Resilience for Smallholder Farmers during Pandemic: Model Conceptualization for Agriculture and Food Supply Chain Dynamics

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The emergent COVID-19 pandemic has affected agriculture and food supply chains worldwide, causing problems related to food production (Stephens et al., 2020), food loss and waste (Aldaco et al., 2020), food access (Aday & Aday, 2020), and food security (Dev & Kabir, 2020), primarily due to travel restrictions and lockdown regulations (Garnett, Doherty, & Heron, 2020; IPES, 2020; United Nations, 2020). Similarly, shifts in consumer behavior, a consequence lockdown induced lifestyle disruptions and psychological stress (Aldaco et al., 2020), have led to shortages or surpluses of certain goods. The coping strategies employed by small-scale farmers due to the pandemic can result in broader welfare implications (Haga, 2020; Galiano & Hernandez, 2008) and, thus, heightens the importance of building resilience in these communities (Bhavani & Gopinath, 2020).

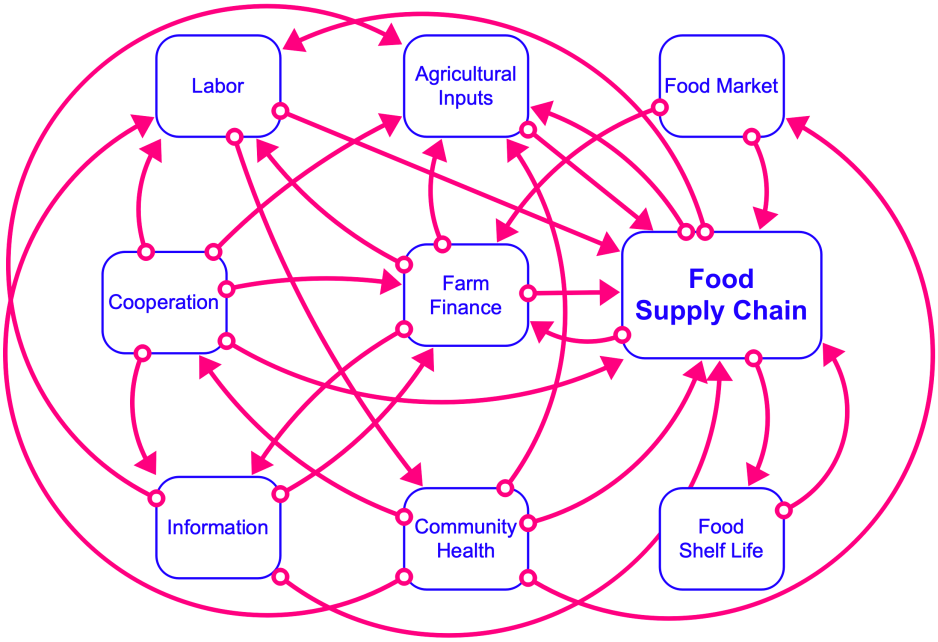
Agriculture and food supply chain resilience and vulnerability have been investigated in several previous system dynamics modeling studies. As the major contribution of our study to the existing literature, we aim to understand the disruptions to agriculture and food supply chain resilience under the influence of a community health crisis.

The modeling purpose (objective) of our study is to investigate the short-term (i.e., months) and medium-term (i.e., 1-2 years) effects of immediate COVID-19 related policy actions to facilitate both input access and market access of small-scale producers, help maintain agricultural production, and suppress the increasing food loss and waste at the farm level during health crises. Within the context of this modeling purpose, the problem customers are defined as smallholder farmers, and the decision-makers (i.e., problem owners) are selected as farming communities (including relevant unions and cooperatives).

In this study, we focus on the presentation of problem definition, dynamic hypothesis formulation, and qualitative model building stages as a starting point for the further steps of quantitative model development and policy analysis. Consisting of series of project meetings, model building sessions, individual and team assignments, project management activities, and eight team members from diverse countries (India, Nigeria, Philippines, Sweden, Turkey, and the US) with different perspectives on the issue, the work presented in this paper is an international, six-month-length system dynamics modeling project which was entirely conducted in the online environments.

