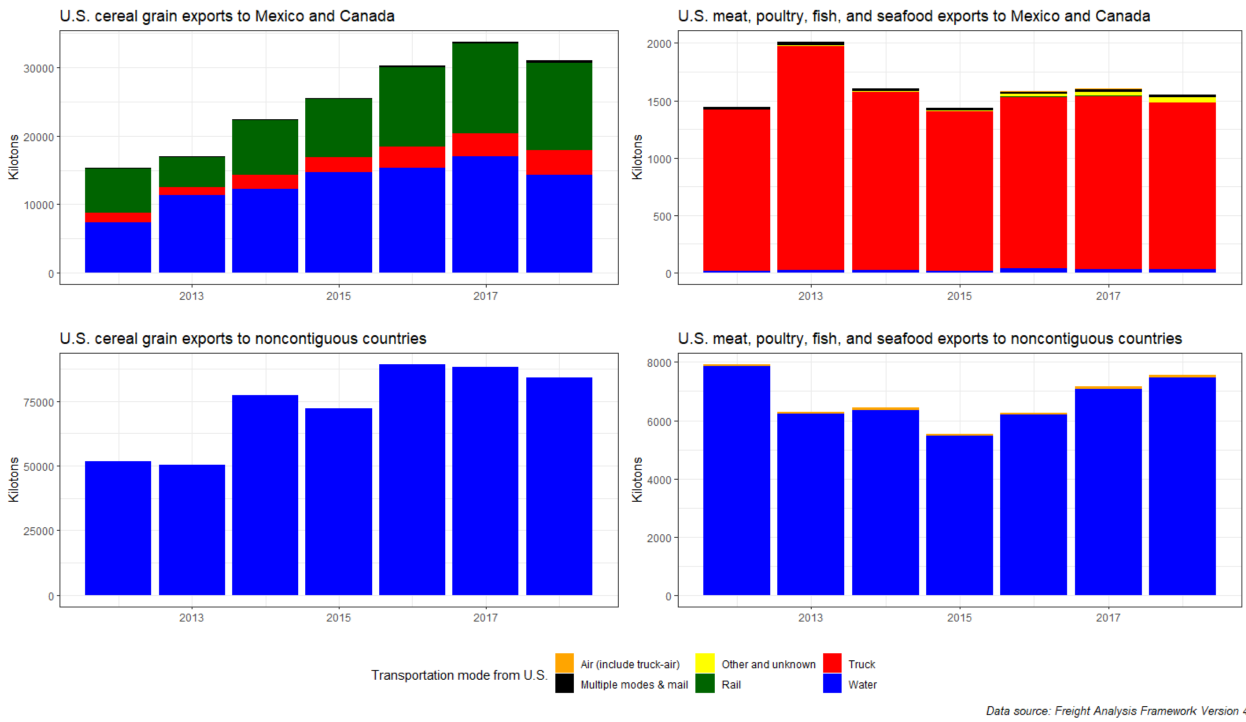

Figure 3.2: Cereal Grain and Meat Movements from U.S. Exit Zones by Mode 2012-2018

Gravity models provide the intuitive result that trade flows decrease when trade friction (specifically transport costs here) increases, however agricultural products have a variety of geographic, physical and market characteristics that can lend themselves to distinctive transportation profiles. Whereas transportation demand is derived demand for an agricultural good, transportation supply consists of terminal costs, linehaul costs, and capital costs. Terminal costs include the handling at the origin, destination, and transloading. Linehaul costs include items such as fuel and equipment maintenance; and capital costs include equipment and infrastructure. These costs are heavily dependent on transportation mode choice and the measurements of transportation supply often address a single supply component for a specific mode. Measurements of physical capacity can include the number of lanes on a highway, which applies to linehaul costs, and the number of cranes at a port, which applies to terminal costs. Similarly, speed measurements apply to linehaul efficiency, while dwell time relates to terminal efficiency. Finally, there are inventories of capital stock in the road/rail/ocean freight networks. These measures can indicate congestion at a terminal or along a route, and transportation equipment availability.

The usual indirect measures correlated with transportation costs included in gravity models are distance (continuous), adjacency (dummy), island (dummy), and landlocked (dummy). Each of these independent variables give insight to transportation mode choices and transportation cost. Islands are only accessible via water or air, landlocked countries are not accessible via water, and every transportation mode will require greater fuel to travel greater distance.[7]

We ideally hope to capture how additional distance or changes to transportation costs affect marginal trade flows as transportation profiles and transportation system performance vary. For example, the marginal change in flows between two countries due to increased fuel prices will differ based on the transportation profile of the commodity. Information about mode can be used to further accuracy, even in the absence of direct cost measurements. Data are often available for transportation mode, or reasonable assumptions can be made, for internal transportation mode of the exporting country, the transportation mode between countries, and the transportation mode of the importing country. Given that transportation costs vary over time and by mode, the information can be used to build a panel with transportation information that varies

[7] A landlocked country may have access to a canal system, but the goods will still need to be transloaded onto a different type of vessel before it reaches the destination country.

over time and by country pair.

3.2. Infrastructure

Because infrastructure determines which inland modes are possible, as well as affecting both the fixed and marginal costs of each possible mode, the quality and quantity of infrastructure can significantly affect trade flows. Often, authors will use or create an index to quantify many facets of infrastructure. Commonly used indices are listed in appendix 1 and most include elements such as the number of distribution facilities, hub throughput and capacity, road/track density, as well as qualitative assessments from industry. Ultimately, these indices reflect the contribution of infrastructure on the supply of transportation services.

While infrastructure is a main component of transportation systems, infrastructure variables are not as conveniently incorporated into panel data analysis compared to other transportation data. First, due to the nature of infrastructure projects, there is often little variation year-to-year. Second, the indices readily available are not specific to the infrastructure facilities relevant to certain agricultural goods (for example bulk or cold chain). Third, specific to the context of trade, expanding transportation infrastructure and increasing trade flows often occur simultaneously, and the direction of causality is ambiguous. For example, Bensassi et al. show infrastructure increases Spanish exports while Nguyen and Tongzon find that growth in trade with China results in Australian transport sector growth.

Complicating analyses for agricultural goods is the fact that agriculture is seasonal, which results in peak-demand times for transportation services. Highly seasonal production strains storage, processing, and transportation facilities causing congestion when transportation demand exceeds transportation system capacity.[8] The pressure seasonality puts on infrastructure is

[8] Likewise, supply disruptions can cause congestion, such as Mississippi River flooding halting barge traffic.

difficult to capture on an annual basis, but could be used to weight annual transportation prices, or provide annual variation on infrastructure availability. Though it is usually more feasible to capture seasonality within a general equilibrium, partial equilibrium, or multi-market model, infrastructure can still provide important insights for agricultural goods if there exists information on the status of critical infrastructure or within-year flows.

3.3. Distortions/Policy

As with the previous components of transportation systems, policies that distort transport costs can be applied at the origin region, along a route between an origin and destination, and in a destination region. Origin (or destination) specific policies may affect internal transportation costs, external transportation costs, or both. External transportation costs may also be affected by trade and environmental agreements.

Examples of U.S. policies that distort internal transport costs – through all three types of transport cost – include the Foreign Dredge Act of 1906 and the USDOT electronic logging device mandate that went into effect in 2017. The Foreign Dredge Act of 1906 prohibits foreign dredgers from dredging in the United States. Rivers and ports require dredging for both maintenance and improvements, and reduced competition among dredging firms ultimately increases the costs of waterway and port infrastructure. Navigation restrictions due to foregone waterway improvements result in excess freight traveling via more expensive modes. Compare this type of policy to the electronic logging device mandate which requires nearly all commercial trucks to have electronic devices recording hours-of-service in addition to other data.[9] Although this policy was not a change in hours-of-service rules per se, it was a large change in the enforcement of these rules. With electronic logs, drivers have less flexibility over how their

[9] There are some exemptions to hours-of-service rules for agriculture. https://www.fmcsa.dot.gov/hours-service/elds/eld-hours-service-hos-and-agriculture-exemptions

dwell time at terminals is recorded, increasing terminal costs. Despite the divergent nature of these policies, they both result in mode-specific changes to internal transportation costs.

Along with the Foreign Dredge Act of 1906, the 1920 Merchant Marine Act (also known as the Jones Act) is an example of national policy that increases external costs. The main segments of the 1920 Merchant Marine Act specify that goods shipped between U.S. ports must be shipped on vessels that are U.S. built, U.S. flagged, owned by a company that is at least 75 percent U.S. owned, and crewed by a minimum of 75 percent U.S. sailors. This policy applies specifically to domestic shipments, but limits options to reposition containers used in international trade.[10] Without a feeder-ship market, containers are shuffled on land resulting in more expensive terminal costs (Bain and World Bank; Frittelli; and Smith et al.).

Finally, the International Maritime Organization (IMO) changed external trade costs for nearly all maritime trade partners with new emissions regulations effective January 2020. The regulation prohibits vessels from using high sulfur fuel oil. The main shipowner compliance options are to switch to marine gasoil or liquefied natural gas, install scrubbers, or scrap the vessel. More expensive fuel directly increases linehaul costs, while converting engines to use alternative fuels and installing scrubbers increase the costs of capital stock. This policy is likely to affect segments of maritime markets differently depending on fleet composition, the possibilities for alternative routes, and the degree to which member states enforce the regulation (Halff).

In general transportation-specific policy will vary most by country rather than over time. As demonstrated in the examples provided in this subsection, the policies for an importer or exporter can have a direct effect on any of the three main types of transportation costs for both

[10] There is an exemption for empty containers.

internal and external trade costs. Also note that these distortions will influence behavior within transportation *systems*.

3.4. Technology

Technology improvements take many forms and may reduce any cost component mentioned in 3.1 – however, some developments in technology have the potential to reduce several cost components at once. This type of technology underscores the system aspect of transportation by allowing for holistic views of transportation movements (and supply chains more broadly). Both private industry and policymakers are placing increased scrutiny on agricultural supply chains following the 2020 coronavirus pandemic and in expectation of increased frequency of extreme weather events. When transportation systems fail to meet demand for an extended period of time, these are defining moments – and these moments are partly responsible for the widespread movement away from just-in-time inventory and supply chain management strategies towards strategies with more robustness and resilience (Behzadi et al.).

Although new technology for transportation equipment is quickly advancing, the innovations that have the greatest promise for reducing costs related to transportation are being made in the inventory and supply chain management spaces. Often overlooked by those outside the industry, freight forwarding firms play an important role in reducing bureaucratic and price discovery costs in transportation markets. Freight forwarders are experts in the complete process of moving freight from an origin to a destination. They manage negotiation of rates, payment, customs paperwork, insurance, and delays. There can be specialization by region, transportation mode, and type of good.[11] The proliferation of tracking and management technologies being

[11] Freight Forwarders will often accept and organize less-than-truckload shipments not accepted by major carriers. However, this is not the case for perishable products as opportunities are infrequent.
These firms are not to be confused with brokers, because forwarders often do handle freight in their warehouse facilities. They are also not to be confused with carriers, because they typically do not own transport equipment.

applied to improve supply chains provide firms in transportation and these adjacent spaces opportunities to improve their service quality. Examples of these technologies include distributed ledgers and remote sensors, which can speed up customs paperwork, verify environmental conditions throughout the journey, and facilitate cross-border contract enforcement.

Measures related to institutions and corruption, such as those available from the World Bank or Transparency International (see appendix 1 for these data sources), relate to bureaucratic costs that occur during transportation and handling that tracking and sensor technologies are targeted towards reducing. Although faster and more reliable border processing can benefit any type of good, perishable products especially benefit from reduced spoilage. Time delays as measured by requirements to export and imports in Doing Business (World Bank) have been shown to reduce trade flows of perishable agricultural goods (Liu and Yue). We expect that implementation of technologies especially relevant to time delays in agriculture trade will improve these estimated effects. In addition to direct measures of technology, measures of institutional quality and importer/exporter dummies can control for some of the variation in transportation technology.[12]

4. The reduction of agricultural tariffs and associated border distortions

4.1. Tariffs

Tariffs are a brunt and untargeted policy instrument, which have historically been a major source of trade costs (Anderson and van Wincoop). Tariff reduction has been a robust policy recommendation to increase trade and improve welfare, both on theoretical and empirical grounds. For example, early work by Hatta and others paved the way to a large theoretical literature identifying sufficient conditions for welfare-improving piecemeal reforms involving

There is some overlap between freight forwarders and third party logistics providers (3PLs) who will also handle supply chain tasks, such as inventory management, in addition to shipping.

[12] Other variables that may control for some portion of transportation technology are largely context-dependent, for an example see Pascali (2017).

tariffs alone and tariffs with other distortions including those affecting agricultural trade (Hatta; Falvey; Neary; Beghin and Karp; and Anderson and Neary). Empirical exercises have also established the welfare gains and distributional consequences of tariff reductions in agriculture and other sectors (Goldin and van der Mensbrugghe; and Anderson et al., 2006).

