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WAGENINGEN UNIVERSITY & RESEARCH

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Wageningen Centre for Development Innovation
Wageningen, March 2021

Report WCDI-21-146

Fonteijn, H., J. Groot and X. Guo, 2021. *Analysing the resilience of food systems with scenario analyses and reverse stress tests; Concepts and an application on the Ethiopian sesame seed value chain.* Wageningen Centre for Development Innovation, Wageningen University & Research. Report WCDI-21-146. Wageningen.

This report can be downloaded for free at https://doi.org/10.18174/543747 or at www.wur.eu/cdi (under publications).

The COVID-19 pandemic, and especially its responses such as lockdowns and transport restrictions shocked the world in 2020. Rapid assessments of the crisis showed that especially poor people were hit hard, facing immediate threats to their food and livelihood security. Varies UN agencies indicated that progress towards achieving SDGs is likely to be set back by decades. The people suffering from hunger is on the increase. With that context in mind a research was started at Wageningen University to assess impact of shocks such as COVID-19 on the **most vulnerable** groups of people, anticipated to suffer even more.

The research assignment developed three methodologies that allows both academic as well as support organisations to better understand how more vulnerable groups in society respond to crisis and what room there is to enhance their resilience. These methodologies were tested in two case studies (migrant labourers in the sesame sector in Ethiopia, jobless migrant youth from pastoral communities in Somaliland). Concepts and methodologies are described in seven reports that to a large extent build on each other.

1. Guijt, J. and N. Rozemeijer. Enhancing the resilience of those most vulnerable to (food) system shocks – Synthesis paper. https://doi.org/10.18174/543741
2. Wigboldus, S. and J. Jacobs. Enhancing the resilience of those most vulnerable to (food) system shocks – Clarifying and unpacking key concepts. https://doi.org/10.18174/543742
3. Wigboldus, S. and J. Jacobs. Enhancing the resilience of those most vulnerable to (food) system shocks – Towards a sense-making framework and assessment methodology. https://doi.org/10.18174/543743
4. Roo, N. de and J. van der Lee. Exploring vulnerability and resilience from a multifaceted and systemic perspective – Case studies in Ethiopia and Somaliland. https://doi.org/10.18174/543744
5. Wattel, C.J., M. Sopov and M.A.J.M. van Asseldonk. Responsible finance for vulnerable groups under COVID-19. https://doi.org/10.18174/543745
6. Wattel, C.J., M. Sopov and M.A.J.M. van Asseldonk. Finance for Resilience Tool (FORTE) – A rapid assessment tool. https://doi.org/10.18174/543746
7. Fonteijn, H., J. Groot and X. Guo. Analysing the resilience of food systems with scenario analyses and reverse stress tests – Concepts and an application on the Ethiopian sesame value chain. https://doi.org/10.18174/543747

The authors would like to acknowledge funding from the Wageningen University & Research "Food Security and Valuing Water programme" that is supported by the Dutch Ministry of Agriculture, Nature and Food Quality.

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Report WCDI-21-146

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Contents

List of abbreviations and acronyms

ABM	Agent-based models
ECB	European Central Bank
ECX	Ethiopia Commodity Exchange
ETB	Ethiopian Birr (currency)
FSA	Food System Analysis
HLPE	High Level Panel of Experts on Food Security and Nutrition
LMIC	Low and Middle Income Countries

1 Introduction

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Food security forms an integral part of the sustainable development goals. The next 30 years will pose substantial challenges to food security worldwide, with the world population expected to grow to 9 billion by 2050 and climate change to have adverse effects on agricultural productivity. Food insecurity is however unequally distributed both between and within countries. The effects of COVID-19 form an especially poignant demonstrator of this inequality: whereas middle-class households in high-income countries continue to have access to a diverse range of food items at affordable prices, COVID-19 is expected to cause 130 million people to experience acute hunger, additional to 135 million in 2019 (Anthem, 2020). COVID-19 presents a unique challenge to the food system when compared to common stress scenarios, such as adverse weather events and commodity price volatility: the main impact of the epidemic has been on the livelihoods of the most vulnerable people, mainly because of movement restrictions and lockdowns. This in turn has disrupted supply chains for a number of crops and regions, both in terms of food production (seasonal labourers cannot travel to farms to work during harvest and other labour-intensive activities), food processing (meatpacking plants becoming sites of disease spread) and food distribution (closure of informal markets, leaving both their consumers ill-served and their suppliers and traders without income). This diverse set of effects emphasizes the necessity for a systems approach when studying food systems and innovation when it comes to designing stress scenarios.

