VALUMICS
Food Systems Dynamics

H2020 VALUMICS Project

Implementation of system dynamics and agent-based modelling simulation of fairness in food value chains

Research Findings Brief
September 2021

Content

This brief summarises the VALUMICS implementation in software of a hybrid system dynamics and agent-based model with the objective of assessing the impact of interventions influencing fairness in food value chains.

Hybrid system dynamics / agent-based model

Techniques such as agent resource mapping and decision tables are used for system analysis, resource flows and agent rules definition

This brief explains the steps carried out in the development and implementation phase of the hybrid system dynamics and agent-based model following the initial conceptualisation phase of the simulation model developed in the VALUMICS project (Olafsdottir et al, 2019, Deliverable D5.2). The conceptualisation was extended using agent modelling techniques and implemented as a software tool. The resulting analyses using this software tool on the VALUMICS case studies can provide a more in-depth understanding of the behaviours of actors that influence decisions and external factors such as regulations and policy influencing the functioning on system. The problem to model had been defined earlier in the conceptualisation phase, about concerns of unfair trading practices (UTPs) associated with power asymmetries in food value chains. Quantifiable indicators were defined for fairness along case study food value chains. Distributive fairness is indicated by the distribution of actors' gross profit margins; procedural fairness by the Lerner Index estimate of market power. (Gudbrandsdottir et al., 2021)

Modelling framework

System Dynamics (SD) applies a top-down view using feedback loops and can capture volumes and financial flows. Agent-based simulation models (ABM) are typically built from the bottom up by identifying real-world actors, modelling them as agents in the system and defining their behaviours and decision-making, including how they interact with other agents and their environment. In the VALUMICS model a hybrid of system dynamics and agent-based modelling is used. SD allows for modelling and investigation of feedback loops and flows of product, information and money. Agents sit within these flows and feedback loops and affect them by their decision making. The main advantage of ABM is its ability to model social interactions: it can therefore contribute to exploring the impact of cooperation, competition and collaboration within supply chains. The behaviour of agents is defined in terms of decision rules, executed when special events occur, and in interactions with other agents.

The aim is to use the model to identify the level of fairness within the system which emerges from the concurrent execution of these decision rules on behalf of multiple independent agents in the food value chain (FVC). The decision-making and agents' behaviours were explored through the VALUMICS case studies. Cognitive maps were used to visualise the stakeholder's perception of the system, actors, quantitative variables and linkages, and so aid in problem formulation. This analysis is further extended using techniques such as agent resource mapping and decision tables for system analysis, resource flows and agent rules definition. Figure 1 shows an example cognitive map for the VALUMICS French wheat to bread FVC case study.

Goal

To experiment on and test various what-if policy and market interventions and to inform development of transition pathways towards more environmentally sustainable and socially fair food value chains

Figure 1. Cognitive map for French wheat-to-bread FVC

These were extended using a rigorous software engineering agile approach of technical design, implementation in program code, and testing/validation. Once parameter values for the case study under investigation have been chosen, multiple runs of the model then simulate the behaviour of the full system of agents over time; statistical analysis of outcomes of these runs (average, min, max, etc.) inform users of the model of what can be expected in different scenarios. Agents at each tier may be of Category I, II or III (small, medium, large). The user may vary agent parameters or indeed environmental parameters such as level of CAP subsidy to investigate the effects of policy and other interventions on transition pathways towards more environmentally sustainable and socially fair food value chains.