Agricultural tariff structure is complicated and highly heterogeneous across goods and countries. Tariffs can be specific (x dollars per physical unit) or ad valorem (in percent of unit price p_A) or both combined. In addition, WTO member countries commit to tariff bindings (not to be exceeded) within the WTO. Then they define Most Favored Nation (MFN) tariff which can be applied to transactions with other member countries, or with countries having MFN status without being a WTO member (e.g., China before its WTO membership received MFN status in the United States, renewable yearly).

Further, applied MFN tariffs are often superseded by preferential tariffs established in regional trade agreements (RTAs), such as the US-Mexico-Canada (USMCA) agreement. These RTAs often have their own bindings and applied rates. Many RTAs have reciprocal zero tariffs on many trade flows. Frequently, tariff concessions are subject to rules of origin to preserve the trade diversion created by the RTA, which benefits producers within the RTA and hurt consumers/users in the RTA through higher prices than would prevail with global free trade. This trade diversion also hurts exporters outside of the RTAs. Trade diversion has decreased given the multiplicity of RTAs and the lowering of tariffs in most countries.

Despite the complex and heterogeneous structure, tariffs on agricultural trade are now low on average compared to pre-1995 levels. However, they remain higher than those on manufacturing goods. To illustrate, the United States has MFN bound tariffs averaging 4.9% (ad valorem equivalent) in agriculture (simple average), and 3.2% in manufacturing. Applied MFN tariffs are 3.9% on average in agriculture (trade weighted average in 2017), and 2.2% in nonagricultural sectors. To provide perspective, Gibson et al. estimated that in 2000, U.S. agricultural tariffs were around 12%. Bureau et al. (2019) also show the substantial global decrease in agricultural tariffs from 2001 to 2013.

The distribution of agricultural tariffs indicates that roughly 39% of U.S. agricultural imports enter duty-free, 40.5% enter at rates between 0 and 5%, and 13.5% enter at rates between 5 and 10%. Table 4.1 shows these bound and applied MFN tariffs by sector for the United States, dairy products, sugar and confectionery, and beverage & tobacco remain protected, with limited imports entering duties free. Tariff data are available for most countries (see Appendix 1).

Table 4.1. U.S. Tariffs and imports by product (from WTO online)

Product groups	Final bound duties				MFN applied duties			Imports	
	AVG	Duty-free in %	Max	Binding in %	AVG	Duty-free in %	Max	Share in %	Duty-free in %
Animal products	2.4	30.8	26	100	2.3	30.8	26	0.5	26.4
Dairy products	19.2	0.3	127	100	19.6	0.3	127	0.1	12.9
Fruits and vegetables, plants	5.0	20.2	132	100	4.7	20.9	132	1.6	24.6
Coffee, tea	3.0	53.5	23	100	3.0	53.5	23	0.5	74.4
Cereals & preparations	3.6	21.0	47	100	3.1	20.1	47	0.7	35.7
Oilseeds, fats, & oils	4.5	23.9	164	100	7.3	25.9	164	0.4	34.0
Sugars and confectionary	13.1	2.9	67	100	14.5	2.7	57	0.2	5.9
Beverages & tobacco	15.1	27.7	350	100	18.4	25.1	350	1.2	49.3
Cotton	5.0	38.3	19	100	5.0	38.3	19	0.0	78.5
Other agricultural products	1.2	58.9	51	100	1.1	61.0	51	0.4	66.5

4.2. Tariff rate quotas (TRQs)

To further complicate matters, several of these imports, often deemed "sensitive products" are regulated with tariff-rate quotas (TRQs), a two-tier tariff scheme. To increase market access, the WTO created TRQs to replace quotas by structuring a low tariff (in-quota tariff) for imports up to the existing or former quota and a much higher tariff (out-of-quota tariff) for imports above the quota (Boughner et al.; and Moschini). TRQs continue to create inefficiencies as former quotas did. The hope was that in subsequent WTO negotiations, two-tier tariffs could be reduced, and quotas expanded. This has not taken place, although quota allocations have expanded through RTAs and preferential trade agreements (PTAs). The administration of TRQs has been a recurrent issue in some countries (Boughner et al.; Chen et al.; and Orden), but not all (e.g., see Barichello on Canadian dairy TRQs). TRQs remain unfilled because rights to exports were allocated to uncompetitive exporters. Rights to import are often allocated inefficiently when there is no mechanism to re-allocate the rights when they are not used, leading to quota under-fill. In some cases, protectionism is the motive to systematic under-fill of the quota, such as found in the US-China dispute (DS517) on Chinese TRQ management for grains (Orden).

In their simplest form, TRQs introduce a discontinuity in equations (1) and (2) with the tariff change once the quota is filled (Moschini; and Boughner et al.). Out-of-quota tariffs are often prohibitive. This possibility complicates the computation of the trade cost element of the TRQs, since the out of quota tariff will overstate the cost of the price-equivalent effect of the TRQ when it is binding. In addition, quality upgrades can occur when exporters face managed trade or when shipping cost per unit is fixed, reducing the relative price of the higher quality good (Ramos et al.). These reasons can lead to "shipping the good apple" out (Ramos et al.; and Hummels and Skiba). TRQ data are widely available from the WTO and other sources.

4.3. Regional and preferential trade agreements

The key reason agricultural tariffs have fallen globally reside in RTAs and PTAs. For example, when looking at trade with RTA partners, the United States has much lower tariffs on its imports than the applied MFN tariff rates suggest. Specifically, most agricultural imports coming from Canada and Mexico enter duty-free (92.3% of agricultural tariffs lines for Canadian exports and 97.5% of tariff lines for Mexican agricultural exports) representing 99% of agricultural trade value with these countries (WTO, 2019). Here again, a few agricultural trade flows within the

USMCA are restricted by TRQs (e.g., Canada dairy imports) and managed trade (sugar flow from Mexico to the US). Despite these exceptions, agricultural trade flows have been greatly and globally liberalized with RTAs, such as the USMCA and continue to be with new agreements such as the Comprehensive and Progressive Trans Pacific Partnership (CPTTP).

Beyond tariff schedules, countries use safeguards and countervailing duties (CVDs) in some special situations, in general, involving some injury or disruption test. The latter can be subject to political pressure, as it was the case for rising sugar imports from Mexico to the United States in 2013-14, leading to U.S. anti-dumping and countervailing duties on Mexican sugar coming into the United States. These duties were later suspended in favor of a managed trade regime capping Mexican exports to the U.S. market (Beghin and Elobeid). The reliance on safeguards and CVDs has not led to major trade impediments. To illustrate, from 1995 to end of 2019, 185 safeguard measures have been notified to the WTO (see 550a) on safeguard measures). When compared to other policy notifications, this number is small. India, Indonesia, and Turkey are the largest initiators of safeguards. 18 dispute cases have mentioned safeguards in agriculture and food markets. A single contentious safeguard often leads to multiple dispute cases by different WTO members.

Many OECD and other advanced economies have been entering a series of RTAs since the early 1990s, at a steady pace (see WTO Regional Trade Agreements Database). In addition, the coalitions of members in some of these RTAs have become large (e.g., eleven countries in the CPTPP, various EU-27 agreements with other countries).

Tariffs have also decreased through unilateral decreases, outside of agreements as documented by Bureau et al. (2019). Finally, tariffs have fallen via various PTAs, which provide non-reciprocal tariff concessions, many of them to least developed or developing countries. These PTAs have increased market access in many OECD countries. Rules of origin constrain these concessions, however. Major agricultural tariff concessions have been made with PTAs as illustrated in Table 4.2 for the United States, with many tariff lines being tariff-free, under Generalized System of Preferences (GSP) and the African Growth Opportunity Act (AGOA) (Tadesse, and Fayissa; and Williams). The EU made comparable concessions under the Everything but Arms Initiative (EBA) (Brenton).

These tariff concessions have had a more limited impact on agricultural exports of less developed countries (LDCs), because of rules of origin, TRQ exclusions, SPS requirements, and other supply chain constraints in countries eligible for the tariff concessions. To illustrate these tariff patterns, in 2018 the United States imported about $128 billion of agricultural goods, of which 39% entered MFN duty free; $20 billion came from countries beneficiaries of GSP extended by the United States, 80% of which entered under PTA or RTA benefits; agricultural imports from LDC-beneficiaries amounted to $1 billion, 80% of which entered under PTA or RTA benefits (WTO PTA database). Over time, tariff preferences under PTAs have eroded relative to prevailing tariffs outside of the PTAs, because countries entered RTAs or gained market access under MFN tariff concessions under the URAA (Bouët et al.; Bureau et al., 2006).

An important element of most RTAs and PTAs is the expectation and commitment to transparency. WTO members provide sufficient information on the various concessions they make on tariffs, the associated rules of origins, NTMs, such that trade partners can take advantage of these concessions. Transparency is addressed more in depth in the section on NTMs.

With these two trends (larger and more numerous RTAs), agricultural tariffs have continued to fall globally, despite the lack of progress in the Doha Round of negotiations of the WTO for further agricultural tariff cuts, and despite the trade policy departures initiated by the Trump administration and the resulting higher tariffs facing U.S. commodity exports.

4.4. The Trump trade integration hiatus

The U.S. departures in trade policies include exiting the Trans Pacific Partnership agreement (TPP) in early 2017, raising tariffs on trade partners in a return to “aggressive unilateralism,” not seen since the Reagan era, in the last three years (Elliott and Richardson; Elliott and Bayard; Fajgelbaum et al.; and Orden). The hiatus also includes stalling the Transatlantic Trade and Investment Partnership (TTIP) negotiations with the EU, and making the WTO dispute settlement and appeal processes nearly inoperable (Orden; and Bown and Irwin). The latter was undertaken by blocking the appointment of judges of the WTO Appellate Body. As reported by Elliott and Bayard and Elliott and Richardson, unilateralism in the 1980s rarely led to trade wars and was moderately successful at gaining market access. In contrast, the trade war with China and other partners on metallic and other products has been bruising for U.S. agricultural commodities (and other sectors), with no end in sight. The unraveling of the phase-one US-China agreement and unmet agricultural export targets are new realities (Balistreri et al.; Chepeliev et al.; and Orden). Many retaliatory agricultural tariffs remain in place and market access has not improved significantly, especially under the disruption brought by the global pandemic.

In addition, Mexico was pressured by the Trump administration to renegotiate NAFTA with threats of tariffs being re-imposed on its trade flows as late as June 2019. The negotiation has taken place in the context of Mexico having 14 FTA/RTAs in place with 50 countries including the EU-27 and EFTA countries, the 2018 11-member CPTPP, and the upgraded USMCA (Villarreal, 2017; WTORTA, 2020). In the last two decades, Mexico has signed a series of RTAs with Central and Latin American countries to integrate into the Americas beyond the USMCA. An implicit objective has been to diversify its export prospects and decrease its dependence on the U.S. market for its exports. The actual gains to U.S. agriculture and economy from the USMCA are modest (Chepeliev et al.) relative to the original NAFTA.

Finally, the Trump administration's early decision to not ratify and leave the TPP agreement was a major blunder, which has penalized U.S. agricultural exports through trade diversion (Bown and Irwin). The remaining eleven TPP partners concluded the CPTPP, which provides preferential market access to its members. U.S. exports are penalized by tariff differentials in these countries unless an agreement exists with that country. For example, Australian beef gets into Japan at a lower tariff rate than U.S. beef does. The United States has agreements with Canada, Mexico, and Japan, which mitigate the trade diversion. Nevertheless, a major opportunity has been lost.

4.5 Export distortions, and bans

Agricultural export distortions were much restricted under the URAA and eventually eliminated through a multilateral agreement in 2015 (Orden). The EU removed most of its agricultural export subsidies with its EU Common-Agricultural-Policy reforms, which became unsustainable under the EBA initiative and commitments under the WTO. Implicit export subsidies remained an issue through other components of farm policies distorting world trade. For example, the former U.S. cotton program, which led to the long US-Brazil dispute at the WTO (DS 267), provided implicit export subsidies and distorted world cotton prices. The current U.S. cotton program is potentially as distortive as the older one, with a negative effect on world prices (Smith and Glauber). Fortunately, this type of egregious case is uncommon.

The topic of export distortions has re-emerged in the ramping up of world prices in 2005-10 but with a twist. Export restrictions were the new issue rather than subsidies. Countries with large grain production, especially rice, imposed export restrictions attempting to secure cheaper domestic supplies. These restrictions actually exacerbated the original price increases (Martin and Anderson) and induced further price volatility and uncertainty by lack of collective action. With the 2020 global coronavirus pandemic, worries were voiced again that some countries might re-iterate with grain export restrictions (Martin and Glauber; WTO, 2020b; and OECD, 2020), although so far these trade impediments have been limited. Ample world supplies temper the concerns of price increases.

