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Introduction

Pol Antràs and David Zilberman

There has been a growing awareness of the importance of agricultural supply and value chains and the need to understand the interactions within and between these supply chains to understand the performance of agricultural markets, their dependence on exchange rates and macro policies, and especially their vulnerability to risk. The performance of agricultural supply chains has received the attention of the Agricultural Economics literature. Zilberman, Lu, and Reardon (2019) emphasize the importance of economic considerations in the design of supply chains to implement agricultural innovation and establish the agricultural market structure with multiple illustrations. Barrett et al. (2020) survey the rich literature on the transformation of agricultural value chains, especially in developing countries. However, the COVID-19 pandemic and concerns about the vulnerability of agricultural systems to climate change emphasize the importance of establishing a solid research agenda on assessing the vulnerability of agricultural and food supply chains to various risks, behavioral responses to this risk, and the use of policy instruments to enhance resilience and mitigate the impacts of shocks to agricultural systems. The workshop and this book are initial steps to develop an integrated research agenda on agricultural supply chains' resilience to risk and policies to enhance it.

The workshop, co-sponsored with the USDA, benefited from the recent

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literature on the impact of the pandemic in agriculture and from the growing efforts supported by the USDA to collect and analyze data on agricultural vulnerability. The chapters in the book are a mixture of conceptual studies and especially promising empirical directions of research on agricultural supply chain resilience to risk. The book addresses supply chain vulnerability to stress broadly defined, but has a big emphasis on the impact of the recent pandemic.

The analysis of risks facing agricultural value chains expands the range of phenomena we must analyze. They include risks from accumulating stock pollution, such as the buildup of greenhouse gases, the accumulation of contaminants in water, and risks faced by industry and consumers from transitory random shocks. The latter shocks include economic shocks, e.g., recession, biophysical and medical shocks (pandemics), and climate and weather shocks (tsunamis, earthquakes, etc.). The heterogeneity of these shocks necessitates a diversity of analytic approaches and modeling. The chapters also differ in how they analyze the economic impact of the risk-causing phenomena. These are early studies in important emerging literature, and we wanted to introduce the reader to these diverse lines of inquiry.

We broadly distinguish between two types of contributions to this volume: ***general studies*** attempting to make broad points with data from several settings and time periods, and studies that are more focused on the ***recent shocks*** (such as COVID-19). We next describe each of these in turn.

General Studies

The general studies fall into several categories. The chapters by Sunghun Lim, and by Reardon and Zilberman, review the structural transformation of supply chains and present methodologies to quantify them and predict future directions. Steinbach presents an econometric study on the vulnerability of global food supply chains to exchange rate vulnerability. An essay by the former Californian secretary of agriculture, A. G. Kawamura, provides a practitioner's perspective on new technological opportunities, emerging economic challenges, and the evolution of agricultural supply chains. There are two methodological studies, one by Taylor and Heal on the use of spatial satellite data to assess the vulnerability of agricultural water and marine systems with an application to fertilizer externalities and their implications for algal blooms; and the other by Lu, Nguyen, Rahman, and Winfree on the use of agent-based modeling to determine the dynamics of crop supply chains under risk. We next describe these chapters in a bit more detail.

In "Symbiotic, Resilient, and Rapidly Transforming Food Supply Chains in LMICs: Supermarket and E-commerce Revolutions Helped by Wholesale and Logistics Co-pivoting," Reardon and Zilberman provide an overview of the findings of large emerging literature on the evolution and transformation

of food supply chain evident in developing countries. Food supply chains are transforming rapidly from traditional to modern supply chain, and the transformation is affected by trade liberalization and globalization (Reardon et al. 2019). The evolution of food supply chain responds to change in technologies and is symbiotic with innovation supply chain, and results in the emergence of new markets where economic considerations affect market structure and capacity. Food supply chain has capacity to adapt to long-term risk by investment in new technologies, diversification of locations and activities, and modification of trade patterns. They adjust to short-term shocks by pivoting to new exchange strategies, digitization, and product innovation. Innovations tend to emerge in response to shocks. The literature on the supermarket revolution, as supermarkets spread throughout the world in the last century, illustrates long-term adaptation and changes to supply chain. The emerging literature on the response of the food sector to the pandemic illustrates some of the pivoting and changes in response to short-term shocks.