To understand and elaborate on the most urgent problems regarding COVID-19 and its effects on agriculture and food supply chains, our team conducted an extensive review of both academic publications and non-academic literature, such as policy briefs and reports published by governmental and non-governmental organizations. The restrictions on transportation, input access, and market access; shortage of farm inputs and workforce; plant shutdowns and disruptions along the production lines; closure of food markets; and changes in consumer behavior and food demand constituted the highlights of our review.

The study resulted in a **stock-and-flow diagram** consists of nine interacting sectors: (1) Food Supply Chain, (2) Food Market, (3) Labor, (4) Agricultural Inputs, (5) Farm Finance, (6) Food Shelf Life, (7) Community Health, (8) Information, and (9) Cooperation.



- Food Supply Chain: The *Food Supply Chain* includes the physical transformation and transportation of the product from *Food Growth* to *Food Consumption*. During the pandemic, *Food Harvest* is severely affected due to a decrease in *Availability of Laborers*. After the harvest, the agriculture and food commodities can either be directly sold to consumers or put into storage (e.g., dry storage, frozen storage) depending on the product characteristics (Olafsdottir & Sverdrup, 2019). Hence, the importance of storage facilities increases under pandemic conditions. Food shipments also play a vital role in the market access of the farmer communities, where the *Transportation Capacity* can be driven by the farmer's own assets or can be enhanced by cooperative structures within the community.

- Food Market and Food Demand: The *Food Market and Food Demand* sector in our model includes the major drivers of pandemic-related changes in the food market from the viewpoint of farmers and farming communities. For a normal agriculture and food commodity, *Food Demand per Capita* is expected to change with the effects of *Disposable Income per Capita* and *Food Price at the Consumer Level*. With the increasing spread of the pandemic, the *Effect of Panic Buying and Hoarding* acts as another short-term effect, whereas the decline in consumer income is expected to generate long-term effects (Hobbs, 2020). Additionally, the *Effect of Shifts due to Food Characteristics* would be another determinant since the demand for processed food has increased and the demand for fresh products has decreased during the pandemic (CBI, 2020), and the shifts across product categories are expected (Hobbs, 2020).

- Labor: Agriculture and food supply chains are labor-intensive, such that labor shortages due to the effects of the lockdown cause several challenges and severe disruptions in the operations to a large extent (Schmidhuber & Qiao, 2020; Stephens et al., 2020). Considering the COVID-19 pandemic, *Restrictions on the Accessibility of Laborers* decreases *Labor Available*, and hence the *Availability of Laborers* for the agricultural operations, which is observed to be mostly affecting the harvesting and pre-sowing activities (Sahoo & Rath, 2020; Torero, 2020) as well as the food shipments. In terms of the effects related to community health, *Restrictions on the Accessibility of Laborers* and *Safety Restrictions in the Working Environment* are expected to decrease *Infection Rate* noticeably.

- Agricultural Inputs: The agricultural *Input Usage Rate* of a farm (including the use of seeds, fertilizer, plant protection) is a key determinant of *Food Growth* and thus is a determining factor to the total throughput of the food supply chain. In the case of large-scale shocks to the agricultural systems,

such as COVID-19, inputs may be available, but accessibility to the farm has become delayed as a result of supply chain disruptions (BFAP, 2020). Evidence indicates that (Marlow, 2020; Pais et al., 2020; Sun, 2020), the *Effect of Pandemic on Input Supply* is not homogenous but depends on local-regional factors. More generally, there is a risk of experiencing more widespread local or regional shortages in agricultural inputs in the coming season due to the effects of the pandemic on *Farmer's Profit* and future *Input Cost*. With the general slowdown of national and international trade, *Input Cost per Unit* is likely to go up due to the pandemic. This will further reduce farmer's purchasing power and suppress the access to agricultural inputs for the coming season(s) (Pais et al., 2020).

- Farm Finance: The pandemic revealed the financial fragilities of rural farming communities in many regions, especially where the income of farmers usually depends on their short-term – weekly or daily – activities (Ali et al., 2020; IFAD, 2020). Many farms already have thin enough profit margins in most years that the overall concern is using *Farmer's Revenue* to maintain *Farmer's Liquidity* in the short-term. Now, of course, this concern is exacerbated by disruptions related to the COVID-19 outbreak. When revenue is not high enough to maintain the *Farmer's Liquidity*, the farmer often has to use credit to maintain liquidity. The *Use of Credit* increases *Debt*, which has two serious risks: *1) Liquidity Risk* and *2) Net Worth Risk*. To prevent these risks, it is critical that the farmer finds new sources of revenue when the agriculture and food supply chain is disrupted, and this is possible if the farmer has information about where those potential sources of revenue are or if cooperation with other farmers has created new opportunities.