5. Nontariff measures (NTMs)

5.1. Trade costs related to standard-like NTMs

Standard-like NTMs have proliferated in the last twenty-five years as suggested by annual reports of the SPS and TBT committees of the WTO. For example, In excess of 26,000 SPS notifications have taken place at the WTO since 1995 (SPSIMS WTO). An even larger amount of TBT notifications has taken place (see WTO IMS). Perishable agricultural products tend to be subject to more regulations and standards (Disdier and van Tongeren; Grant and Arita). These measures have created trade frictions, and concerns among trading partners, many officially reported at the WTO. For example, 469 SPS-specific trade concerns have been logged with the WTO SPS Committee (as of July 2020) and 49 formal disputes have been initiated citing the SPS agreement, leading to 19 fully developed cases. Similarly, official concerns and disputes have been caused by TBTs, many of them affecting trade of agricultural products. So on face value, standard-like measures have been a major source of trade costs.

Many of these concerns have remained unresolved (see Figure 5.1, and Grant and Arita for a detailed analysis of SPS concerns up to 2017). Specifically, out of the aforementioned 469 SPS concerns, 267 of them remain unresolved. Only 168 (36%) of them were fully resolved, and 34 were partially resolved. Similarly, the Dispute Settlement mechanism at the WTO offers a slow resolution to disputes, especially on SPS matters. Disputes are long enough to cripple any foreign firm with unfair practices for years. Even when disputes reach a conclusion, the condemned practice may remain in place at a small price. To illustrate, the US-EU dispute on growth hormone took 13 years to be resolved and the EU market is still closed to U.S. beef, which comes from animals having received growth hormones. The EU is willing to face U.S. duties on selected products for not opening its market, and has allowed some hormone-free U.S. beef to enter the EU.

Frictions and disputes on SPS and TBT measures related to food also reflect cultural differences with respect to food, beyond protectionist motives. Josling, and Heumueller and Josling have offered a lucid disambiguation of these two motives as they looked at food labelling requirements for GMO-free products. They explain how to consider ethical considerations such as the desire to eat GM-free food and the right to avoid deceptive practice. Simultaneously, protectionism can be minimized by requiring evidence of consumer preferences for a label or characteristic.

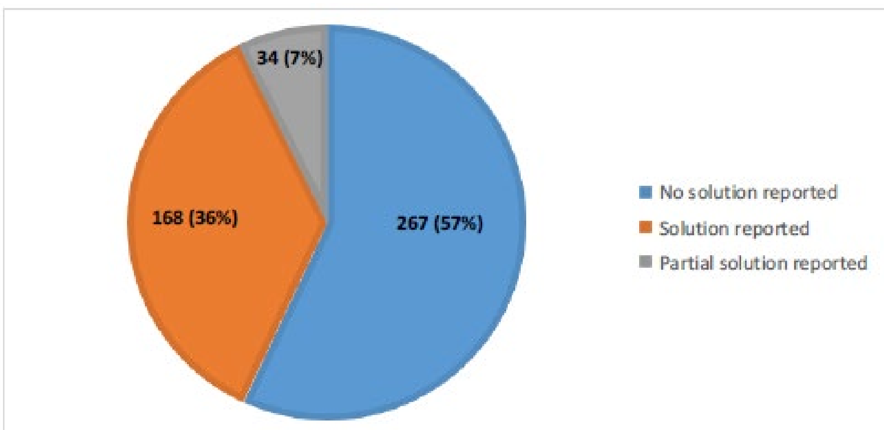

Figure 5.1. WTO SPS concerns from 1995-2019 and their resolution (Source: WTO 2020)

Despite these NTM frictions, agricultural trade has expanded vastly during the same period, as noted earlier. Hence, the frictions have not constituted prohibitive barriers, except for outright import bans, many of them during epizootic episodes. Back-of-the-envelope estimates by Grant and Arita suggest that SPS concerns have had large negative effects. However, more formal analysis would be enlightening. Transparency requirements and periodic consultations in many trade agreements have helped to contain trade costs associated with SPS concerns, as we explain below.

The remainder of this section describes the trade costs associated with these standard-like measures and their impact on trade and welfare. We first review the simple economics of these standards, then we address their potential protectionism. We then discuss transparency requirements present in many trade agreements and their impact on trade costs associated with NTMs.

5.2. The economics of standard-like NTMs

The economics of standard-like NTMs have been extensively covered, notably by Josling et al. (2004), and in earlier investigations (e.g., see Bureau et al., 1998; and Tian). Standard-like NTMs include technical barriers to trade (TBTs) and SPS regulations, as well as other "technical" NTM policies affecting the quality or the way goods are produced and marketed to final users. See the MAST classification for more details on these policies (UNCTAD). These NTMs have common effects on markets, which allow economists to use a common economic approaches to analyze them.

Broadly speaking, they affect the supply of a good by increasing its cost at the margin, by using extra resources to meet the standard or requirements of the policy. This often has a negative impact on domestic supply and competing imports in the sense of increasing their marginal cost, sometimes asymmetrically, depending on the relative ability of domestic and foreign suppliers to meet the standard. In addition, the standard may affect the demand for the good, as consumers may react to the standard if they know about it. For example, lower pesticide residue levels may induce consumers to consume more of a good. A warning label may deter consumers and shift demand to the left. These effects of standards are summarized for a small country case (with an exogenous world price, *wp*) in Figure 5.2 borrowed from Beghin et al. (2015a).

In the Figure, domestic supply *y* shifts to the left to *y'* once the policy NTM is in place. World supply also shifts up to reflect the additional cost of meeting the new standard. The new additive cost is expressed in ad valorem equivalent, *t(NTM)*. The new world supply is now at *wp+t(NTM).* In the same figure demand *x* is shown to have shifted to the right to *x'*, presumably with a policy measure, which encourages consumers to consume more, say, because the product is now known to be safer or more nutritious. What is the trade cost effect of this NTM policy? The answer depends on what impact is being measured. The unambiguous impact on prices is a higher border price (from *wp* to *wp+t(NTM)*).[13] The impacts on trade and consumption are often ambiguous. Imports could increase because domestic supply has shifted to the left and because demand has shifted to the right. These two effects have to be compared to the impact of the higher price on imports. Similarly, the effect on net consumption may be ambiguous, comparing the price impact and the demand shift to the right.

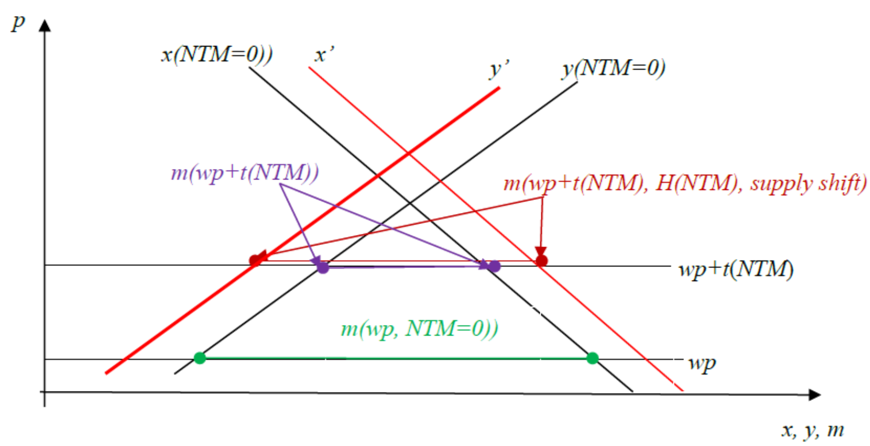

Figure 5.2. The impact of a standard-like policy on supply, demand, price, and trade

This simple framework strongly suggests that inferring trade cost from the impact of the NTM on trade flows will be complicated if not erroneous, if the impact is not decomposed into a

[13] See Cadot et al. for a discussion of the increase in price induced by NTMs. One could come up with some extreme counterexample of a world price decreasing because of a new standard, but this is farfetched in most cases.

price effect and the respective impacts on domestic supply and demand. This problem has plagued many investigations of standard-like NTMs, which have found positive, negative and insignificant effects on trade. Significant negative effects are often posited without rigorous justification or imposed on data from misguided intuition, using the analogy of tariff and border taxes.

The majority of empirical investigations have focused on the net trade impact without decomposing the separate impact on supply and demand. For details on these various estimated effects, see the meta-analyses of Li and Beghin (2012), and Santeramo and Lamonaca, and the review of Beghin et al. (2015b).

This is not to say that other NTMs are not trade restrictive or protectionist (See Hillman for an example of such a case). The UNCTAD MAST taxonomy and NTM database provide an extensive list of NTM distortions, other than technical NTMs (the standard-like measures discussed here) (UNCTAD; and de Melo and Nicita). Figure 5.2 also suggests that market imperfections, such as externalities and asymmetric information can be remedied by these standards (e.g., the shift of demand reacting to information). In general, one needs a more complex framework to address the market imperfection (see Disdier and Marette; van Tongeren et al.; and Wilson and Anton for partial equilibrium approaches; and Beghin et al., 2015a for an economy-wide approach).

Beyond getting rid of protectionist standard-like NTMs, international trade theory does not provide guidance on welfare improving policy reforms. This is unlike for taxes and tariffs. Establishing protectionism takes place at two levels, one easy one, and one more complex. The easy tests of protectionism deal with the violation of basic tenets of WTO agreements (Hooker and Caswell). Standards have to be based on a risk assessment and proper science, or address potential informational asymmetries (Wilson and Anton; and Grant and Arita); they have to meet domestic treatment (no discrimination between domestic and imported of like-products). Precautionary measures cannot last without establishing the science; and all measures should be least-trade restrictive for a given correction level of a market imperfection (see Marette for the analysis of the choice of instruments).

The WTO also encourages but does not require use of international standards, such as those established by CODEX Alimentarius. As countries face specific conditions, a standard could deviate from international ones without being presumably protectionist. However, systematic deviations from international norms to impose more stringency than that implied by international standards should be met with skepticism. Li and Beghin (2014) provide such investigation on pesticides and veterinary drug residues. They show that the EU, Taiwan, Australia, and Turkey systematically exceed the stringency of CODEX when they set their standards. Beyond the issue of level of the NTM policy instrument, the enforcement of these policies could also be protectionist, say, using arbitrary inspection criteria leading to refusals (Grundke and Moser; and Baylis et al.).

Beyond these simple tests, establishing protectionism is more complex, in the presence of market imperfections. The presence of market imperfections justifies the presence of a standard-like NTM, but its exact level of stringency has to be determined. Baldwin (1970) and (2000), and Fisher and Serra define the non-protectionist standard as the one maximizing global welfare. A domestic social planner maximizing just domestic welfare could set up the optimum standard at a protectionist level, inducing a barrier to imports and hurting importers (Fisher and Serra). The criterion is conceptually clear but difficult to implement empirically for at least two reasons. First, many standards and policies are set at once leading to the issue of how to account for their interactions and optimum levels. Second, what “global” means is quite subjective in terms of the country and market coverage (close substitutes, cross-price effects).

In addition, several authors have added political economy dimensions to the analysis of protectionism of technical measures. This addition generates more ambiguity in results. The standards can actually be set below their optimum level and be anti-protectionist, depending on rent-seeking influence and the ease of meeting the standard for example (Swinnen and Vandemoortele, 2008 and 2011).

The last element to integrate is the transparency of standard-like NTMs. Non-transparent standards act as a tax on trade and reduce welfare, independently of their level of stringency. We discuss transparency next.

5.3. Transparency and trade costs

Transparency is an intuitive yet vague concept. In the context of the WTO, it means clarity in regulating economic activity and trade. The objective is to achieve a greater clarity, predictability and information about trade policies, rules and regulations of WTO Members. A pivotal element is the use of notifications. Under the SPS Agreement, notifications are used to inform other Members about new or changed regulations that may significantly affect their trading partners. Transparency under the SPS Agreement also includes answering reasonable questions, and publishing regulations. Trade costs induced by these NTMs can increase when these policies are not notified properly or not spelled out properly.

Beyond the WTO, many RTAs have transparency clauses or chapters on proper notifications, approval processes for biotechnology innovations, reciprocity, and other measures to reduce unnecessary transaction costs to meet these NTMs.

RTAs with "deep integration" objectives do reduce the price wedge (*t(NTM)*) (shown in Figure 5.2) created by standard-like NTMs, as shown by Cadot et al., and Cadot and Gourdon. The latter authors decompose the impact of NTMs on prices and supply and demand in a unique framework combining price differential created by NTM policies, and the framework of Xiong and Beghin to decompose the impact of standard-like NTMs on supply and demand. They find that RTAs with more extensive transparency measures reduce the price wedge created by NTMs. Transparency remains difficult to measure, despite some attempt to formally conceptualize what it is (van Tongeren).