Following this survey chapter, we have several mostly empirical studies on various aspects of transformation on supply chain and information systems. In "Global Agricultural Value Chains and Structural Transformation," Sunghun Lim studies the impact of participation in agricultural value chains (AGVCs) on the structure of production in the participating agrarian economies. Does participating in AGVCs lead to subsequent growth in manufacturing? Does it lead to an expansion of the service center? The author provides answers to these questions using a panel data set covering 155 countries for the period 1991–2015. Building on the EORA Multi-Region Input-Output tables (MRIOs) generated by the UNCTAD-Eora Global Value Chain database, Lim begins by computing country-year measures of AGVC participation following standard tools in global input-output analysis (see Borin and Mancini 2019; Wang et al. 2017). He then studies the extent to which high AGVC participation has predictive power for both GDP and employment shares in agriculture, services, and manufacturing. His results suggest that AGVC participation increases GDP and employment in the agricultural and service sector, while decreasing them in the manufacturing sector. Counter to conventional wisdom about structural transformation, Lim's evidence indicates that modern agrarian economies appear to be leapfrogging the manufacturing sector to directly develop their agriculture and services sectors through their participation in AGVCs.

Lim then digs deeper and studies whether positioning in AGVCs matters for structural transformation. After decomposing the total AGVC participation into upstream participation and downstream participation in AGVCs, he finds that the core leapfrogging result applies for both upstream and downstream participation. However, he finds some divergence on the relative effect of upstream and downstream participation on the share of GDP

and employment in the agricultural sector, and he interprets this result as suggestive that upstream AGVC participation leads to more labor-intensive agriculture than downstream AGVC participation.

In "Exchange Rate Volatility and Global Food Supply Chains," Sandro Steinbach analyzes the impact of exchange rate risk on global food supply chains. The conventional wisdom is that an increase in exchange rate uncertainty causes an increase in revenue uncertainty, which will hamper the exchange of goods and services across international borders. Nevertheless, several authors (Johnson 1969; Franke 1991; De Grauwe 1988) have identified a number of mechanisms under which exchange rate volatility can actually enhance international trade flows. It is then perhaps not too surprising that the extant literature on the impact of exchange rate volatility on international trade has failed to produce unambiguous and robust results (see, for instance, Tenreyro 2007), though the majority studies point toward a negative impact. Steinbach's paper contributes to the ongoing debate by investigating the relationship between exchange rate volatility and global food supply chains employing product-level trade flows for 781 agricultural and food products and for a balanced panel of 159 countries for 2001 to 2017. The author estimates a sectoral gravity model and addresses concerns related to endogeneity, heteroskedasticity, zero trade flows, sampling, and reverse causality. Furthermore, both the short-run and the long-run effects of exchange volatility are studied.

The paper finds evidence for interesting heterogeneous effects of exchange rate volatility on global food supply chains both across products and across time horizons. While the mean trade effects are positive for short-run and long-run volatility, these effects vary substantially according to product and industry characteristics. More specifically, Steinbach finds that the majority of agricultural products are positively affected by short-run exchange rate volatility, whereas aquaculture and horticulture products are negatively impacted by both short-run and long-run exchange rate volatility. Furthermore, he finds a positive association between exchange rate volatility and trade flows for upstream products (according to the measure in Antràs et al. 2012) and a negative association for downstream products. Finally, Steinbach demonstrates that if one adopts alternative specifications that do not account for several sources of bias, one finds negative and significant effects of exchange rate volatility, in line with the bulk of previous studies. In sum, the results of the paper enhance our understanding of the implications of exchange rate volatility, which is a primary source of international risk exposure for global food supply chains.

In "Fertilizer and Algal Blooms: A Satellite Approach to Assessing Water Quality," Charles A. Taylor and Geoffrey Heal study the impact of the use of fertilizer in agricultural supply chains on water quality in the form of aquatic hypoxic zones and algal blooms. Nutrient pollution is one of the most challenging environmental problems of our age, and is caused by

excess nitrogen and phosphorus, coming primarily from fertilizer use but also from human and industrial waste. These nutrients feed the growth of phytoplankton, thus producing algal blooms, which are considered to produce harmful environmental and health effects when concentrations achieve sufficient density. Nevertheless, as Taylor and Heal point out, the economic impacts of hypoxia and algal blooms and the related external cost of fertilizer are difficult to quantify because of the challenges in linking accumulated downstream pollution to specific upstream sources. A second challenge to rigorous estimation of the social cost of fertilizer is the lack of a temporally consistent, administrative-level data set on water quality.

In their paper, the authors make creative use of a novel satellite-derived measure of algal bloom intensity that spans 30-plus years and encompasses lakes, rivers, and coastal aquatic resources across US counties. More specifically, Taylor and Heal construct a county-level measure of algal bloom intensity derived from over three decades of Landsat satellite imagery and processed using computing power available through Google Earth Engine. Their "bloom algorithm" is based on the near-infrared (NIR) band with an atmospheric correction for shortwave radiation (SWIR).