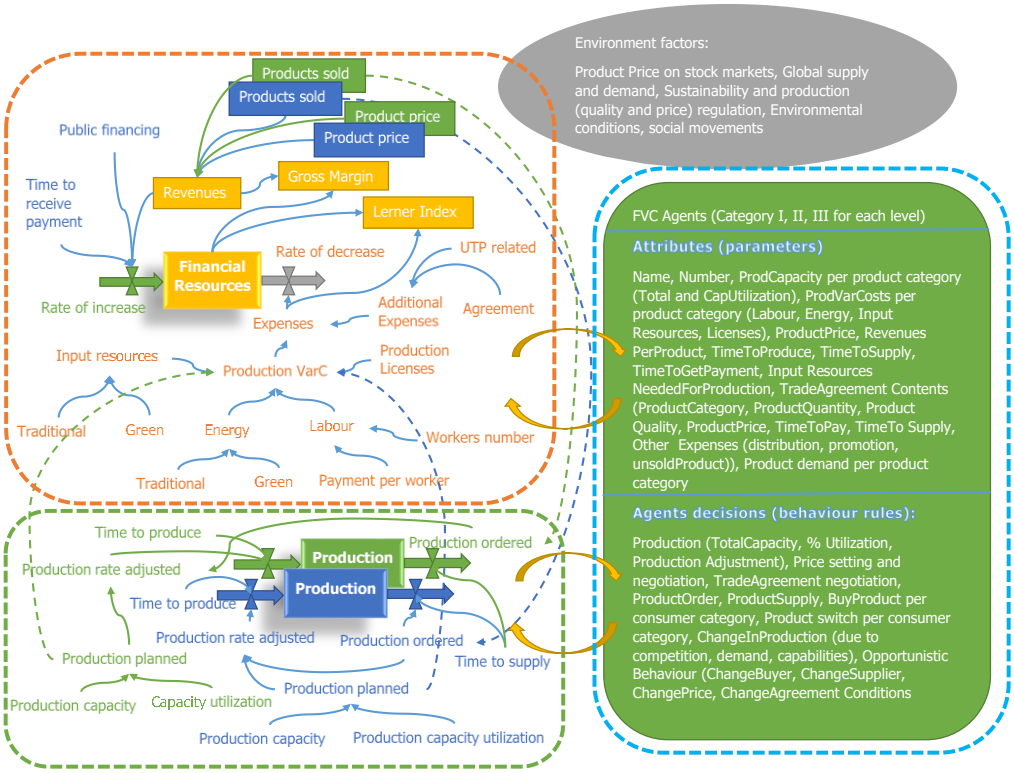

Figure 2. Hybrid SD/ABM simulation modelling overview

The technical design methodology is summarised in Figure 2. Flows (financial and material) are shown on the left using SD methodology while the attributes and behaviours of a typical agent are on the right, together with the environmental factors it interacts with.

Model inputs and outputs

Input parameters to the model include levels of production and demand, exchange rates, levels of subsidies and other data. Outputs include jobs levels and value-added distribution.

Experimental environment variables

The aim is to allow adjustment of other entry/environment variables, such as the level of CAP subsidies, fiscal policies, changes in UTP regulation or the world wheat price.

What if scenarios

Hybrid approach of qualitative and quantitative modelling and simulation to address fairness in FVCs from the perspective of socioeconomic sustainability

Model inputs and outputs

The major input variables for the model are:

- total volume produced and total volume demanded
- currency exchange rates, wheat protein levels and levels of trade barriers
- production volumes per agent:
  - 'farmland',
  - 'land productivity' and
  - 'farm capacity utilisation'.

The model also provides means for experimenting with:

- public financing interpreted as additional income e.g., CAP subsidies
- world price uncertainties' effects on price formation along the FVC, giving input variables connected to 'global market price' (Euronext, Chicago) and to 'average campaign price'
- time delays connected to production and financial flows if regarded as proxies for UTPs
- input variables can include 'other expenses imposed by one actor on another'

The output variables to be analysed are:

- the structure of the chain, e.g., the number of each category of actor active at each tier of this FVC (to analyse how many agents have decided to stop producing the type of product);
- the total number of jobs provided along the chains by the remaining actors (examine the evolution of the number of workers employed and the number of workers laid off);
- the value-added distribution (observe the evolution of gross margins).

The simulation output related to value distribution can exhibit product price evolution and evolution of revenues and profit margins for each category of the included actors.