While it is difficult to pin down an estimate of the cost of the lack of transparency, recent studies (Ing, et al., 2017; Lejárraga et al., 2013)) have estimated the implicit reduction in trade cost from transparency efforts in nontariff measures, often achieved through deep integration. Several studies rely on a gravity approach using variation in perceived government transparency broadly defined. Lejárraga et al. (2013) reviewed a large number of RTAs and collected their transparency provisions (e.g., notification requirements for SPS and TBT). The collected variables are incorporated in a gravity framework to gauge their effects on bilateral trade flows. Not surprisingly, the transparency provisions do facilitate trade with RTA members.

Ing et al. follow Wolfe and his 3-levels of transparency requirements in the WTO (early requirements through notification obligations in the GATT, monitoring through countries policy reviews, and finally dissemination of information through web-based instruments and portals). Portals are mandated by the 2014 WTO Trade Facilitation Agreement (from the "Bali" agreement). The latter information allows for direct measurement of transparency measures rather than perceptions using NTM inventories. Ing et al. construct a transparency index for 187 countries, available in the appendix of Ing et al. The index is currently a cross section index but could be updated into a panel indicator as time elapses. The WTO Trade Facilitation Agreement (TFA) entered into force in 2017. The authors show unsurprisingly that OECD countries tend to have the highest level of transparency given their institutional capacity. Several measures included in their index could be easily updated over time from 2017 on, such as the existence of a TFA portal to provide a partial measure of transparency.

The measures developed by Ing et al. correlate imperfectly among themselves and with government transparency scores from the World Economic Forum for its global competitiveness index and the World Bank's policy and institutional assessment (see appendix 1 for sources). These new transparency measures and index of Ing et al. could be used in the typical gravity framework to characterize the impact of transparency on trade flows. The lack of time variation is an issue. The Global competitiveness index of the World Bank and the Country Policy and Institutional Assessment indices have time variation as an asset. Transparency measures are important for agriculture in the case of approval of biotech products for example. It features prominently in new trade agreements like the China-US phase one agreement (USTR).

6. Promising research directions on trade costs

6.1 Gene editing and trade

A promising area of research on agricultural trade cost originates with biotechnology and new plant breeding technologies (NPBTs). New and more precise biotechnology tools have emerged to create novel food or attributes in a more targeted way (Qaim, 2020). These new tools seemed to be able to avoid the missteps, which plagued GMO innovations in agriculture and food markets and their low acceptability among consumers in many countries, including the United States. These NPBTs are key to maximize agriculture's productivity, profitability and sustainability, to supply a continually increasing world demand for protein and oil for feed, fuel and food (Anderson et al., 2019; Qaim, 2020). NPBTs are more precise tools to change the genome of plants. They often use the plant's own genome or the genome of related plants through cisgenesis. Despite the safety of these "gene-editing" techniques, new evidence suggests they may be controversial with environmental groups, and consumers, although not as much as GMO were (NAS; Caputo et al.; and Marette et al.). These apprehensions are internationally present (Marette et al., 2020; Qaim, 2020; and Schmidt et al.).

There are emerging frictions over NPBTs used to innovate in agriculture and food markets (Bain et al.; Bunge and Dockser Marcus; NAS; Martin-Laffon et al.; Qaim, 2020; and Schmidt et al.). Novel food and attributes in agricultural goods have to be assessed for the potential risk they may create for human health and the environment. Regulations in many countries are process-oriented rather than product oriented, and legacies of GMO regulation (Schaefer; and Schmidt et al.). Even in the United States, novel foods obtained through transgenic biotechnology are regulated differently than the same novel foods obtained through conventional breeding or gene-edited techniques assimilated to mutagenesis. Despite this similarity, some consumers may view these novel foods as different and may want to see them labeled. Given the vast differences across countries and culture and regulations, asynchronous approvals and heterogeneous regulations will prevail. A redux of the GMO scenario is predictable with import refusals, foregone trade and welfare opportunities for consumers, innovators, and farmers because of asynchronous and slow approvals or approvals for different uses (Qaim; Disdier and Fontagné; de Faria and Wieck,; and Henseler et al.). This area is ripe for more case studies as new foods and varieties are emerging using NPBTs.

6.2. Integrating components of transport systems

In section 3 we have proposed a series of enhancements to the traditional use of distance as a proxy for the cost of transportation, depending on context and the data available. Needed topics of research in agricultural transportation that could be used to improve our understanding of agricultural markets and trade are how recently imposed transportation policies might affect agricultural shipments, and if performance improvements to transportation systems as a whole provide benefits (or detriments) to agricultural shipments.

Both the U.S. electronic logging device mandate for trucks and the International

Maritime Organization's 2020 low sulfur fuel mandate for marine shipping are thought the to increase the costs of their respective modes (Roka et al.; Thayer et al.; and Kass et al.). There is likely some incidence between shippers and carriers, and the relative costs of U.S. internal and external transportation costs compared to other countries have changed. While research does exist for these policies in general, there is little research currently available evaluating the effects on agricultural exports and agricultural markets in general.

Transportation system performance has improved over time whether the measurements are speed, volumes, or the quality of the journey itself. However, agricultural shipping rates are often less than those of manufacturing goods by weight or volume. Carriers have less incentives to focus performance improvements on lower revenue shipments beyond the efficiency gains within their own operations. Alternatively, smart systems record and send data to carriers about transportation conditions and events which allows carriers to monitor service quality and performance more closely. They also improve communication among customs agents, shippers, and carriers. Therefore, these systems might provide larger returns to perishable agricultural goods by improving safety and quality than dry manufactured goods. Heterogeneous returns to smart technologies and system-wide performance improvements have implications for both trade in agricultural goods as well as a better understanding of the benefits of smart technologies in supply chains more generally.

6.3. Mainstreaming and improving estimation methods

Advances in gravity-based analyses of trade flows could be more routinely applied to agricultural trade cost issues. For example, Duan and Grant estimated trade costs in agricultural trade using Novy's approach to bilateral trade and border effect (Novy). Novy uses an approach developed by Head and Ries, and Head and Mayer to measure "free-ness" or "phy-ness" and a proper measure of internal trade cost (within a country) and those trade costs crossing a border between two countries, called the border effect. Using the approach one can derive an average implied bilateral trade cost factor between countries just using observed panel trade data and CES elasticities. The trade cost factor can be used as a left-hand side variable in a regular gravity framework using the usual trade cost determinants. The main drawback of this approach is the potential sensitivity of the trade cost estimate to the value of the CES elasticity values.

Another recent improvement in gravity equations is the development of relative transportation costs into an internal and international transportation element using an approach reminiscent of Novy, with a focus on internal distance and allowing the bilateral distance effect to vary over time (Yotov; and Yotov et al.). This approach could readily be used in agricultural trade cost analysis using a gravity approach.

Estimates of trade cost based on gravity equation approaches tend to yield large trade cost estimates, which can appear implausible when introduced in calibrated models for a validation exercise (Balistreri and Hillberry). The implied resources devoted to trading goods are extremely large. Validating agricultural trade cost estimates in calibrated models could be an enlightening exercise to gauge their plausibility.

There is still a lack of attention on separate and distinct effects of NTMs on import unit cost, supply and demand. Their impact on welfare is not sufficiently investigated, as authors focus on trade effects, which we have argued are not that informative or could actually be misleading. Health/environmental costs and benefits should be more systematically incorporated into analyses. The disentanglement proposed by Cadot et al. identifies the separate effects on import unit value, supply and demand of NTMs. The method requires panel data, which have become increasingly available. They do not consider welfare, however. The welfare analysis proposed by Disdier and Marette, van Tongeren et al., and Wilson and Anton are clearly feasible and could be more frequently implemented. They account for market imperfections and/or risk and are more informative.

Finally, the aggregation of various standard-like NTMs remains a major challenge. Various measures such as frequency and counts of NTMs are inadequate to capture stringency, regulatory heterogeneity, or the cumulative effect of various measures. This topic is challenging, in the higher risk-higher payoff category. A major breakthrough on meaningful aggregation and without requiring heaps of data would advance the field.

7. Conclusions

Agricultural trade costs are significant as many agricultural goods are low-value, bulky and perishable. Trade cost are hard to measure for at least two reasons. Transportation cost is difficult to generalize and capture in a realistic way, because it is heterogeneous across goods, transportation modes and time. Second, standard-like NTMs are hard to account for in an exhaustive way with limitations on aggregation, data availability and the difficulty to measure their effects on consumers and market imperfections. Tariffs have fallen dramatically and except for the anti-trade stance of the Trump administration, their global levels will continue to converge to nearly negligible levels through large RTAs.

Nevertheless, as discussed here, much progress has been achieved in measuring the extent of these costs. Promising directions exist to better gauge their magnitude and effects. In particular, we suggested several ways to improve estimates of trade costs from transportation, with available data sources and methods. The field of transportation economics has much to contribute to trade analysis (Blonigen and Wilson).

We provided several policy insights and implications. Transportation distortions remain large and unaddressed. Much could be gained by liberalizing transportation services. Addressing NTMs remain complex given the difficulty to empirically estimate optimal standards. Too few investigations have attempted to incorporate welfare measures in their analysis of standard-like NTMs. Transparency remains difficult to measure but the available evidence suggests that transparency reduced trade cost and is welfare-improving in that sense. Many countries remain deficient on their transparency requirements with the WTO, for example.

We are hopeful our research directions will find some interested readers and takers.

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Appendix 1. Trade cost data sources for agricultural trade analysis

Distance, cultural distance, business-based trade costs and transportation-related data

The Bureau of Transportation Statistics and Federal Highway Administrations provides the Freight Analysis Framework (FAF) estimating U.S. freight flows at: https://ops.fhwa.dot.gov/freight/freight_analysis/faf/

The Baltic Exchange provides indices of ocean shipping prices by vessel types and route: https://www.balticexchange.com/en/data-services/market-information0/indices.html

Both Lloyd's List and Drewry do have data ocean shipping costs for agricultural products by route (including reefer containers), however these are must be custom ordered and are expensive.

The world port index created by the National Geospatial Intelligence Agency includes information about port facilities and services: https://msi.nga.mil/Publications/WPI (nga.mil currently not working?)

Statistics Canada have a freight analysis framework: https://www150.statcan.gc.ca/n1/en/catalogue/50-503-X

Trans-Tools freight model offers data/forecasts for European freight, including cost information: http://www.transportmodel.eu/

USDA AMS provides direct transportation costs for many domestic agricultural shipments, refrigerated and bulk, including some export routes: https://www.ams.usda.gov/services/transportation-analysis/data

The GeoDist database of the CEPII offers a series of distance bilateral distances, colonial links, contiguity and other geographical measures: http://www.cepii.fr/cepii/en/bdd_modele/presentation.asp?id=6

National/internal distances are available at the US ITC: https://catalog.data.gov/dataset/dynamic-gravity-dataset-1948-2016

OECD data on maritime rates are useful but are limited in panel format: https://stats.oecd.org/Index.aspx?DataSetCode=MTC (not working on 8/9/20 but was 2 weeks ago)

CIF/FOB ratios are available from the OECD for a 1995-2016 panel: https://stats.oecd.org/Index.aspx?DataSetCode=CIF_FOB_ITIC#

The World Bank Doing Business covers a wide range of trade costs related to doing business included for trading across borders with panel data: https://databank.worldbank.org/source/doing-business

The World Bank's Logistics Performance Indicators (LPI) provides a large panel dataset on quality of infrastructure and other variables: https://lpi.worldbank.org/

The World Economic Forum provides various measures of infrastructure quality in panel format: http://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2019.pdf

Transparency International provides measures of corruption perception index in panel format useful to proxy associated trade costs: https://www.transparency.org/en/cpi

RTAs, FTAs and associated tariffs

WTORTA has the full list of preferential trade agreements for each WTO member and the comprehensive list of preferential tariffs at HS-6 digit for these countries on a bilateral basis. http://rtais.wto.org/UI/PublicPreferentialTariffAnalysis.aspx?PreferentialMarketCode=C840

CPB (US International Trade Administration) has the following FTA tariff rate search tool by FTA partner and HS code for the US, https://beta.trade.gov/fta/tariff-rates-search

See also https://www.cbp.gov/trade/priority-issues/trade-agreements/free-trade-agreements

USDA has its FTA ag tariff tracker: https://apps.fas.usda.gov/agtarifftracker/Home/Search

WTO I TIP and SPSIMS on SPS regulations http://spsims.wto.org/

WTO on tariffs and WTORTA on preferential trade and preferential tariffs
http://rtais.wto.org/UI/PublicPreferentialTariffAnalysis.aspx?PreferentialMarketCode=C840

Tariffs and market access

The WTO with its TAO webpage provides data on tariffs, TRQs, and export subsidies:
https://tao.wto.org/welcome.aspx?ReturnUrl=%2f%3fui%3d1&ui=1
or http://tariffdata.wto.org/