Recently, Food Systems Approaches (FSA) (Ericksen, 2008; Van Berkum, Dengerink, & Ruben, 2018) have focused on the systemic characteristics of food systems and how they enable food security. A food system is defined by the HLPE as follows (Fanzo et al., 2017): “A food system gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outputs of these activities, including socio-economic and environmental outcomes.” Van Berkum et al. (Van Berkum et al., 2018) emphasize both the functioning of the individual components of the food system and their interrelationships, with special attention to potential feedback loops. Food security is defined as one of the outcomes of the food system, along with socioeconomic outcomes, such as livelihood and social/political capital and environmental outcomes such as impact on climate change. The FAO defines food security as consisting of (at least) 4 components:

Food security as defined by the FAO consists of 4 components:
1. Availability: the supply of food through production, distribution and exchange. This also includes physical aspects of distribution and other supply chain aspects.
2. Accessibility: the affordability and allocation of food. Pointing towards poverty as the main driver of food insecurity. Accessibility is related to the allocation of assets and capacities within a household to food consumption (and in competition with other needs, such as education). Direct access is the situation in which households produce their own food (partially). A household's access to sufficient food might not ensure sufficient allocation of food to all its members.
3. Utilization: Effective metabolization of food. This relates to food safety but also health factors such as intestinal parasites and sanitation
4. Stability: The ability to obtain sufficient food over time. Food insecurity can be transitory (e.g. related to extreme events), seasonal (hunger months) or chronic.

The fourth component, stability, is closely linked to the concept of resilience, which refers to the ability of socio-economic systems (e.g. food systems) to maintain or recover functionality after perturbations. A food system is therefore resilient if an extreme event, such as a drought or price volatility does not substantially increase food insecurity or that its recovery time to business-as-usual levels of food insecurity is limited. Food system resilience can be evaluated *post hoc* by analysing food security in response to extreme events that have historically occurred. This however severely limits the variety of (combinations of) extreme events that can be investigated to the ones that have occurred in the historical record. Moreover, even if a food system (for instance in a country) has responded well to an extreme event in the past, this does not guarantee good performance in a future occurrence of a similar event, since food systems are highly dynamic and their response to extreme events will therefore change over time. The evaluation of food systems resilience therefore calls for an *in silico* laboratory, in which a variety of food systems architectures can be tested against a multitude of scenarios.

At the level of individuals, a food system consists of agents who are endowed with different productive capacities (farming, labour, trading, investing, etc) and who have different food consumption requirements (because of cultural preferences or age). These agents put their productive capacities to use to fulfil their consumption requirements. For instance, a subsistence farmer could divide her attention between farming the land and participating in off-farm jobs. This allows her at harvest time to consume and store produce from her land, while the off-farm income allows her to supplement her food sourced at her own farm with other food types. This is at once a diversification strategy concerning food types and income sources and acts as a risk management strategy to protect against local harvest failures or shortages in off-farm labour opportunities. A wet market food seller will use his productive capacities (including his trading network) to buy food from farmers directly or from wholesalers and then to sell it to consumers. A food systems approach requires therefore not only the description of different types of agents (including their productive capacities and their food consumption requirements), but also of the connections between these agents. Moreover, the behavioural repertoire of these agents is constrained by their local physical environment: for instance, sub-Saharan subsistence farmers grow different crops than European industrial farmers. Moreover, infrastructure plays a large role in determining whether locally produced food can be marketed to nearby or distant concentrations of consumers: transportation networks play the obvious role here, but so does a reliable electricity grid for the storage and processing of fresh products. A food systems model must also incorporate global markets interacting with agents both as another option to source food and as a competition for local food producers to market food. Finally, social aspects, including the role of collective organization of these agents (in the form of families, villages, governments, cooperatives) and culturally determined food preferences must be taken into account. A complete representation of all these factors would therefore result in a model with considerable complexity. Many models have therefore focussed on specific parts of the food system: Berger et al. (Berger et al., 2017) have for instance focused on the effect of policy interventions on the ability of smallholders in Ethiopia to adapt to climate change by designing a detailed agent-based model for smallholders in this context while keeping the effects of markets (local or global) as extraneous factors. On the other

extreme end of this modelling space reside network flow models, an example of which is presented in Marchand et al. (Berger et al., 2017) which model country-level trade and its effect on food security. Such models typically leave the allocation of food to individuals outside the scope of the model.
Once a model is developed to represent the food system, food security can be tested under different extreme event (or stress) scenarios. Since extreme events can occur at the level of (different types of) agents and of the specific connections between these agents, we have in previous work (Van Oort, Fonteijn, & Hengeveld, 2020) distinguished between these two categories of shocks and have created a shock typology that consists of 3 generic sub-types of shocks per shock category (see Table 1). These shocks also distinguish between the effect of international trade shocks and regional trade shocks.