Agent decisions and behaviour exploration: what-if scenarios

The model is intended to assess the impact of policy interventions (e.g., level of subsidies, changes in supply and demand, trade shocks), described as input variables to the simulator as above. These are implemented as a policy scenario simulator for policy experimentation and optional recommendations.

- Testing how a change in volumes produced/consumed may impact the whole of the food value chain in terms of
  - structure of the chain,
  - total number of jobs and
  - value-added distribution along the chain
- Different "scenarios" connected to production and external financing
  - "industry-led" market
  - "artisan-led" market
  - changing level of CAP subsidies ("public financing")

Model development

An agile iterative approach was used for:

- ***Conceptualisation***
- ***Functional specification***
- ***Formulation and Implementation***
- ***Testing***
- ***Use of model***

Hybrid SD/ABM stages of development

The hybrid SD/ABM work was first carried out for a generic FVC; this was then specialised to three VALUMICS case study FVCs: French wheat to bread, North Italian region raw tomato to processed tomato, and Norwegian farmed salmon to fillets. The major stages of the model development were:

- Conceptual specification of the model: (iterative process)
  - Information audit on qualitative and quantitative information
  - Work with domain expert partners on problem structuring and definition
- Functional specification of the model (iterative process)
  - Qualitative modelling with partners, using cognitive and agent mapping
  - Qualitative and quantitative information gathering using decision tables
- Formulation and Implementation: Technical specification and program code (agile approach)
  - Agent decision procedural description, conditional factors and what if questions
  - Developed through flowcharts leading to pseudocode and thence program code
- Testing of the model: validation and verification by subject matter experts
- Use of the model: parameter setup and running of scenario simulations.

User interface

The hybrid simulation model allows the user to enter parameter values and view output. Parameter values can be saved for reuse or modification to generate a new scenario.

User interface: Dashboard

Figure 3 shows part of the top-level dashboard interface for entering parameter values for the example of the French wheat to bread FVC. These can be saved for reuse or modification (to a greater or lesser extent) to generate a new scenario.