The World Bank provide the TRAINS database on tariffs and trade flows
http://databank.worldbank.org/data/reports.aspx?source=UNCTAD-Trade-Analysis-Information-System-(TRAINS)

The World Bank offers Doing Business on ease of doing business, delays, and quality of institutions: https://databank.worldbank.org/source/doing-business

MacMap is another popular dataset on market access and tariffs: https://www.macmap.org/

OECD's AMAD dataset focuses on agricultural market access: https://www.oecd.org/site/amad/

Safeguard measure notifications are available with the WTO at:
https://www.wto.org/english/tratop_e/safeg_e/safeg_e.htm

TRQ

CBP.gov: https://www.cbp.gov/trade/quota/guide-import-goods/commodities

CPB also has a tool kit using Descartes CustomInfo. https://www.customsinfo.com/

See also AMAD above for detailed data on TRQs

NTMs

The WTO's I-TIP webpage provides NTM and other policy notifications data:
https://www.wto.org/english/res_e/statis_e/itip_e.htm

Bryant Christie Inc provides a series of SPS data, some in panel form for pesticides and veterinary drugs MRLs, food additives and contaminant limits: https://www.bryantchristie.com/

SPS and TBT concerns are provided by the WTO at http://spsims.wto.org/ and http://tbtims.wto.org/

The World Bank has TRAINS: https://databank.worldbank.org/source/unctad-%5e-trade-analysis-information-system-(trains)

CEPII offers various measures and indicators of NTMs win its NTM-MAP dataset:
http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=28

Trade Monitoring from the WTO provides information on trade facilitation and trade restrictive measures for many policy instruments:
https://tmdb.wto.org/en/explore#page=1&members=&g20=0&measure_type=&after_dt=&before_dt=&affected_members=&product_chapters=

The World Bank WITS database on NTMs: https://wits.worldbank.org/tariff/non-tariff-measures/en/ntm-datadownload

The Impact of COVID-19 and Associated Policy Responses on Global Food Security

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Abstract
We analyze the impact of the COVID-19 pandemic and associated policy responses on the global economy and food security in 80 low- and middle-income countries. We use a global economy-wide model with detailed disaggregation of agricultural and food sectors and develop a business as usual baseline for 2020 and 2021 called "But-for-COVID" (BfC). We then shock the model with aggregate income shocks derived from the IMF World Economic Outlook for 2020 and 2021. We impose total-factor productivity losses in key sectors as well as consumption decreases induced by social distancing. The resulting shocks in prices and incomes from the CGE model simulations are fed into the USDA-ERS International Food Security Assessment model to derive the impact of the pandemic on food security in these 80 countries. The main effect of the pandemic was to exacerbate the existing declining trend in food security. Food insecurity increases considerably in countries in Asia through income shocks rather than prices effects. We also review trade policies that were put in place to restrict imports and exports of food, and we evaluate their potential for further disruption of markets focusing on the food-security implications.

Keywords: COVID-19, food security, trade costs, market disruption, pandemic

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1. Introduction

Global food security is an important concern, particularly in low- and middle-income countries. In these countries, depending on sources (SOFI USDA), between 811 million (SOFI 2021) and more than 1 billion (Baquedano et al. 2021) people are estimated to be food insecure while agricultural markets and trade remain volatile because of disruption in supply chains. Global food insecurity has been on the rise in recent years even before the COVID-19 pandemic which accentuated the growing insecurity (SOFI 2021). The COVID-19 pandemic and associated policies responses have had a considerable impact globally, disrupting agricultural and food supply chains, contracting trade and income in most countries --often impacting the vulnerable economic groups-- and shrinking the travel and hospitability sectors an important source of revenue for not only OECD economies but low- and middle income countries. The food retail industry, in its food-away-from-home segment, has also been affected as many restaurants closed. Supply chains have been disrupted by labor shortages. The economic recovery in the second half of 2020 and first half of 2021 has been surprisingly fast in high-income countries, led by the United States (IMF 2021b). But in low- and middle-income countries outside of China, reflecting less access to vaccines, it has been much slower (IMF 2021b and WHO 2021).

Governments responded to the pandemic first by imposing social distancing policies, and then by reopening in a staggered fashion with several key sectors reopening at a fraction of their pre-pandemic levels (travel, hospitality, and retailing in particular). Agriculture was recognized as essential by many governments and face fewer restrictions. Further, programs have been put in place to soften the blow of the income shocks for consumers and several industries including in low- and middle-income countries with the help of international financial institutions. In OECD countries considerable unemployment took place in 2020 and then a recovery in labor markets has been taking place in 2021 as economies started re-opening, but unemployment levels still remain high (IMF 2021a).

As the pandemic remains a foreseeable health threat and force of disruption, it is important to assess the implications of these economic shocks and partial recovery on global food security. What have been the impacts of the pandemic and associated policies on global agricultural, food supplies and trade, income, and consumption levels? Our paper assesses the impact of the pandemic and its various disruptions and policy responses on global food security, with its detailed impact on world food supplies and consumption by income group using aggregate income information derived from the IMF (IMF 2021a).

We use an integrated modeling structure combining a world Computable General Equilibrium (CGE) model based on the GTAPinGAMS structure (Lanz and Rutherford 2016) with the USDA ERS' International Food Security Assessment (IFSA) model (Beghin et al. 2017; and Baquedano et al. 2020) to assess the impacts of the COVID-19 pandemic shock of 2020, and the uneven recovery in 2021. The version of the IFSA model used in this paper uses an expanded database and focuses on 80 low- and middle-income countries. The CGE model provides changes in real prices of food, and real income which are then incorporated into the disaggregated food demand system of the ISFA model to predict nutritional gaps and food insecurity by income decile in these 80 low-and-middle-income countries.

We find that the aggregate real income shocks and those affecting unskilled labor were the major cause of a considerable increase in food insecurity. With the number of food insecure increasing by 163.2 million in 2020 compared to a 2020 but for COVID-19 (BfC) baseline. This increase caused by the pandemic shock comes in addition to the increasing food insecurity estimated in the BfC baseline in 2020, relative to 2019 (84.2 million). India, Nigeria, Central and Southern Africa, and Central and Southern Asia accounted for most of this increase caused by long-term trends. The pandemic exacerbates food insecurity in India, Central and Southern Asia, Pakistan, Latin America and the Caribbean, South East Asia and East Africa. Interestingly, we find that effective unskilled labor use falls but their real wage increases, partially offsetting the blow of lower employment. Food insecurity patterns for 2021 (1,042.5 million insecure people) imply a mitigation of income shocks with the uneven recovery and fewer food-insecure people than in 2020 but still above 2019 by 174.6 million.

Real food price changes contribute to a much lesser extent because the bulk of disruptions in food supply chains take place well beyond the farmgate, sparing most of agricultural production. Reliance on trade actually decreases in many countries during the pandemic because of reductions in food demand and increases in trade costs induced by logistics issues. Many real local food prices fall. These trade contractions also translate into income reductions in export-dependent countries. We also note that trade-restricting policies have been limited in scope and over time and have had no measurable impact on food security and markets. Not included in this exercise is the fact that world commodity markets had ample supplies in 2020, mitigating excessive price volatility, unlike during the 2007-2008 food crises.

Our paper contributes to the set of analyses based on general equilibrium models used to investigate COVID-19's impacts in different countries, including China (Zhao 2020), the UK (Keogh-Brown et al. 2020), India (Sahoo and Ashwani, 2020), Brazil (Porsse et al., 2020) Kenya (Nechifor et al., 2021), Burkina Faso (Zidouemba et al., 2020), and global or regional levels (Laborde et al. , 2021; Djiofack et al., 2020; McKibbin and Fernando, 2020; Maliszewska, et al., 2020; Zhang et al., 2020; Zhao, 2020; Keogh-Brown et al., 2020; and Pravakar Sahoo 2020).

Our analysis contributes to the literature on the economic impact of COVID-19 in several ways. The paper considers the two phases of the pandemic, that is, the steep contraction of 2020 and the uneven path to recovery projected for 2021. Early studies had to make educated guesses on the likely income shocks and recovery paths of various countries. We differ from many previous analyses in the way we model the pandemic shocks with our calibration to the IMF outlook estimates as well as creating a counterfactual baseline. The combination of two modelling frameworks (the multi-region general equilibrium model with the IFSA food-security model) is unusual, noting that IFPRI's evaluation by Laborde et al. (2021) has a related setup with a recursive dual structure.

CGE models are typically used to simulate the impact of exogenous shocks and policy changes on income, trade and welfare (Giesecke and Madden 2013). Here, we follow He et al. (2022), Bauer, Haltom, and Rubio-Ramirez (2005), Beckman, Baquedano and Countryman (2020) and Monte, Redding, and Rossi-Hansberg (2018) by reversing the process. We take exogenously observed and projected changes in GDP under COVID-19, as well as trade and labor shocks and then recover the underlying fundamental conditions in labor and food markets, which are consistent with these large shocks in deviation from an established BfC baseline scenario. (See Section 2 and footnote 2 below).

2. Modeling assumptions

Scenario assumptions

The model uses GTAP 10 2014 nominal data for the initial calibration. The benchmark is then extended to 2019 based on the GDP growth and macro data as reported by the IMF and on the shares of consumption, public spending, investment, and trade including aggregate exports and imports.[1,2] The GTAP data are aggregated to 17 regions or countries covering low- and middle-income countries as well as major trade partners (e.g., China, Europe, and USA) capturing global economic activity. The GTAP data are also aggregated to focus on 30 sectors centered on agriculture, food, and those sectors with specific shocks related to the COVID-19 pandemic.

[1] The WEO projections of aggregate imports and exports (measured in US dollars) at the regional level do not impose global consistency on capital flows. While we target regional trade imbalances based on the WEO projections, we use a transparent least-squares procedure to find the calibrated trade imbalance such that globally there is no net borrowing or lending. That is, the sum across regions of all net trade surpluses must be zero.

[2] In typical CGE applications technologies are held fixed while GDP and its components are endogenous to policy shocks. In our exercises, however, we are interested in finding a set of technical productivity shocks that are consistent with income (GDP) and other outcomes related to the scenarios. Our strategy, therefore, is to use the model in reverse. Variables, like GDP, are constrained and productivity levels are adjusted such that these constraints are consistent with an equilibrium. For each constraint there is an associated productivity instrument. As an example, GDP in a region (measured in units of local private consumption) is constrained to be equal to the projected target, and associated with this constraint is an instrument that scales the productivity of regional endowments of primary factors. In our aggregate treatment we abstract from decomposing these shocks along the lines of employment, unemployment, or productivity per worker. There is simply a scalar coefficient that adjusts the benchmark 2019 endowment of value-added factors which might be interpreted in different ways, especially with regard to the labor market. For additional details see the technical description in He, et al. (2022), section 3, which applies the same strategy of outcome targeting in the context of a multi-region model of China under COVID-19 productivity shocks.

The BfC scenario extends the average growth rate observed in countries between 2014 and 2019, to 2020 by applying the average growth rate to the 2019 observed GDP figures in the IMF's WEO projections. The 2020 IMF figures become the COVID-19 shock for 2020, inclusive of the fiscal stimulus put in place by various governments in OECD countries, but much less so in lower-income countries, except in West Africa. Many lower-income countries experienced a contraction of public expenditures. See table 1.b. for details for 2020. For 2021, we proceed slightly differently because the 2021 WEO growth projections actually exceed our average 2014-2019 historical growth rates for many countries, leading to an unexpected expansionary COVID scenario relative to BfC scenario for many countries. To establish the 2021 BfC GDP targets we take the 2020 BfC GDP target and scale it by the ratio of WEO projected 2022 to 2021 GDPs. This uses the WEO projected region/country growth rate from 2021 to 2022 as a proxy for the BfC growth rate from 2020 to 2021. The logic is that the IMF-reported growth rates from 2020 to 2021 are still substantially contaminated by the projected COVID recovery, and are therefore inappropriate for the BfC baseline. Furthermore, if we did use the IMF growth rates from 2020 to 2021 we would get substantially similar results in the 2021 scenarios as compared to the 2020 scenarios because by construction the BfC and COVID growth rates are the same. We report the income levels for 2020 and 2021 under the developed BfC and the COVID scenarios (as well as the 2019 benchmark) in Table 1.a.

We take the deviations (COVID-BfC) to measure the impact of the pandemic relative to the baseline. We then rely on these underlying conditions and parameters to derive the implied real income shocks for unskilled labor and food price changes consistent with the observed and projected shocks in deviation from the BfC baseline.[3] The fiscal stimulus measures and contractions

[3] For some regions, however, the combination of the 2019 base and the historic growth rate indicates a BfC GDP that is "below" the WEO 2020 projections. We view this as an anomaly. For these regions (Nigeria, CIS, NAF, EAF, WAF) we recalculate the BfC 2020 GDP target as the WEO 2020 (COVID) projection less the average global income shock.

taken by governments in 2021 are shown in Appendix Table A.1. They follow a similar pattern as those of 2020.