Table 1

	Agent-level			Connection-level		
	Production shock	**Cash shock**	**Hoarding shock**	**Farmer-International trade**	**International trade**	**Regional trade**
	Crop failure	People loose cash	People buy more food than normal	Farmers cannot sell to intl. Traders	Consumers cannot buy from intl. Traders	Consumers cannot buy from regional Traders
	Drought, Flood, etc	Civil war; Financial crisis	Anticipated food shortages	Export ban	Cyber-attack, lockdown due to infectious disease	Earthquake, Tsunami destroys infra
	No production	Loss of purchasing power	Smaller traders' stocks	Link between farmers and international traders blocked	Link between consumers and international traders blocked	Link between consumers and regional traders blocked
	Delayed impact, stocks not immediately depleted. Those not connected to the intl. market are most vulnerable	Immediate impact. Shift in buying order, poorest can no longer buy food.	Foods shortages elsewhere	Consumers in other regions affected. Can regional traders absorb the extra supply?	Cascading effect of increased depletion of regional stocks.	Cascading effect of increased depletion of international stocks can affect other regions.

A regular stress test consists of defining a shock scenario and then applying this shock scenario to the model. This framework therefore implicitly assumes that the causal link between shock and agent food security is well-understood: for instance, a drought in a food-exporting country causes global food prices to rise which makes it more difficult for a relatively poor urban worker in a food-importing country to satisfy his food requirements. However, COVID-19 has shown that these causal links are often going beyond immediately obvious effects: whereas pandemics were widely recognized as a serious risk to the world economy previous to COVID-19, the specifics of the effects of COVID-19 differ from food system to food system and are often quite unexpected. Stress testing alone is therefore not a sufficient framework to analyse the resilience of a food system.

A similar problem is encountered in finance, in which stress testing is a widely used tool(Schuermann, 2014). In the financial domain, institutions (banks, insurers, asset managers) are often required by their regulators (e.g. ECB) to run regular stress scenarios comprising of adverse economic circumstances. A retail bank might for instance be asked to predict the effect of a substantial rise in unemployment, in combination with a drop in house prices on the default rate of their residential mortgage portfolio. Since residential mortgages make up a substantial part of the balance sheet of most Western commercial banks, a depreciation in the value of these mortgages (by recognizing provisions for non-performing loans) can quickly start to threaten the bank's solvency. Such a stress test, therefore, establishes whether current capital buffers are sufficient to avoid insolvency. This, however again presumes that the relationships between unemployment, house prices and mortgage defaults are well-known and that this is the only effect on the bank's balance sheet and that the set of relevant stress scenarios can be defined exhaustively *a priori*. Regulators have therefore put forward the reverse stress test as an additional analytic framework. A reverse stress test specifically tries to determine under what circumstances banks would default: in such a test the circumstances under which a bank would default are determined (reduction in mortgage portfolio value, liquidity crisis) after which scenarios are designed which would lead to these circumstances (Grundke, 2011). We believe that a similar framework could be useful for food systems.

A food systems reverse stress test starts by identifying all agents, their roles in the food system and their connection. For instance, supermarkets play a crucial role in the distribution of food in high-income countries, while their role is increasing in more and more LMICs (Reardon, Timmer, Barrett, & Berdegué, 2003). Supermarkets have proven to be remarkably resistant during the COVID-19 crisis and have even profited from the problems other competitors face, such as restaurants and outdoor fresh markets. The requirements for supermarkets to ensure their functioning are:
1. Reliable supply (dependence on upstream agents such as distribution centres, transport companies and the infrastructure supporting transport)
2. Intact local operations (dependence on infrastructure such as electricity and water)
3. A minimal set of workers

After defining the functional requirements for all agents and their connections, scenarios can be devised that target these requirements specifically. Examples of these scenarios for supermarkets include:
1. An oil crisis could seriously undermine the ability of transport companies to transport food between distribution centres and supermarkets
2. A terrorist attack could target distribution centres
3. A new pandemic could predominantly affect young people, who in turn would become reluctant to work their shifts in supermarkets at (close to) minimal wages.

An evaluation of these scenarios is ideally supplemented with detailed information of the corresponding agents and their connectivity. For instance, the (temporal) removal of a distribution centre because of a terrorist attack only has serious consequences if it has high centrality (Newman, 2018) within the supply chain network. After collecting all scenarios for each agent and connection type, they can be examined for overlap and grouped. These combined scenarios can then be assessed for their total impact on food security and their likelihood. A subsequent investigation can then test what alternative configurations of the food system would lead to improved food security under these newly defined stress scenarios.