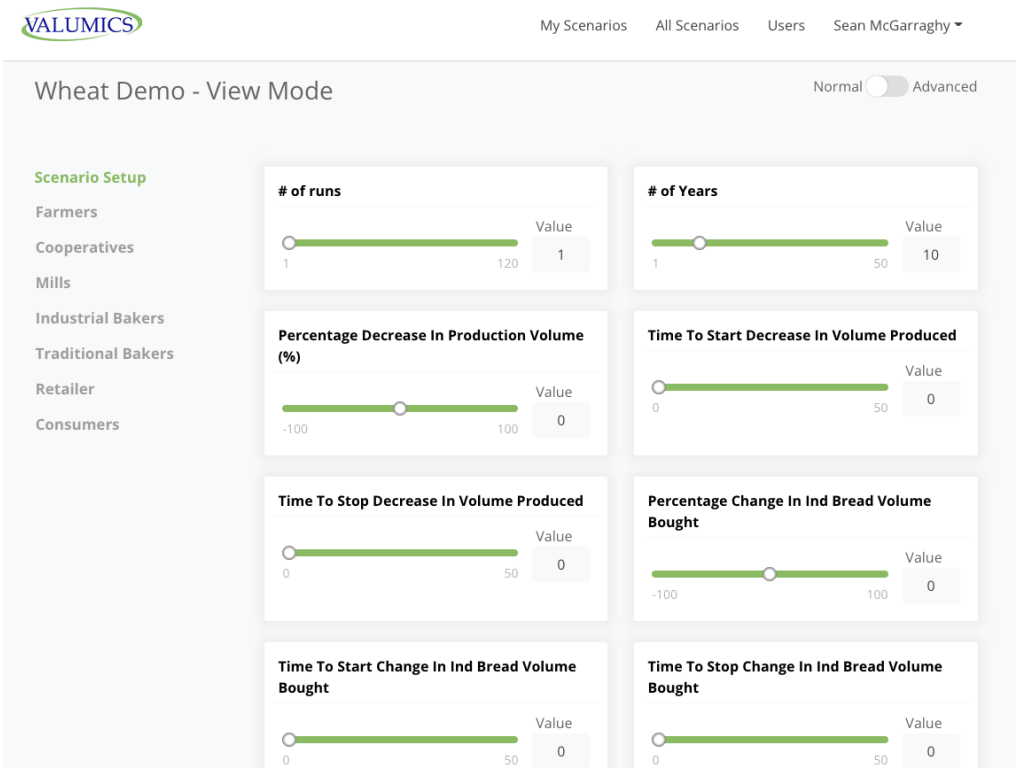

Figure 3. Excerpt from top-level dashboard interface for the French wheat to bread FVC

Figure 4 shows an example of output from the model for the French wheat to bread FVC. Computed values may be exported as comma-separated values (csv) or as pdf files, and graphics may also be exported as pdf files.

VALUMICS food value chain case studies modelled

The French wheat-to-bread food value chain

The North Italian region raw tomato to processed tomato value chain

The Norwegian farmed salmon to fillets value chain

Simulator

This simulator aims to provide insights about the factors that influence actors' decisions connected to changes in supply and demand.

Exploiting the models

Further development and exploitation of the VALUMICS models is planned for policy work and publications, extending the existing models to enrich agent behaviour, and further adapting the generic base model to the salmon value chain and other FVCs.

Lack of research data

Problems include:

- ***The "legal entity" scale***
- ***Firms operating in multiple sectors***
- ***Extensive information exists on agricultural producers, less so on prices in food processing stages of the food value chain.***

Figure 4. Excerpt from model output for the French wheat to bread FVC

Conclusions

The system analysis work was an iterative development in the conceptualisation phase and through further technical analysis the model was implemented as a policy scenario simulator for a generic four-echelon FVC, then specialised to the VALUMICS case study FVCs: French wheat to bread; North Italian region raw tomato to processed tomato; and Norwegian farmed salmon to fillets (ongoing). A rigorous software engineering approach was used in this development. (McGarraghy et al., 2019, McGarraghy et al., 2021, Esposito et al., 2021).

Exploitation of results, limitations and data gaps

All models are simplifications but can be useful when enriched with reliable data. The lack of data turned out to be a major limiting factor in the model building in VALUMICS; and high-impact assumptions needed to be made when data gaps were encountered, especially concerning firm level data and particularly for non-farmer actors. Secondary data from different European level data, national level data and regional level data was available on e.g., Eurostat, FAOSTAT, Euro monitor databases and national databases, while FADN and Amadeus databases were used for micro data respectively on farm and company level:

- Secondary data from different databases have different structures caused by divergent product classifications, time periods covered, commodity aggregations, and geographical reach. At the farm level the FADN data was detailed and possible to reconstruct to meet the

Market transparency

EU regulatory measures to improve market transparency in the agri-food supply chain is set to provide information for these intermediate steps

modelling and analysis needs in VALUMICS. However, at the processing industry level, the data available does not provide physical volumes passing through the processing industries; thus, it is difficult to link biophysical flows and socio-economic outcomes.

- Other limitations constraining the research and development of the model were the facts that data is aggregated at the national level and that no data is available regarding the share of differentiated vs commodified / standardised production.
- Data is available at the firm level for specific firms; however, it is often incomplete (e.g., few data on business expenses) and big firms are often over-represented in the sample.
- Another factor causing difficulties is that firms are classified based on their sector of activity. For firms operating in more than one sector, all data values are assigned to the dominant sector. Also, some of the food processing is also realised by retailers (e.g., cutting and packing meat) so it is difficult to separate their main business from the processing activities.

Key sources for further information

To discuss the research presented in this brief, please email: sean.mcgarraghy@ucd.ie or go@hi.is

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Deliverables

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