Beyond matching aggregate value added in each country to the IMF GDP predicted shocks, we also shock Total Factor Productivity (TFP) in key sectors affected by the pandemic. The IMF macro forecast does not say anything about sector-specific shocks. This is the motivation to include these in the calibration of the COVID scenario. The sector-specific TFP shock reflects the asymmetric nature of the scenario with a reduction in the productivity of all factors in sectors deeply affected by the pandemic and border closing—trade (wholesale and retail), warehousing and support activities, water transport, and other transport and distancing policies.[4] We also capture the sharp decrease in demand in sectors for which consumers scaled back their consumption because of self-imposed or required distancing to abate health risk. We do this by scaling back the utility weight into the utility function. This corresponds to a decrease in effective utility of the good affected by the decrease. Demands are scaled back for hospitality and tourism related sectors (accommodations and food services, recreational and other services, and air transport). Finally, we capture the loss of productivity in perishable agriculture (meat and dairy, and vegetables, fruit, and nuts) as in Laborde et al. (2021). These shocks work their way through the model and translate into labor productivity changes and labor income, in particular for unskilled labor categories, which exacerbates food insecurity issues. Table 1.b summarizes the shocks in percent deviation from the BfC baseline for 2020. Shocks for 2021 are shown in Appendix Table A.1. The TFP and demand shocks are shown in Table 1.c for 2020. Corresponding TFP and demand shocks for 2021 are set at 50 percent of the 2020 shocks.

The estimated changes in real income, income distribution and in real food prices are then fed recursively in USDA's IFSA model (Beghin et al. 2017; Baquedano et al 2020) to predict food insecurity consequences of COVID-19 in 80 low- and middle-income countries.

[4] The TFP shocks are imposed similarly in all countries and regions, which is a limitation as situations differ. It is transparent however.

Additional assumptions

Regarding aggregation of sectors, all agricultural and food sectors are kept as in GTAP10, although we aggregate Meat and Dairy products into a single category we aggregate all nonfood manufacturing into a large single manufacturing sector. We keep the three GTAP transport sectors disaggregated, as well as warehousing with wholesale and retail trade, accommodation food and service activities (tourism-hospitality related), and recreation to simulate sector specific shocks in TFP and demand as discussed above. The detail sectoral aggregation is available from the authors.

Table 1.a. GDP levels in 2019, 2020BfC, 2020COVID, 2021BfC, 2021COVID ($ billion nominal dollars)

country-regions	**2019**	**2020 BfC**	**2020 COVID**	**2021 BfC**	**2021 COVID**
Central Africa	208.4	199.7	179.1	208.5	201.5
China	14706.3	15638.4	15072.3	16917.4	17011.0
Commonwealth of Independent States	197.3	195.5	189.1	209.4	206.2
Central and Southern Asia + Other Asia	856.0	881.8	743.1	974.7	840.3
East Africa	255.4	270.5	262.2	287.1	278.3
Ethiopia	92.6	103.1	96.6	101.9	94.0
Europe + GBR and CHE	18469.6	18420.0	17878.8	19668.4	20252.2
India	2870.5	3073.7	2708.8	3339.0	3049.7
Latin America and the Caribbean	1085.5	1096.1	961.2	1161.0	1057.7
North Africa	689.0	716.7	694.4	759.8	752.4
Nigeria	448.1	444.0	429.4	508.2	514.0
Pakistan	276.1	283.0	262.8	301.8	291.9
Rest of World	23690.5	23563.3	22090.0	24878.6	24466.1
Southern Africa	98.9	98.4	92.6	105.1	100.8
South East Asia	1871.9	1969.6	1807.7	2137.8	1964.0
USA	21433.2	22313.2	20932.8	23620.4	22675.3
West Africa	244.7	262.7	254.8	284.7	286.1

Table 1.b. Shocks (COVID-BfC baseline) in percent deviation from 2020 run

Variable shock	GDP target	Balance of Payments	Government expenditures	Investment	Capital	Skilled labor	Unskilled labor
Central Africa	-9.9%	-9.9%	-10.3%	-8.5%	-1.1%	-1.1%	-14.3%
China	-3.8%	-4.1%	7.9%	0.0%	-7.8%	-7.8%	-10.8%
Commonwealth of Independent States	-3.2%	-3.2%	8.9%	-11.9%	0.0%	0.0%	-2.2%
Central & Southern Asia + Other Asia	-16.2%	-16.2%	-4.0%	-12.6%	-11.7%	-11.7%	-32.0%
East Africa	-3.2%	-3.2%	-3.3%	-10.8%	-7.0%	-7.0%	-9.3%
Ethiopia	-7.0%	-7.0%	-8.3%	-16.6%	-13.7%	-13.7%	-19.1%

Europe including GBR and CHE	-2.9%	-3.5%	15.0%	-5.9%	-0.4%	-0.4%	-2.1%
India	-12.7%	-12.7%	3.0%	-18.4%	-13.6%	-13.6%	-28.6%
Latin America & the Caribbean	-12.4%	-12.4%	-2.4%	-22.1%	-7.8%	-7.8%	-23.8%
North Africa	-3.2%	-3.1%	2.0%	-11.1%	-5.2%	-5.2%	-7.4%
Nigeria	-3.2%	-3.2%	-5.3%	-2.9%	0.3%	0.3%	-1.5%
Pakistan	-7.3%	-7.3%	0.1%	-6.8%	-6.4%	-6.4%	-15.3%
Rest of World	-6.2%	-7.1%	11.3%	-4.5%	-2.3%	-2.3%	-9.1%
Southern Africa	-5.9%	-5.8%	0.4%	-1.0%	-1.7%	-1.7%	-7.4%
South East Asia	-8.6%	-8.6%	2.1%	-15.4%	-9.4%	-9.4%	-18.7%
USA	-6.4%	-5.2%	24.6%	-5.2%	-6.9%	-6.9%	-13.2%
West Africa	-3.2%	-3.2%	21.6%	-3.5%	-8.7%	-8.7%	-11.3%

Table 1.c. 2020 Selected sectoral shocks TFP (-1.25%) and demand shocks (-7.5%)[*]

Meat and Dairy	-1.25
Vegetables fruit and nuts	-1.25
Trade	-1.25
Warehousing and support activities	-1.25
Water Transport	-1.25
Other Transport n.e.c.	-1.25
Accommodations and food services	-7.50
Recreational and other services	-7.50
Air Transport	-7.50

[*]These shocks are specific to listed sectors. Other sectors than those listed do not incorporate these shocks.

The IFSA model estimates the calorie intake per income decile in 80 low- and middle-income countries. The various food goods in the IFSA model are aggregated into 4 groups (major grain, other grains, roots and tubers, and other food) and then further aggregated into grain calorie equivalent to yield a total calorie intake. The specification follows a PIGLOG formulation relying on income, price, and income distribution data to derive projected consumptions over time (Beghin et al. 2017). The model looks at price impacts on food access from the consumer side and does not account directly for household production balances.

With the IFSA model in mind, we focus on grains and roots and tubers, which are the key staple foods of interest. The IFSA model incorporates real income, income distribution data (Theil's inequality index), and the real price of the main grain by country (processed rice, wheat crop price, other grain crop price including corn), a second grain price capturing grains other than the main grain, and the price of roots & tubers which is represented by the price of vegetables and fruits sector (v_f sector) in GTAP10. The price of other foods in IFSA is not mapped here as we only consider the price changes in these staple food items. The IFSA demand specification does not capture the substitution possibilities across the 4 food groupings. This simplification tends to overstate the impact of price changes which are typically correlated in the case of global shocks.

3. Agricultural and food trade policy responses to COVID-19

Early in the pandemic, IFPRI researchers raised concerns about the emergence of trade restrictions endangering food security but also noted that export restrictions were phased out rapidly (Laborde et al., 2020). Price levels only moderately increased (Vos et al. 2020). The concern was to see another price spike in world grain prices induced by export restrictions as documented in Martin and Anderson (2012) and Ivanic and Martin (2008), in previous crises. Rice prices surged in 2007-08, mostly through export restrictions. Such price increases exacerbate poverty in vulnerable households who spend a disproportionate share of their income on food.

Trade policy responses to COVID-19 focused mostly on export restrictions related to medical supplies (CRS, 2021). Agricultural and food trade was also targeted by some policies (ITC-MacMap, 2021). According to the database maintained by the ITC-MacMap, fifty-four agri-food trade restrictive policies were implemented affecting various goods from onions to rice and wild animals. The composition is as follows: 23 export restrictions, 4 export quotas, 3 export licenses, and 7 import bans, and 14 SPS restrictions on imports. The only potentially significant restrictions on commodity markets focus on rice from India (licensing), Vietnam (export quotas for 37 days), and Russia (temporary quotas and duties on grain exports) (USDA-FAS, 2021).

To counter these restrictions, twenty-eight countries implemented trade facilitating measures to pre-empt price increases for food imports. There were twenty-three tariff reductions, eliminations and/or quota increases, and a few cases of easing some certifications requirements. Overall, these measures have had limited impact on availability and prices of major commodities such as rice given that most major producers showed some restraint in their policy reactions to the pandemic. Their impact on prices and availability of grains has been moderate. High stock-to-use ratios in early 2020 for most grains helped to stabilize prices.[5] The concerns of higher price levels and volatility created by potential trade restrictions had faded by end of 2020 (Baffes and Wu 2020). Therefore, we do not attempt to model their impact and focus on trade cost increases created by logistic disruptions in transportation, trade, and warehousing sectors.

4. Scenario Results

Impact on real Income

The income shocks are shown in Table 2 for 2020. The impact on factor income combines the shock on effective supplies of factors and change in returns and cost of living. Table 2 shows the real income shocks derived using the local price index (the true-cost-of-living index for the representative agent), in many cases the change in return (wage relative to the cost of living) mitigates the large shock imposed on unskilled labor. The resulting shock on factor income of unskilled labor is in many cases not as large as the skilled labor income impact or even GDP shock, such as in the Central and East Africa regions.

Capital income takes the brunt of the economic impact of COVID-19, such as in Central and Southern Asia region and Pakistan. The impact of the economic contraction is widespread affecting both demand and available supply of effective labor and capital.[6] In some cases, the reduction in availability of labor or capital is stronger than the reduction in demand, leading to increase in nominal returns. In addition, the local cost of living falls in many countries relative to the BfC cost of living which contributes to higher real returns for factors. In any case the income shocks are very sizable, especially in Central and Southern Asia, Central Africa, India, and Latin America and Caribbean regions which leads to large exacerbations of food insecurity as later

[5] Supply shocks in 2021 contributed to higher staple prices, except for rice.
[6] The model adjusts factor productivity to match the macro shocks, decrease in demand and loss of sectoral TFP and resulting factor rewards.

discussed.

Table 2. Income shocks in percent deviation from the BfC scenario (2020 COVID-19 run)				
Income category	skilled labor	Unskilled labor	Capital	GDP
Central Africa	-11.41	-7.06	-11.22	-9.86
China	-2.84	-3.54	-3.91	-3.85
Commonwealth of Independent States	-1.54	-3.01	-3.66	-3.24
Central & Southern Asia + Other Asia	-15.94	-14.41	-16.16	-16.20
East Africa	-4.25	-1.76	-3.40	-3.24
Ethiopia	-11.89	-2.32	-7.84	-7.00
Europe including GBR and CHE	-2.39	-3.87	-2.83	-2.93
India	-11.78	-8.34	-13.94	-12.71
Latin America and the Caribbean	-13.62	-8.99	-13.16	-12.43
North Africa	-3.24	-1.82	-3.55	-3.24
Nigeria	-3.67	-1.92	-4.08	-3.24
Pakistan	-7.04	-4.99	-7.65	-7.33
Rest of World	-5.10	-5.27	-7.06	-6.22
Southern Africa	-4.93	-5.11	-6.85	-5.86
South East Asia	-9.31	-6.33	-8.86	-8.65
USA	-5.77	-6.00	-6.87	-6.44
West Africa	-0.12	-5.52	-3.29	-3.24

Impact on food prices

Food price changes are expressed in relative deviation from the BfC baseline in real terms. Nominal prices are deflated by the local cost-of-living index. They are shown in Table 3, in percent change. The majority of food prices decrease in both runs, except for the two perishable food sectors, affected by the greater loss of productivity and level of disruption in supply chains. For the other sectors, the dominant influence is the demand contraction brought about by reduced incomes in all markets. This leads to price decreases in most but not all cases for 2020.