A reverse stress testing framework is both relevant for high income and for low- and middle-income countries. In high-income countries, they can lead to a new risk assessment of current food systems, which have proven to be remarkably resilient in recent global crises (2008 global financial crisis, COVID-19). Although food security is already under more threat in LMICs, it would still be a useful exercise to perform this bottom-up analysis of food security and to start evaluating the different trade-offs between for instance local food production and dependence on food imports that alternative food systems arrangements would entail. Such an analysis should definitely involve stakeholders from start to finish, both to collect sufficient data and to check assumptions and to collect and evaluate different interventions.

The following sections will focus on a particular case study involving seasonal labourers in the sesame value chain in Ethiopia to develop the necessary modelling toolbox and associated data requirements to perform stress tests and reverse stress tests on food systems in LMICs. After briefly introducing the case study itself, section 2 develops a minimalistic agent-based model for this case study and (partially) implements the model to investigate the data requirements of such models. Section 3 discusses the preliminary results from this model and its potential usefulness, once it would have been fully developed.

2 Case study: Seasonal labourers in the Sesame value chain in Ethiopia

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The previous section has outlined the rationale for stress testing and reverse stress testing frameworks and their designs. Here, we further develop the modelling framework that supports both stress testing and reverse stress testing and resulting data requirements in the context of the case seasonal labourers in the Sesame value chain in Ethiopia.

About 500.000 young poor people are working in sesame production to earn extra income for their own and their families (see: Roo, N. de and J. van der Lee (2021). Exploring vulnerability and resilience from a multifaceted and systemic perspective – Case studies in Ethiopia and Somaliland). Sesame farms are very dependent on this hired labour. During the growing season, the workers migrate from their livelihoods to the production areas where they either a) engage in sesame farming by renting or sharecropping, b) work on a short term base to perform tasks on the farms or c) work full-time on a farm.

These seasonal labourers are extremely vulnerable to shocks as was demonstrated by the COVID-19 crisis, when travel restrictions impeded the migration of the seasonal labourers to their work places. Anticipating labour shortages, the farmers reduced their acreage to maintain profitability. It is currently unclear to what extent seasonal labourers were able to secure wages (and thereby food) and what other coping mechanisms they turned to. However, this example shows that seasonal labourers present a powerful example of a vulnerable group in an otherwise thriving value chain.

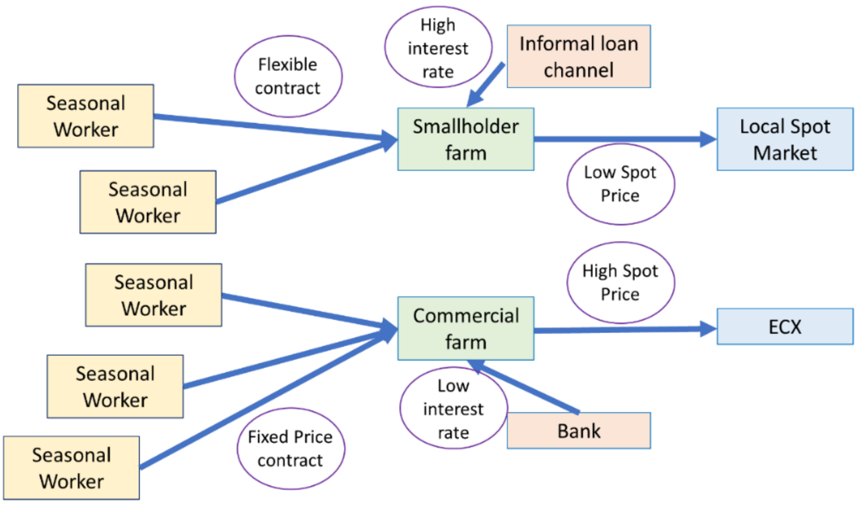

Figure 1 *Stylized representation of the Ethiopian Sesame Value Chain. For clarity, we show only one smallholder farm, commercial farm, bank, informal loan channel and local spot market, whereas, in any simulation, many of these will be present*

After consultation with experts we designed a network representation of the full Sesame value chain in Ethiopia, which is shown in Figure 1. The central agents of this network are the farms, which are separated into a smallholder farm class and a commercial farm class because they are clearly different in terms of their size, access to credit and access to markets. More specifically, the size of commercial farms varies substantially, even between woreda's. The average acreage of commercial farms varies between 16 ha (Somali) and 462 ha (Gambella), whereas the country average acreage is around 200 ha (Ali, Deininger, & Harris, 2015). Commercial farms can access credit from commercial banks and they sell their sesame directly on the central Ethiopia Commodity Exchange (ECX), where it will be mainly sold to international buyers. Smallholder farms, on the other hand, of an acreage between 2 to 5 hectare account for 50% of all farms and 30% of the farms are even smaller than 2 hectares (Wijnands, Biersteker, & Hiel, 2007). Smallholder farms, in contrast can only access informal loan channels (sometimes called 'loan sharks') who are often local Sesame buyers who provide credit in return for a later delivery of sesame (after harvest) at a fixed price. Irrespective of this line of credit, smallholder farms only sell on local spot markets, from which traders will then sell on the ECX. In conclusion, smallholders are at a disadvantage with respect to commercial farms, because they do not benefit from economies of scale, they can only access expensive credit and they sell only indirectly to the ECX, which will reduce their price since intermediary traders also take a margin.