- Food Shelf Life: Lockdowns introduced to combat the spread of the pandemic have resulted in a general slowdown of the usual food supply chain logistics and an increase in food waste and food loss due to the limited shelf life of fresh agriculture and food products. At the farm level, a pandemic-related decrease in the operational capacity introduces longer lag times between the point of harvest and the entry of the food into the designated cold chain. With more *Food Loss* at the pre-harvest and post-harvest stages, it takes a longer time than usual to fill up a batch for shipment, thus increasing the *Time to Flow from Farmer to Post-Production*. This delay increases the rate of *Shelf Life Expiring* because the food is more exposed to pests and other environmental variables, increasing its rate of degradation (Piergiovanni, 2019). The overall result is an increase in *Food Loss* and *Food Waste* along the entire supply chain caused by extended time-delays, particularly at the farm level where food is left exposed to the elements, waiting to enter the cold chain for transportation to post-production.

- Community Health: The Community Health sector represents the impact of the propagation of disease within the community. If the *Infected Local Population* increases, it imposes *Restrictions on the Market Accessibility of Consumers*, *Safety Restrictions in the Working Environment*, and *Restrictions on the Accessibility of Laborers* to reduce the infection rate. *Restrictions on the Accessibility of Laborers* leads to a decrease in food and agricultural production capacity, and then creates excess workload on the available laborers. The excess workload increases *Pressure in the Working Environment*, which could further lead to an increase in *Infection Rate*, causing further *Restrictions on the Accessibility of Laborers*. Compulsory *Safety Restrictions in the Working Environment* such as personal protective equipment is expected to decrease the *Infection Rate* but may also create additional *Pressure in the Working Environment*.

- Information: In building resilient food systems, learning is a key process that contributes to adaptations in dealing with changing and uncertain conditions (Mukhovi et al., 2020). Throughout every step of the food supply chain, lack of access to timely information can lead to gaps in knowledge that are critical to the resilience of farmers, especially the smallholders. These can include *Information about Credit Programs*, *Information about Markets*, *Information about Inputs*, and of course, *Information about Food Loss at the Farm Level*.

- Cooperation: Cooperation supports the establishment of local food networks and contributes to the development of socially sustainable food systems (Hingley et al., 2011). From the viewpoint of the farmers, cooperation represents a vital means to facilitate access to critical resources like input, credit, labor, storage, and information, access to which have been negatively impacted by the pandemic.

Our results suggest that the most severe effects of the pandemic for many farmers might not be observed in the short-term time horizon but in the medium-term. The pandemic has made it difficult for small-scale farmers to harvest and transport goods due to the implementation of lockdown measures and travel restrictions related to COVID-19. Such challenges were also associated with the increase of food loss and food waste as food shelf life shortens due to suboptimal handling. Closure of restaurants

and schools resulted in more discarded perishable food, while changes in consumer behavior significantly magnified food waste and purchases of non-perishables. These ultimately left farmers with fewer customers and less profit, which may affect their ability to invest in future inputs due to a lack of capital or credit.

A more troubling effect suggested by our findings is the irrecoverable coping strategies that might be adopted by smallholder farmers as a consequence of the pandemic. Primarily, actions such as sales of assets to stay in business can erode future productivity or, worse, lead to bankruptcy. This feedback could potentially cascade failure in the food system despite the participation of small farms in securing food for both rural and urban people. Moreover, our analysis suggests that the main impact of the pandemic on small-scale farmers is not related to how much food is produced but rather to the inability of farmers to handle produce when shocks to the supply chain occur. In the future, the economic impacts of the pandemic, coupled with low demand and reduced access to the market, might lead to lowered profit margins for the producing farmer communities.

Our study presents a general overview of the agriculture and food supply chain resilience from the perspective of smallholder farmers and farming communities, and it serves as a starting point to explore dynamic behavior and to facilitate individual and collaborative reasoning. To make case-specific policy analysis and recommendations, stakeholder engagement and participatory modeling studies, model quantification, and extensive validation of the model are still necessary.

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