Looking first at the two sectors experiencing mostly price increases, prices in the Vegetable, fruits, root & tubers sector increase the most, especially in Central Africa (5.86 percent), Central and Southern Asia (5.44 percent), Ethiopia (3.40 percent), and LAC (2.89 percent). Smaller increases of less than 2 percent take place in Pakistan (1.82 percent), India (1.45 percent), and East Africa (1.40 percent). Meat and Dairy product prices increase moderately, by 2.25 percent in Central and Southern Asia, 1.67 percent in India, and 1.23 percent in Pakistan and 1.19 percent in South East Asia. Other Meat and Dairy price increases are even more limited, even though they are observed in most countries.

Grain prices increase in a few countries and decreases in many others. For example, in the Cereal grains n.e.c. sector, prices increase in Central Africa (4.60 percent), Central and Southern Asia (3.78 percent), and Ethiopia (1.78 percent) and LAC (0.91 percent). Other countries and regions experience price decreases for the same grain category, notably a decrease of 1.45 percent in West Africa. Rice prices increase in Central Africa (1.98 percent), Ethiopia (1.78 percent), India (1.32 percent), and West Africa (0.84 percent). Rice prices decrease in China (-0.89 percent).

Wheat prices increase in Central and Southern Asia (2.74 percent) and Ethiopia (1.49 percent) but also decrease in many other countries, driven by the demand-income contractions. For example, wheat prices decrease by 1.64 percent in Central Africa and 1.23 percent in Nigeria. Oilseed prices increase as well, in Central Africa (4.96 percent), Central and Southern Asia (1.41 percent), Ethiopia (1.84 percent), and LAC (1.1 percent), and decreases in most other regions. Vegetable oil prices decrease in most countries. In summary, Central Africa, Central and Southern Asia, Ethiopia, and Latin America and Caribbean regions are the most affected by price increases and face large income contractions. These are the hotspot for increases in food insecurity under COVID.

Price impacts for 2021 are shown in Appendix Table A.3. Income recovery takes place in some countries and food prices exhibit some moderate changes either positive or negative depending on the shift of food demands induced by income variations. Still income shocks dominate in 2021.

Impact on trade

Aggregate agricultural and food trade effects are shown in Table 4 for the 2020. Agricultural export values fall for all countries and the magnitudes of these contractions are large in absolute value.

Table 3. Impact on real food prices (deflated by local cost-of-living index) in deviation from baseline (2020 run)

region	Fish	Grains other than wheat and rice	Meats and Dairy	Oilseeds	Rice	Sugar	Vegetables, fruits, root & tubers	Vegetable oil	Wheat
Central Africa	-1.02	4.60	0.48	4.96	1.98	-0.03	5.86	-1.10	-1.64
China	-1.14	-0.67	0.89	-0.63	-0.89	-0.88	0.78	-0.76	-0.68
Commonwealth of Independent States	-1.31	-0.92	0.75	-0.87	0.41	-0.50	0.52	-0.35	-0.49
Central and Southern Asia & Other Asia	-1.15	3.78	2.25	1.41	0.86	-2.04	5.42	-1.88	2.74
East Africa	-1.23	-0.11	0.71	-0.14	0.28	0.12	1.40	-0.02	0.31
Ethiopia	-5.10	1.76	0.12	1.84	1.78	-3.49	3.40	0.66	1.49
Europe including GBR and CHE	-1.59	-1.36	0.10	-1.34	-0.75	-1.30	0.04	-1.04	-1.40
India	1.19	-0.32	1.67	0.14	1.32	-0.13	1.45	-1.17	-0.58
Latin America & the Caribbean	-2.59	0.91	0.86	1.10	-0.26	-0.33	2.89	-0.81	0.48
North Africa	-1.07	-0.25	0.83	-0.37	-0.44	-0.28	0.94	0.07	-0.13
Nigeria	-1.41	-0.63	-0.10	-0.62	-0.13	-1.16	0.68	-0.47	-1.23
Pakistan	-1.72	0.13	1.23	0.36	-0.29	0.12	1.82	-0.08	0.34
Rest of World	-1.78	-0.95	0.38	-1.26	-0.69	-1.24	0.58	-1.10	-0.79
Southern Africa	-1.24	-0.20	0.73	-0.33	0.41	-0.55	1.14	-0.01	0.10
South East Asia	-1.67	0.09	1.19	0.00	-0.10	-0.36	1.07	0.00	-0.77
USA	-2.50	-2.14	0.31	-2.18	-0.71	-0.87	-0.51	-1.18	-2.04
West Africa	-1.32	-1.45	0.70	-1.35	0.84	-0.22	-0.06	-0.07	0.04

Imports of agricultural and food goods also fall but often by smaller percentages than agri-food exports fell, except in the EU and the USA. Ethiopia increases its imports of food slightly, by 3.45 percent. With that exception, all countries decreased their reliance on foreign market to fulfill consumer demand. Export revenues for these agri-food sectors fell as well in all countries, contributing to the loss of income. These magnitudes are all computed using the global cost-of-living benchmark as the price of a "common global basket."[7]

Table 4. Agricultural and food trade impact in deviation from the BfC scenario 2020 COVID-19 runs (in percent)

Country/region	Exports	Imports
Central Africa	-18.28	-5.34
China	-12.77	-15.72
Commonwealth of Independent States	-12.05	-7.58
Central & Southern Asia + Other Asia	-30.54	-1.43
East Africa	-11.36	-3.63
Ethiopia	-19.16	3.11
Europe including GBR and CHE	-15.69	-17.42
India	-16.72	-11.96
Latin America and the Caribbean	-23.37	-5.63
North Africa	-11.48	-2.12
Nigeria	-14.21	-3.96
Pakistan	-13.06	-6.69
Rest of World	-15.06	-15.95
Southern Africa	-12.43	-11.57
South East Asia	-17.28	-6.68
USA	-12.43	-23.93
West Africa	-7.63	-12.52

At the agri-food sectoral level (detailed tables available upon request), there are large changes, positive and negative in imports, depending on the country. We find increases in wheat imports in Central and Southern Asia (30.71 percent) and Ethiopia (25.57 percent), oilseeds in Central Africa, meat and dairy in Central and Southern Africa (14.35 percent) vegetables, fruit, roots and tubers in

[7] The global cost-of-living price index is computed as the benchmark-consumption weighted average of the local (regional) cost-of-living indexes, where the benchmark is the 2019 equilibrium.

Ethiopia (10.89 percent). However, there are many more large import decreases as well, especially in the USA, EU and China.

For the 2020 COVID run, exports in most sectors in most countries fall by 10 percent or more. There are large decreases, exceeding 20 percent in rice exports in Central and Southern Asia, Central Africa, India, Latin America and Caribbean, Southern Africa, and South East Asia. We also observe large decreases in exports of roots and tubers from Central Africa, Central and Southern Asia, and LAC. Similar patterns are projected for wheat in the same countries and in Ethiopia. Exports of other grains n.e.c. fall by more than 20 percent in Central and Southern Asia, and LAC. Meat and dairy exports fall similarly in many of the same countries. In sum, Central and Southern Asia and then LAC exhibit the most accentuated changes in agri-food exports. These changes are behind the aggregate changes shown in Table 4.

Impacts on aggregate food trade for the 2021 are shown in appendix tables A.4 with more muted contraction patterns than in 2020. Noticeable, are the increase in food imports in North Africa, Ethiopia, and Nigeria. Agricultural and food sectoral results for 2021 are available from the authors upon request.

Impact on terms of trade

We have two aggregate measures of changes in purchasing power in the regions covered by the CGE model. First, we look at the true cost-of-living index over the benchmark weighted average of these indexes globally, which provides a gauge of the impact of local cost of living relative to the “global” benchmark cost of living (how well a country’s cost of living is faring relative to what is happening globally). Second, we have a more traditional terms of trade measures (index of export prices over an index of import prices). They are shown in Table 5 for 2020 runs in percent change from BfC values.

First, we note that changes are small in absolute value for both indicators. Relative cost of

Table 5. Terms of trade effects and change in relative cost of living in deviation from the BfC scenario 2020 (in percent)		
Regions	Relative cost of living/ global benchmark	Terms of trade change
Central Africa	0.46	-0.60
China	-0.90	-0.12
Commonwealth of Independent States	-0.82	-0.88
Central & Southern Asia + Other Asia	3.02	0.82
East Africa	-0.99	-0.74
Ethiopia	-0.33	1.02
Europe including GBR and CHE	-0.11	-0.01
India	0.41	1.67
Latin America and the Caribbean	1.05	0.27
North Africa	-1.11	-0.69
Nigeria	-0.14	-1.92
Pakistan	-0.15	0.48
Rest of World	0.08	-0.08
Southern Africa	-0.95	-0.34
South East Asia	-0.17	0.03
USA	0.12	0.53
West Africa	-1.34	-0.59

living falls in many countries, except in Central and Southern Asia (+3.02 percent), and LAC (+1.05 percent). The largest price decreases are in West and Northern Africa regions (-1.34 percent and -1.11 percent). Elsewhere, relative changes in the cost of living are less than 1 percent. Terms of trade improve for India (+1.67 percent) and for Ethiopia (1.02 percent), and deteriorates for Nigeria (-1.92 percent), and to a lesser extent for Commonwealth of Independent States, Central and Southern Asia, and East Africa regions (less than a 1 percent decrease).

The two measures of relative purchase power are poorly correlated. One would expect a negative correlation if all goods were tradable –improvements in terms of trade would lead to a reduction of the local cost of living. This is not the case, however, as import dependency varies across regions. For example, terms of trade improve in India but its relative cost of living also increases.

Conversely, Nigeria experiences a deterioration of its terms of trade but its relative cost of living falls. Results for 2021 are available upon request from the authors. They are qualitatively comparable with small magnitudes and imperfect correlation between the two measures.

5. COVID-19's impact on food insecurity trends

Our analysis builds on previous findings of Baquedano et al. (2021) and Beckman et al. (2021) of the effects of COVID-19 on food security in two ways. First, as discussed above the shocks to income, as proxied by GDP changes, and price are more robust and take into account the influence of trade shocks as well as distinguishing the effects on skilled and unskilled labor. This is important, as the IFSA model, directly uses the GDP and price shocks to derive the estimates of food insecurity from COVID-19. Second, unlike the previous studies we evaluate the increase in food insecurity from 2019 on to our BfC baseline and then under COVID-19 in 2020 and 2021. This allows us to decompose the deterioration of food security over time into its two components (one created by the pandemic, the other reflecting underlying trends observed in recent years). The previous studies only compared a 2020 scenario without COVID-19 to a 2020 scenario with COVID-19. Moreover, at the time of these studies the effects on GDP and food prices for 2020 where unknown and were based on early projections. Our estimates for 2020 are now more definitive as the effects on GDP and prices are known.

The food security results highlighted below are for a subset of the GTAP results presented above, as the expanded IFSA database only covers 80 low- and middle-income countries. A much lower number than the GTAP database which covers the world. All macroeconomic shocks to GDP and prices are based on 2019 price levels for the two scenarios (BfC, and COVID-19). The USDA's International Food Security Assessment (IFSA) defines food insecurity as the inability of a person to consume 2,100 kcal per person per day (Baquedano et al., 2020). Using this definition our discussion on food security focuses on the number of food-insecure people. The first major finding is consistent with FAO et al. (2021); food insecurity had been increasing even before the COVID-19 pandemic, driven mainly by regions and countries with protracted conflicts or protracted economic crises.

The number of food-insecure people under the BfC scenario was estimated to have increased on average 31.9 percent from 2019 to 2020 as implied by figures in Table 6. This increase represents the baseline metric to separate the effects from COVID-19 and long-term trends. When the GDP estimates that incorporate the global effects of COVID-19 are considered, the number of food-insecure people is estimated to have increased by 42.3 percent (see Table 6). Hence, about 34.1 percent of the increase in food insecurity between 2019 and 2020 is caused by long-term trends and 65.9 percent by COVID.

For 2021, the food security trends tapers under the BfC scenario with a small decrease in food insecurity of -0.4 percent with respect to its 2020 level. Under the COVID scenario in 2021, the food security situation improves with the number of food insecure declining 8.5 percent with respect to the high COVID levels in 2020. Still COVID is estimated to have a strongly negative impact on food insecurity, responsible for 50.4 percent of the estimated increase in food insecurity relative to its level in 2019. The other 49.6 percent comes from underlying longer trends driven by conflicts and economic crises.[8]

Table 6. Food insecurity evolution in the BfC and COVID baselines

	2019	2020	2021
	Number of food-insecure people (millions)		
But for COVID-19	779.6	869.3	866.2
COVID-19	779.6	1,042.5	954.3

Source: Estimates derived using USDA's International Food Security Assessment Model

The number of food insecure in 2021 remains nearly 22.4 percent higher than in 2019. (Table 6). The

[8] The decomposition comes from comparing food insecurity in 2020 under the BfC and COVID scenarios and their evolution from 2019, and similarly in 2021.