Agent-based models (ABM) are a class of models that is ideally suited to representing this situation: ABMs allow for a heterogeneous group of agents, whose actions are bounded by their local environment (including interactions with local other agents) and thus limited information. Moreover, these agents are assumed to decide their actions based on finite cognitive resources. Classical economical models, such as Computable General Equilibrium models, on the other hand, assume homogeneous agents (often in the form of a representative agent) who have perfect instantaneous knowledge of all relevant variables and unlimited cognitive capacity to calculate their optimal action. Ideally, the design of an ABM is an iterative process involving multiple rounds of stakeholder consultation. This could take the following form:

1. The design of a model outline (such as in Figure 1), comprising of all agents, their connections and the relevant connection modes (in this case in the form of contracts)
2. A first consultation round with stakeholders to check the completeness of the model design.
3. A preliminary implementation of the model to design how the agents are initialized, which decisions they take during each run (and in which order) and how these decisions are reached.
4. A second consultation round with local stakeholders to investigate the representation of agent decisions in the model and to arrive at a first parameterization of the model.
5. Scenario design: this includes business-as-usual scenarios, extreme events scenarios and scenarios under different policy environments.
6. A third consultation round to discuss the appropriateness of these scenarios and their outcomes.

This iterative process was not possible in the Ethiopian Sesame case, both because of time constraints and because of the Tigray War that began in November 2020. Since the overarching theme of this project was a focus on the most vulnerable and their resilience, we decided to focus on the seasonal workers and their interactions with the farms on the labour markets. After an initial consultation with local stakeholders, we assumed that labour contracts are negotiated on a central market place between the available labourers and farmers. For simplicity, we assume that the season consists of a single negotiation moment, during which a contract for the full season is negotiated.

Figure 2 provides an overview of the labour market negotiation process. Each labourer and farmer starts with a known quantity of labour they supply/demand: labourers supply one unit of labour each, while commercial and smallholder farms demand labour proportional to the land area they own. We have performed a preliminary literature review to estimate the labour demand per ha for commercial and smallholder farms. Each labourer and farm also have a (randomly selected) opening bid/ask price and a (randomly selected) reservation price, which is the contract price below/above which the labourer/farm will refuse to agree to the contract. These reservation prices are centered around ETB 5000,- (roughly €100,-) for the complete growing season, which is the amount a seasonal labourer expects to earn.

```
while total labour supply > 0 and total labour demand > 0
{
        # Negotiation round
        For each labourer i in all available labourer
        {
                Select random farm j
                If p_bid, farm j > p_ask, labourer i
                {
                        create labour contract for labourer i and farm j with
                                p_bid,farm j as wage price
                        remove labourer from available labourer pool
                        remove one unit of labour from farm's labour demand
                }
        }
        # Price-adjustment round
        For each available labourer
        {
                Count available labourers
                Calculate total labour demand

                {
                        create labour contract
                        remove labourer from available labourer pool
                        remove one unit of labour from farm's labour demand
                }
        }

}
```

Figure 2 *Overview of the labour market simulation*

This negotiation process consists of multiple rounds of a two-stage procedure: a negotiation round and a price-adjustment round. These rounds stop if either there are no available labourers, or if total remaining labour demand is zero. In each individual negotiation round, each labourer visits one randomly selected farm (the farm visited in the previous round by the current labourer is excluded from selection) and checks whether the bid-ask prices match. If so, a labour contract is made up by the labourer and the farm, the labourer is removed from the active pool of labourers and one unit of labour is removed from the farm's labour demand (see Figure 2 for more details).

After all available labourers have approached one farm, the bid and ask prices are changed to take into account the remaining labour supply/demand. If a labourer notices that the labour supply is high with respect to the labour demand, we expect him to drop his ask price substantially, while if the labour demand is high with respect to the labour supply, we expect a minimal adjustment to the ask price. For each farm, we expect the opposite behaviour. We have implemented the bid/ask price adjustment process by first defining the range of relative price changes that were allowed: $[\Delta p_{min}, \Delta p_{max}] = [0.5\%, 5\%]$. Next we calculate the ratio $r_{supply-demand}$ using an estimate of the total current labour demand and the total labour supply (we assume that all agents can count the number of available labourers and that all agents can estimate the total labour demand by multiplying the number of available farms by an estimate of the average demand per farm): $r_{supply-demand} = \frac{\#\ labourers\ available}{estimate\ labour\ demand}$.