They then show that their constructed bloom intensity is higher in agricultural regions. There is significant geographic variation in where bloom intensity increased and decreased the most from 1984 to 2020, but there seems to be a general upward trend in the upper Great Plains and along the 100th meridian.

In their econometric results, Taylor and Heal study how bloom intensity is shaped by various factors, including fertilizer use. To compute an annual and county-level measure of fertilizer use, the authors employ data from the US Geological Survey (USGS) on nitrogen and phosphorus use from 1987 to 2012. The underlying data are based on fertilizer product sales compiled by the Association of American Plant Food Control Officials (AAPFCO). Their findings provide strong and robust evidence for the effect of fertilizer use on water quality. Specifically, fertilizer-associated farm pollution drives water quality impairment both locally and downstream from the fertilizer use, and these impacts occur across short-term, medium-term, and long-term horizons. Their findings are of utmost policy relevance, especially given that fertilizer use is mostly exempt from federal regulation under the Clean Water Act despite being the major source of water quality impairment in the US.

In "Demand Shocks and Supply Chain Resilience: An Agent-Based Modeling Approach and Application to the Potato Supply Chain," Liang Lu, Ruby Nguyen, Md Mamunur Rahman, and Jason Winfree address some of the implications that emerge from demand shocks on agricultural food supply systems. Existing literature put a lot of emphasis on understanding the risks in the supply side of the agricultural supply chain. Yet, the COVID-19 pandemic reveals the risks from demand side and their impact

throughout the food supply chain. In the case of the pandemic, there is evidence that surpluses and shortages arose from the quick transition of demand from restaurants, hotels, and schools to cooking at home: for example, potato shortage on supermarket shelves and farmers' dumping potatoes at the same time. The paper develops an agent-based model to assess the impact of demand shock on food supply chain based on the case of Idaho's potato supply chain. Five types of agents (farmers, shippers, processors, retailers, and logistics companies) are modeled in this multi-echelon potato supply chain. The model allows for simulating how agents along the supply chain respond to sudden demand changes (demand shocks happening early or late in the growing season). Results showed that not only the magnitude but also the timing of the demand shock have different impacts on various stakeholders of the supply chain. When a demand drop occurs early in the season, even after the disruption period, the fresh potato price is comparatively low for the remaining time of the season. Meanwhile, since the supply chain gets a long period to absorb the surplus inventory, the amount of disposed potatoes is small. When demand drop occurs late in the season, the supply chain cannot absorb the surplus supply of potatoes within a short period. Therefore, farmers have no choice but to dispose of unsold potatoes before the new harvesting season starts. Early demand rise resulted in a 139 percent price hike compared to the baseline scenario, while the late demand rise scenario was responsible for a 56 percent price hike only.

In "The Performance and Future of Ag Supply Chains," A. G. Kawamura, previous secretary of agriculture of California, a farmer and a thinker, presents an essay about factors that affect agricultural supply chain in the present, including his perceptions about the future. His experience suggests that we live in an era of very fast agricultural technologies that are associated with dramatic changes in the structure of agricultural business and supply chain. He views these changes as driven by three forces: (1) globalization, the opening to China, and the large new market opportunities, as well as potential competition facing US agriculture; (2) new technologies resulting from revolutionary discoveries in information science, biology, and robotics; (3) concern about the environment and development, in particular climate change. The UN Sustainable Development Goals provide targeting for policy makers in government, NGOs, and industry. Environmental considerations are added to concern about quality and price in consumer choices. These rapid changes lead to the evolution of agricultural technologies and the structure of the industry, with new forms of farming, ranging from small organics to large industrial producers, allowing them to pursue diverse consumers. The only certainty in the food sector is change. Kawamura is aware that agrifood is subject to continuous scrutiny that led to change but is quite satisfied with the resilience of the food systems in response to the COVID-19 pandemic.

The above studies identify how the structure of supply chains and their

performance are affected by risk consideration, shocks, and new information. The major shocks between 2018 and 2022—the COVID-19 pandemic, African swine fever, and changes in international trade agreement—provide evidence of the impact of shock in the supply chain. They are discussed in the next section.