Table 7. Food insecurity in number of food-insecure people in 2020 and 2021 in levels (millions) and share of population (%)

Region			But for COVID-19				COVID-19			
	2019		2020		2021		2020		2021	
	Number of food Insecure	Share of the population food insecure	Number of food Insecure	Share of the population food insecure	Number of food Insecure	Share of the population food insecure	Number of food Insecure	Share of the population food insecure	Number of food Insecure	Share of the population food insecure
	(million)	(%)	(million)	(%)	(million)	(%)	(million)	(%)	(million)	(%)
TOTAL	779.6	18.3	869.3	20.1	866.2	19.8	1,042.5	24.1	954.3	21.8
Commonwealth of Independent States	6.1	8.5	6.9	9.5	6.8	9.3	7.9	10.9	7.2	9.9
Central and Southern Asia	96.3	31.3	101.9	32.7	93.0	29.5	127.0	40.8	112.6	35.8
India	129.4	9.9	153.7	11.6	158.7	11.8	216.7	16.3	188.2	14.0
Pakistan	80.8	35.3	83.3	35.7	75.6	31.7	96.5	41.3	79.7	33.4
South East Asia	50.2	10.2	58.5	11.7	59.4	11.8	69.0	13.8	68.0	13.5
Latin America and the Caribbean	45.4	8.2	55.0	9.8	48.0	8.5	77.4	13.9	54.2	9.6
North Africa	10.9	5.7	12.9	6.6	21.9	11.1	14.3	7.4	25.6	13.0
Central Africa	66.5	48.7	81.4	57.8	89.2	61.5	91.3	64.9	91.6	63.1
East Africa	103.7	40.3	100.1	37.9	105.1	38.7	106.4	40.2	110.0	40.5
Ethiopia	22.7	21.6	22.9	21.2	33.8	30.5	28.1	25.9	38.1	34.3
Southern Africa	86.7	43.3	96.2	46.9	90.4	43.1	103.8	50.7	92.7	44.2
West Africa	32.7	17.6	33.0	17.4	33.0	16.9	35.4	18.6	32.4	16.6
Nigeria	48.2	23.1	63.6	29.7	51.5	23.5	68.6	32.0	54.1	24.6

Source: Estimates derived using USDA's International Food Security Assessment Model higher number of food insecure in 2021 relative to pre-pandemic levels, implies that about half of the change in the number of food-insecure people reflect long-term dynamics and not COVID-19 trends. All the modeled regions saw a sharp increase in the number of food-insecure people because of the pandemic as shown in Table 7. The five most affected countries and regions by the pandemic are: India, Central and Southern Asia, Pakistan Latin America and the Caribbean, and South East Asia. India is estimated to have seen the largest increase in the number of food insecure in 2020 because of the COVID-19 pandemic of any region. The increase in the number of food-insecure people in India from the pandemic is 63 million (see Table 7). The decline of India's food security metrics is mainly explained by an increase in the number of people in lower-income deciles considered food insecure because of the pandemic. For example, prior to the pandemic, the third income decile was estimated to be food secure, after the pandemic the decile is considered food insecure. In 2021, India, Central and Southern Asia, South East Asia, and East Africa, and Latin America and the Caribbean are the most affected countries by the pandemic in terms of increased food insecurity. These geographical results are broadly consistent with the new analysis of Laborde et al. (2022) revisiting the impact of COVID "2 years later." They estimate that hunger in South-Asia was the most exacerbated in 2020 and to a lesser extent still in 2021. Our relatively low estimates of food-insecure people in West Africa due to COVID is also consistent with estimates of Laborde et al. (2022). Our estimated increase in food-insecure populations is higher than the mid-range estimate in SOFI (2021) (118 million) and close to the upper bound of the projected range in SOFI (161 million). Our 2020 estimate of 163.2 million is higher than the estimate of Laborde et al. (2022) of 123.7 million. Our 2021 estimate of 86.5 million is lower than IFPRI's estimate of 99.4 (Laborde et al. 2022). These differences originates in the difference in modeling assumptions, and macro projections done at different times and assumed caloric requirements. Broadly, various estimates are in agreement that South Asia has been most impacted and more than Africa, and that 2020 was the worst exacerbation of food insecurity relative to 2021.

6. Conclusion

We analyzed the impact of the COVID-19 pandemic and associated policy responses on the global economy and food security in 80 low- and middle-income countries. We used a global economy-wide model with added detailed disaggregation of agricultural and food sectors and a BfC baseline for 2020. We incorporate aggregate income shocks, sectoral losses in productivity, rising transaction costs, and decreases in demand induced by distancing. We compute changes in income and food prices from the pandemic shocks in 2020 with and without the effects of COVID-19. To compare and contrast trends in 2020 and potential paths of economic recovery in 2021 we use GDP growth estimates from the IMF as explained previously.

The resulting shocks in prices and incomes from the CGE model simulations were incorporated into USDA ERS' IFSA model to analyze the deterioration in food security in these 80 countries. Negative income shocks dominate the impact of lower cost of food. Food insecurity increases in 2020 considerably in countries in Asia and Latin America and the Caribbean through income shocks rather than prices as aggregate income and income of unskilled labor falls considerably in many countries. Few sectors exhibit price increases as income contractions reduce demand in most sectors and most countries.

Our findings confirm that food insecurity had been deteriorating prior to the COVID-19 pandemic, as food insecurity was found to be on an upward trajectory when considering a scenario without the effects of COVID-19 on the global economy. The main effect of the pandemic was to sharply increase the deteriorating trend in food security in the 80 low- and middle-income countries covered in this study. Most of the increase in the number of food insecure people from COVID-19 in 2020 is driven by large Asian countries, particularly India, Bangladesh (not shown in the table), and Pakistan. Sub-Saharan African and Latin America and the Caribbean countries also saw a sharp increase in their food insecurity levels. Moreover, the increase in the number of food-insecure people in 2020 was driven by the effects of the COVID-19 pandemic. By contrast in 2021 relative to 2019, roughly half of the deterioration of food security is caused by long-term trends and the other half by the continued pandemic. The projected uneven recovery in 2021 means that the pandemic is not quite as debilitating as it was in 2020, and as a result continued long-term trends account for a larger share of the food insecurity.

We also noted that most countries of interest experience moderate terms-of-trade deteriorations and losses of purchase power on world markets; these countries also experience more dramatic decreases in exports and often as well in imports, except Ethiopia. The fall in agricultural export revenues was considerable in many countries. The decreased reliance on trade was not induced by restrictive trade policies, but rather by the generalized demand contractions, as a result of lower incomes, damping agri-food export demands and by general equilibrium export supplies. Income derived from export sales fellf. Similarly, imports contracted because of lower income in importing countries.

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Appendix table A.1. Shocks (COVID-BfC baseline) in percent deviation 2021 run							
Variable shock	GDP target	Balance of Payments	Government expenditures	Investment	Capital	Skilled labor	Unskilled labor
Central Africa	-3.354	-3.352	-5.386	0.739	-1.169	-1.169	-5.244
China	0.636	-0.146	7.966	4.471	-14.616	-14.616	-13.206
Commonwealth of Independent States	-1.625	-1.614	4.821	-12.302	-6.547	-6.547	-7.687
Central & Southern Asia + Other Asia	-15.703	-15.691	1.927	-6.280	-22.123	-22.123	-41.034
East Africa	-3.433	-3.344	-5.508	-8.868	-13.827	-13.827	-16.986
Ethiopia	-8.602	-8.576	-8.829	-20.541	-13.292	-13.292	-20.760
Europe including GBR and CHE	3.161	1.613	19.133	0.590	-3.790	-3.790	2.416
India	-10.079	-9.946	-0.147	-11.253	-21.419	-21.419	-32.770
Latin America & the Caribbean	-9.524	-9.418	-3.431	-16.014	-12.151	-12.151	-24.391
North Africa	-1.073	-0.558	-7.360	-27.825	-10.491	-10.491	-10.736
Nigeria	1.307	1.399	-4.893	-6.302	-12.292	-12.292	-9.560
Pakistan	-3.583	-3.511	2.097	-3.180	-11.044	-11.044	-15.019
Rest of World	-1.741	-4.211	6.699	0.541	-5.376	-5.376	-6.565
Southern Africa	-4.336	-4.315	-2.059	-2.596	-7.947	-7.947	-12.261
South East Asia	-9.289	-9.143	1.851	-16.139	-18.901	-18.901	-29.305
USA	-4.410	-0.904	24.231	-0.783	-12.182	-12.182	-16.681
West Africa	0.549	0.617	20.471	1.614	-16.028	-16.028	-14.550

Appendix Table A.2. Income shocks in 2021

Appendix Table A.2. Income shocks in deviation from BfC scenario for 2021

Income category	Capital	Skilled labor	Unskilled labor	GDP
Central Africa	-3.653	-3.504	-2.548	-3.354
China	0.799	1.529	-0.189	0.636
Commonwealth of Independent States	-1.720	-1.142	-1.151	-1.625
Central & Southern Asia + Other Asia	-14.080	-12.374	-13.682	-15.703
East Africa	-3.370	-4.323	-1.831	-3.433
Ethiopia	-9.814	-14.294	-2.951	-8.602
Europe including GBR and CHE	3.587	3.997	0.087	3.161
India	-10.275	-8.481	-6.081	-10.079
Latin America and the Caribbean	-9.445	-10.026	-6.558	-9.524
North Africa	-0.868	-3.585	1.433	-1.073
Nigeria	-0.071	-0.474	3.937	1.307
Pakistan	-3.502	-2.893	-2.586	-3.583
Rest of World	-1.953	-0.824	-1.708	-1.741
Southern Africa	-4.657	-4.013	-3.415	-4.336
South East Asia	-8.664	-9.326	-6.437	-9.289
USA	-4.459	-3.495	-4.166	-4.410
West Africa	0.462	2.978	-2.128	0.549

Appendix Table A.3. Impact on real food prices (deflated by local cost-of-living index) in % deviation from baseline (2021 run)

region	Fish	Grains other than wheat and rice	Meats and Dairy	Oilseeds	Rice	Sugar	Vegetables, fruits, root & tubers	Vegetable oil	Wheat
Central Africa	-0.56	0.97	0.23	1.13	0.41	-0.19	1.57	-0.03	-1.63
China	-0.52	-0.86	0.26	-0.59	-0.43	-0.47	-0.05	-0.29	-0.89
Commonwealth of Independent States	-0.52	-0.31	0.38	-0.37	0.20	-0.44	0.45	-0.44	-0.36
Central and Southern Asia & Other Asia	-0.49	3.63	1.75	1.65	1.19	-1.85	4.60	-1.39	2.53
East Africa	-0.71	0.55	0.40	0.52	0.20	0.22	1.44	0.15	-0.73
Ethiopia	-6.20	3.09	-1.05	3.24	0.44	-4.12	4.24	0.70	2.63
Europe including GBR and CHE	-0.48	-1.69	-0.41	-1.25	-0.16	-0.56	-1.27	-0.45	-2.07
India	1.10	-0.02	1.03	0.31	1.17	0.04	0.91	-0.66	-0.21
Latin America & the Caribbean	-1.48	0.96	0.63	1.16	0.11	0.12	2.10	-0.35	0.38
North Africa	-0.34	0.16	0.38	0.24	0.32	0.00	0.96	0.39	-0.46
Nigeria	-0.60	-0.36	-0.12	-0.36	0.25	-0.51	0.29	0.76	-0.50
Pakistan	-0.87	-0.10	0.45	-0.09	-0.31	-0.14	0.71	0.47	-0.07
Rest of World	-0.84	-0.71	0.10	-0.71	-0.42	-0.62	0.00	-0.42	-0.80
Southern Africa	-0.65	0.11	0.40	0.20	0.49	-0.21	0.83	0.13	-0.48
South East Asia	-0.92	0.68	0.95	0.86	0.77	0.18	0.91	0.49	-1.36
USA	-1.52	-1.22	0.13	-1.29	-0.44	-0.43	-0.50	-0.69	-1.32
West Africa	-0.83	-2.11	0.47	-1.86	0.87	-0.07	-1.44	0.31	-0.83

Appendix Table A.4. Agricultural and food trade impact in deviation from the BfC scenario 2021 COVID-19 runs (in percent)		
Country/region	**Exports**	**Imports**
Central Africa	-8.26	-2.95
China	-6.22	-9.59
Commonwealth of Independent States	-7.98	-0.12
Central & Southern Asia + Other Asia	-25.93	-2.36
East Africa	-9.25	-1.73
Ethiopia	-20.96	9.36
Europe including GBR and CHE	-7.92	-11.11
India	-11.65	-8.85
Latin America and the Caribbean	-17.69	-2.73
North Africa	-6.07	19.57
Nigeria	-7.94	3.78
Pakistan	-7.35	-5.29
Rest of World	-7.78	-7.59
Southern Africa	-8.15	-4.82
South East Asia	-14.95	-3.96
USA	-7.90	-19.20
West Africa	-0.28	-8.07