The relative price adjustment for each labourer is now calculated by applying a logistic transformation function with adjustable parameters α and β:

$$\Delta p_{ask} = \Delta p_{min} + \frac{\Delta p_{max}}{1 + exp\left(-\alpha * \left(r_{suppply-demand} - \beta\right)\right)}$$

For the farms, the relative price adjustment is calculated as follows:

$$\Delta p_{bid} = \Delta p_{min} + \frac{\Delta p_{max}}{1 + exp\left(-\alpha * \left(\frac{1}{r_{suppply-demand}} - \beta\right)\right)}$$

After some experimentation, we have set $\alpha = 5$ and $\beta = 1$ to achieve slow change for low $r_{supply-demand}$ and faster change as $r_{supply-demand}$ approaches 1.

COVID-19 has substantially changed the labour market in the Sesame Seed Value Chain: farms anticipated labour shortages during the growing season because of potential travel restrictions for the seasonal labourers. They have therefore reduced their acreage substantially. However, it is currently unclear whether the available labourers during the growing season matched the reduced demand. We have therefore different setups which consist of the same set of farms and resulting labour demand, but different numbers of available labourers. When there would be 700 labourers, labour supply and demand are exactly matched. For each setup we simulate 10 years: the starting bid/ask price of the farms/labourers for each year is the contract price of last year.