Studies on Recent Shocks

Several of our studies assess economic challenges associated with recent shocks. The study by Delgado, Ma, and Wang assesses the impact responses to the outbreak of African swine fever (ASF) in China on prices and consumption. The chapter by Ma and Lusk is an investigation of the impact of the US meat supply chain's concentration on its resilience to shocks like the current pandemic. This study is especially relevant,9 given the proposals for new regulations on the structure of the meat sector. The study by Ramsey, Goodwin, and Haley addresses the disruptions in the labor market of the food sector as a result of the pandemic. This study assesses the labor impacts of the pivot away from sit-in restaurants to take-home food, the emergence of food delivery services, and the vulnerability of food processing workers to COVID-19. Finally, the study by Arita, Grant, Sydow, and Beckman assesses the resilience of the global agricultural trade to the pandemic. It teases the impact of the pandemic compared to other shocks and demonstrates how they vary across sectors and countries.

In "Exploring Spatial Price Relationships: The Case of African Swine Fever in China," Michael Delgado, Meilin Ma, and H. Holly Wang exploit a natural experiment to study spatial mechanisms behind the dynamics of market integration. In particular, the paper is focused on a temporary ban on inter-province shipping of live hogs induced by the 2018 outbreak of African swine fever (ASF) in China. This is a particularly interesting setting because China is the world's largest producer and consumer of pork, and furthermore, pork consumption is concentrated in large cities in coastal provinces, while its production is in rural areas. Inter-province transportation of live hogs has thus been a dominant feature of the Chinese hog market. In response to the ASF outbreak, the central government immediately imposed an inter-province shipping ban for live hogs, which greatly disrupted market integration across provinces. The ban was lifted a few months later when cases diminished.

The authors assemble a unique data set of weekly provincial hog prices, and they employ state-of-the-art spatial network econometric techniques (c.f., de Paula et al. 2018) to estimate the strength of price co-movement across provinces pre and post the ban. More specifically, Delgado and coauthors identify a pre-ban period, a ban period, and a post-ban period and study price integration during those periods. The methodology parameterizes the price links across provinces to facilitate estimation of those connec-

tions via generalized method of moments (GMM), while controlling for province- and time-specific factors.

Their first finding is that the hog market was highly integrated across provinces prior to the ban, with longer geographical distances between two provinces not significantly weakening the strength of their price linkage. The shipping ban dramatically broke down spatial integration (see their figure 7.2). Although the ban only lasted a few months, the authors document that even during the post-ban period, longer distances remained a significant obstacle to spatial price linkage, implying faster reintegration of hog prices between proximate provinces than remote ones. The authors then use variables such as geographic distance and the length of time period under ban for any pair of provinces to explain the slow market reintegration process measured by the price relationships previously estimated. The authors' preferred interpretation of the results is that the slow reintegration of markets was due to the interplay between arbitrage opportunities and imperfect information. More specifically, they ascribe the slow recovery of integration to producers' and processors' reluctance to reassume trading with distant partners, compared with partners nearby, given the incomplete public information regarding ASF. The authors conclude that information transparency is a key factor in fostering market integration in the aftermath of shipping bans used to curb animal pandemics like ASF.

In "Concentration and Resilience in the US Meat Supply Chains," Meilin Ma and Jayson L. Lusk analyzed to what extent a less concentrated meat processing sector is less vulnerable to shocks including shutdown of plants. Their analysis is based on a model of meat supply chain that includes competitive livestock production and retailing, and a rather concentrated meat processing sector. They used simulations to assess the impacts of different changes in the structure of the meat packing sector—in particular, impact of shocks and changes on the wedge between consumer and animal producer prices and the welfare effects on various sectors. The analysis consisted of simulations that assessed the impact of changes on three possible structures of the industry: processing done by large plants; processing done by small plants; and the current model, which is a mix of the two. The system was calibrated assuming linear demand and marginal cost curves, as well as the fact that larger processors have higher fixed costs but lower marginal costs. The results suggest the complex relationship between structure and resilience. For example, when the industry is facing 10–30 percent risk of plants' shutdown, more concentrated packing assures a higher probability of obtaining higher level of output and higher expected outcome, while less concentrated packing assures that output doesn't fall below a minimum threshold of 40 percent. A more concentrated packing sector structure may result in higher variability of responses to shock than a more diffused structure. However, at least in the case of beef, expected total welfare tends to be lower under more diffused structure than under concentrated structure because the latter allows taking

advantage of economy of scale. These results are consistent with other findings reported in the survey by Azzam and Schroeter Jr. (1995).

This study is the first one to assess the resilience to external shock of the meat sector, and suggests the need for more research, using both simulations and, perhaps, econometric studies comparing regions or different time periods. There is a place for ex-ante studies that may assess the role of technological innovations in processing and other parts of the meat sector in ensuring resilience and improving welfare. The framework can be expanded to analyze some of the multiple policies suggested to reform the meat sector.