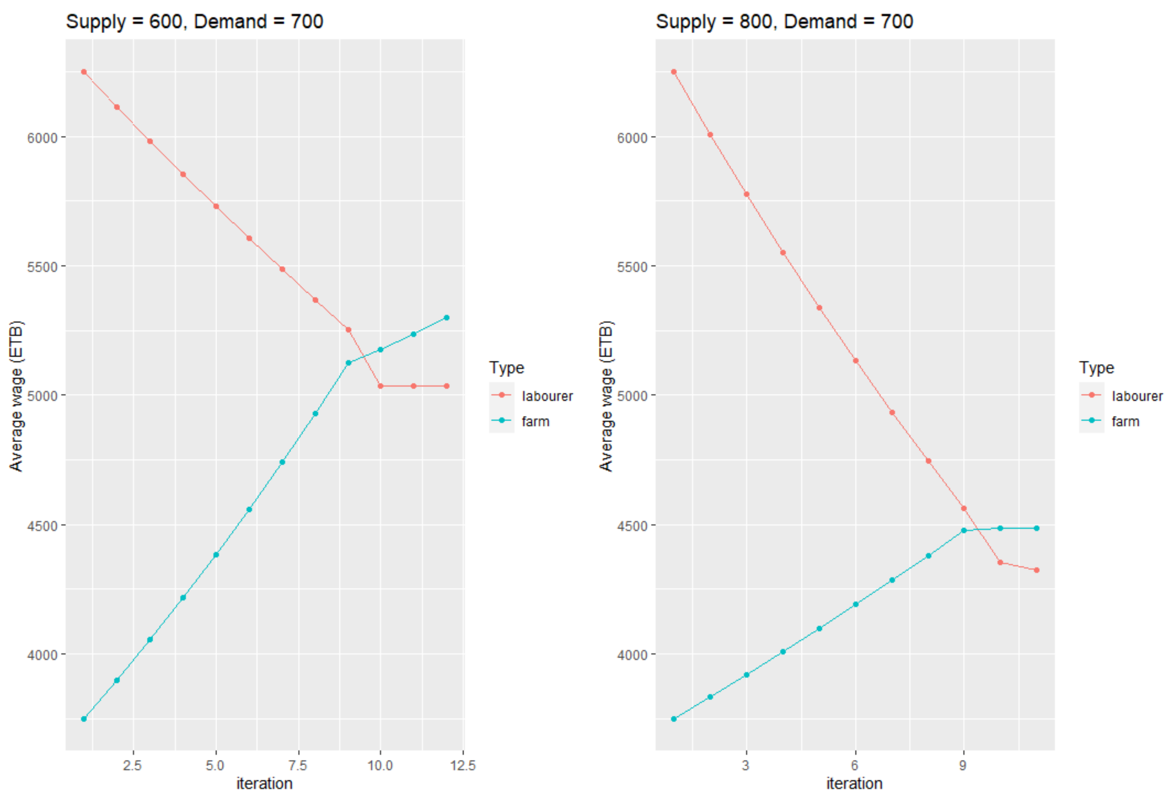

Figure 3 *Bid/ask prices during 2 rounds of labour market simulations*

Figure 3 shows the behaviour of the bid/ask prices during the simulation of the first year of two scenarios with 600 and 800 available labourers at the start of the simulation. Note that the average wage is the bid/ask wage of all *remaining* farms/labourers and that this is *not* the settlement wage. In both scenarios, the labour market requires approximately 12 rounds for the markets to clear. In a market with labour shortage (first scenario) the bidding wage rises faster than the asking wage, which causes the wage to converge on a higher level, whereas in a situation of labour surplus, the opposite pattern can be observed. This pattern is further supported by Figure 4: as the number of labourers varies from a clear shortage (500 labourers) to a clear surplus (900 labourers), the average settlement wage drops substantially. It is also interesting to note that for a substantial labour shortage (500 labourers) prices rise yearly if this situation persists, whereas the corresponding year-on-year wage drop in the labour surplus scenario (900 labourers) is less substantial and converges faster.

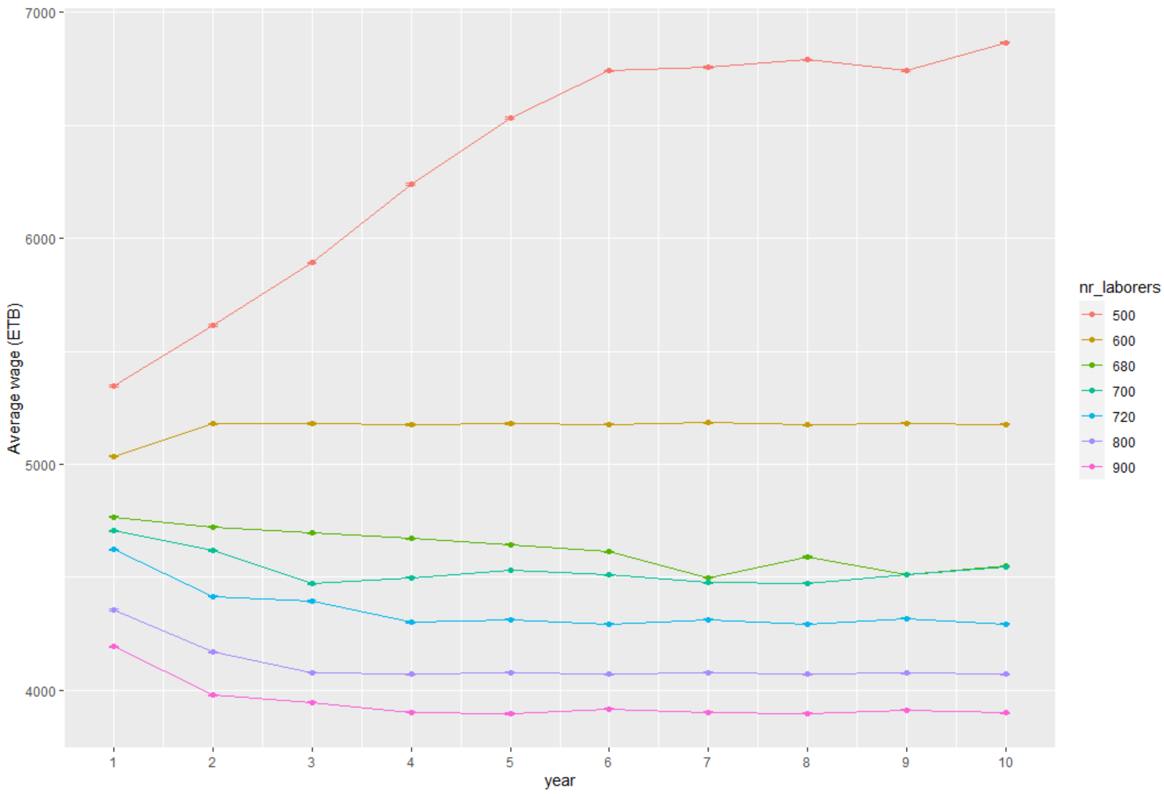

Figure 4 *Average wage in the different scenarios*

The previously presented simulations present the labour market as a decentralized operation, in which bilateral negotiations play a central role in price discovery. Other price discovery mechanisms, such as in markets with a central auctioneer (e.g. stock exchanges) are more common but are not realistic in this use case. It is therefore interesting to note that the usual laws of supply and demand emerge from such a decentralized price discovery situation and that convergence is relatively fast.

3 Discussion

Stress testing food systems requires an adequate understanding of the system in terms of its parts, the connections between those parts and the behavioural repertoire of each part. Such an understanding is often mediated by a narrative, in this case the Sesame Value Chain in Ethiopia, its role in supporting seasonal labourers and its response to COVID-19. Such an analysis has at least two goals:

1. To better understand the current crisis and policy options that are available now to respond; and
2. To be better prepared for future crises by investing in the resilience of the vulnerable group(s) of interest.