In "Labor Dynamics and Supply Chain Disruption in Food Manufacturing," A. Ford Ramsey, Barry K. Goodwin, and Mildred M. Haley analyze the dynamics of wage and employment in the food manufacturing and animal processing sector and use the estimate to assess outcomes during the pandemic.

The authors estimated both wages and employment in the food manufacturing and animal slaughter industries using county-level data. Food manufacturing has a higher rate of employment and less variability than the animal slaughter industries, perhaps because of higher reliance on migrant workers in the animal slaughter sector. However, regions with higher food manufacturing prices have higher animal slaughter wages. The wages and employment tend to increase by the extent of use of the productive capacities of the industry and by the price of output. Higher volatility of wages tends to increase average wages, but higher volatility of employment tends to reduce average wages. The paper finds that wages in food manufacturing and animal slaughtering in the early part of 2020 were slightly higher than what was expected given the magnitude of the shock, but later in the year, the deviation from predicted prices was smaller. That suggests manufacturers needed to induce employees to work during the early part of the pandemic in 2020, but later in the year, the volatility of wages declined, and the availability of labor increased. The analysis suggests that the pandemic had significant impact on labor in food processing sectors early in the pandemic, but the labor situation recovered relatively fast. The analysis relied on county data, but further insight can be gained using plant-based data and distinguishing between different types of employment and labor relationships and contracting.

In "Has Global Agricultural Trade Been Resilient under COVID-19? Findings from an Econometric Assessment of 2020," Shawn Arita, Jason Grant, Sharon Sydow, and Jayson Beckman show that overall the pandemic has half the effect on agricultural trade (5–10 percent reduction) than trade in nonagricultural commodities, but impacts vary by agricultural sectors. While some effects can be obtained by comparing ag trade patterns of 2019 and 2020, econometric analysis enables separating the impacts of the pandemic from impact of animal diseases (African swine fever, ASF) and policy (US-China trade agreement). For example, the overall trading in

pork increased in 2020 because of the reduced severity of ASF, despite some reduction due to the pandemic. Furthermore, the analysis also shows that quarantines and trade and movement restrictions resulting from COVID-19 have had stronger impact than the disease itself. The analysis suggests that the impact of the pandemic was more significant on the demand than the supply side. Non-food items like skin hides, ethanol, and rubber suffered the steepest reduction in trade because of the pandemic, while most commodities didn't suffer much, and trade in rice actually increased. It seems that low-income and less-developed countries were more vulnerable to the pandemic, and COVID-19 contributed to reduction in income. Transfer policies in developed and some developing countries reduced the impact of COVID-19 on agricultural trade. Finally, the trade reduction because of COVID-19 occurred mostly early in the pandemic, and smaller disruptions continued throughout the year, indicating signs of adjustment and recovery.

The analysis suggests that global agriculture trade was resilient to COVID-19, and major impacts were more on luxury non-food groups than on essential food commodities. The impact of COVID-19 on agricultural trade and the resulting welfare of individual groups should be further studied with more detailed data on outcomes within countries.

Conclusions

Agriculture and other industries consist of a web of interrelated supply chains, which evolve and adapt in response to changes in technology, policy, and biophysical and medical shocks. This book hopes to provide an important launching pad for the emerging research agenda on the vulnerability of agricultural and food markets to shock. In addition, it supplies methodological and empirical foundations for economists, and valuable information for policy makers and the general public, especially when relating to the impact of COVID-19 and other shocks in the late 2019 and early 2020s. Economic research can and should gain understanding of the evolution and the economics of supply chain, how product supply chains are linked to innovation policies and institutions, and how the evolution of supply chain shapes markets, trade patterns, and economic welfare (Zilberman et al. 2022). Agriculture and natural resources can provide important past lessons and case studies on the economics of supply chain and its implications for major policy issues associated, for example, with climate change, food security, biodiversity, and economic development.

This book contributes to emerging literature on the economics of agriculture and food supply chains and their responses to risks. It suggests that the agrifood sector is facing multiple categories of risks. Unfortunately, some of them have not received much attention from economic research. Thus hopefully, the works presented here will inspire further research on the eco-

nomics of supply chains and the response to diverse categories of risks by firms and supply chains. The analysis of these risks requires access to new sources of data and multidisciplinary understanding that will further enrich the economic stock of knowledge.

While much of the activities in agriculture are increasingly outside the farm gate, the USDA has provided mostly data and information about agriculture. This information has contributed immensely to the development of economics, and for agricultural policy and analysis. However, at present, significant information gathering and data collection are needed to understand the behavior and evolution of food and agricultural supply chains. There would be substantial value to USDA pursuing such an effort, and the design and management of this information collection will require creative research that will challenge and enhance the capabilities of economics and the data sciences.

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