For the first goal, narratives provide a great basis to start an investigation of policy options. Quantitative models, such as the ABM presented above, can then serve as an evaluation tool of the efficacy of policy options and to probe any unintended consequences of a policy. For the second goal, narratives on past and present crises again are a useful starting point. However, when designing policy options to increase the resilience of target (vulnerable) populations, it is necessary to go beyond the historically known crises and to also build resilience towards unknown scenarios. COVID-19 provides a great example of a scenario that has taken the world by surprise: in the minds of the public (and it seems of many policy makers) a pandemic was first and foremost a health crisis with limited impact on the wider economy. It can be argued that the COVID-19 crisis was a health crisis at the start, but that the economic consequences, especially in LMICs, quickly overshadowed any public health effects. This presents policy makers with a paradox: it is tempting to build policy on data from known crises because of the availability of such data. However, the greatest impact is to be expected from ‘unknown’ crises, because policy makers, companies and people are the least prepared for such crises. Resilience mechanisms therefore should include specific factors that contribute to resilience in most, if not all, adverse scenarios. A generative model for food systems, such as the ABM presented in this paper, can be used to study the mechanisms that in general support resilience of vulnerable groups by running different (sequences of) shocks through the system.

However, this paper has also shown that the creation of a useful representation of a food system is challenging, especially because the data requirements go beyond key figures on food production and consumption. It is also necessary to understand how labourers and farmers negotiate contracts and in which context they negotiate. Here, we have simplified the representation of the negotiation process by putting all farmers and labourers in an imaginary market place and to have them negotiate sequentially and readjust their bid/ask price by taking into account their estimate of labour demand and supply. However, we have good reasons to believe that the negotiation process is much more complex in reality: seasonal labourers move from village to village to seek labour and are therefore not directly in competition with all other labourers. Moreover, it is entirely possible that farmers have preferences for the labourers they hire, be that based on kinship/place of origin relationships or because of good working relationships in previous growing seasons. In principle, all these factors could be taken into account in the simulation by making it more spatial and including place of origin and other information. However, this would (again) substantially increase the complexity of the simulation and therefore its development time. Data requirements for the remainder of the model (including the financial institutions and sesame markets) will be equally demanding. Here too, data are required on how the actors agree on contracts, what influence local producers have on sesame prices and how contracts are enforced (i.e. what happens when a farmer defaults on his debt to a bank). This would require extensive involvement of an even wider set of stakeholders than the ones consulted in this project.

The introduction of the model parts that have not yet been implemented (credit and sesame markets) will add more complexity and realism to the simulations. For instance market expectations on the farmer’s and creditor’s side, financial performance in previous years and their expectation of labour availability in the current growing season will all influence farmers decisions, which in turn will feed back to the labourers’ food security. The current situation is an excellent example: not only did farmers expect labour shortages because of travel restrictions, but they had also already experienced limited labour shortages in 2019, which together have caused them to reduce their acreage. It is currently unclear to us what caused the shortages in 2019 and what the actual labour supply was in the 2020 growing season.

Finally, the model developed in this paper has for now only been used in a forward fashion: given different levels of labour supply, what is the average wage a labourer can expect. Although this constitutes a stress test of sorts (a substantial surplus of labour supply leads to heavily reduced wages) a full stress test would require a complete development of the agent-based model, which was not possible within the scope of this project. The agent-based model could, once fully developed, also be used for reverse stress tests. The usefulness of reverse stress tests in this context might seem doubtful since the conditions the seasonal labourers find themselves in are already distressed in the best of circumstances. This case study is therefore definitely not the most straightforward demonstrator of food systems reverse stress tests. A future reverse stress test could therefore perhaps concentrate on the more materially secure parts of the food system such as the (commercial) farmers. However, it should be noted that a break-down in the functioning of these farmers still would have negative consequences for the seasonal labourers and would therefore be relevant for them, which further supports the notion that for the resilience of the most vulnerable, all elements of the food system must be resilient to shocks.

In conclusion, this paper has introduced the complementary concepts of stress tests and reverse stress tests in the context of food systems context. Focussing on a specific case study (seasonal labourers within the Ethiopian Sesame value chain) allowed us to introduce a minimal network representation of this value chain and to develop a labour market module of an ABM based on this network representation. The experience in developing this module indicated the data requirements of such models and the development effort for creating this framework from scratch. In future work, we hope to complete this model by extensive interactions with (local) stakeholders and to use this model to investigate the interactions between all relevant factors (credit availability, price expectations, labour supply) and their effect on the resilience of the seasonal workers.

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