FUNCTIONAL SPECIFICATIONS AND DESIGN PARAMETERS FOR THE IMPLEMENTATION OF THE QUANTITATIVE MODELLING

PROJECT REPORT D5.2

VALUMICS – UNDERSTANDING FOOD VALUE CHAINS AND NETWORK DYNAMICS

OCTOBER 2019

VALUMICS

Food Systems Dynamics

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727243

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ABOUT

VALUMICS stands for value chain dynamics and is a research project funded by the EU H2020 programme. VALUMICS will enable decision makers to evaluate policy impact on food value chains

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CITATION TO THIS REPORT

Olafsdottir, G, McGarraghy, S, Kasakov, R., Gudbrandsdottir, I.Y., Aubert, P.M., Cook, D., Cechura, L., Bogason, S.G. (2019). Functional specifications and design parameters for the implementation of the quantitative modelling. VALUMICS project "Understanding Food Value Chains and Network Dynamics" funded by European Union's Horizon 2020 research and innovation programme GA No 727243. Deliverable 5.2, University of Iceland, Reykjavik, 47p. DOI10.5281/zenodo.5106552

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Grant Agreement number: 727243

VALUMICS

Understanding food value chains and network dynamics

Start date of project: 01/06/2017 **Duration: 48 Months**

Deliverable: D5.2

Functional specifications and design parameters for the implementation of the quantitative modelling

VALUMICS

Food Systems Dynamics

Project co-funded by European Commission within the H2020 Programme		
Dissemination level of this deliverable		
PU	Public	
CO	Confidential, only for members of the consortium (including the Commission Services)	**X**
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CI	Classified, information as referred to in Commission Decision 2001/844/EC.	

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727243"

Document Status Sheet

Due date of deliverable:	Month no. 26 (with accepted extension to M29)
Actual submission date:	Actual month no. 29
Partner in charge of the deliverable and contributing partners	UoI UCD, IDDRI, UH, SINTEF, UNIBO, ART-ER, CZU, IAMO,
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Version	6.0
Document Status	Final submitted

Change history:

Version	**Date**	**Details** (additions, changes, reviews, performed by whom)
1.0	14.03.2019	Ingunn (UoI)
2.0	30.09.2019	Gudrun (UoI) Input from WD_Wuppertal workshop, WD_Fairness and WD_Case study report WP8
3. 0	07-28.10.2019	Input from Rossen on ABM modelling /Revisions Seán & Gudrun
4.0	28.10. 2019	Sent to partners for review
5.0 /5.1	30.10.2019	Seán & Pierre-Marie additions and comments /Revision GO &SGB
6.0	31.10.2019	Final deliverable submitted

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CITATION TO DELIVARBLE5.2:

Olafsdottir, G, McGarraghy, S, Kasakov, R., Gudbrandsdottir, I.Y., Aubert, P.M., Cook, D., Cechura, L., Bogason, S.G. (2019). Functional specifications and design parameters for the implementation of the quantitative modelling. VALUMICS project "Understanding Food Value Chains and Network Dynamics" funded by European Union's Horizon 2020 research and innovation programme GA No 727243. *Deliverable 5.2*, University of Iceland, Reykjavik, 47p

EXECUTIVE SUMMARY

The overall objective of the VALUMICS project is to produce a comprehensive suite of approaches and tools that will enable decision makers to evaluate the impact of strategic and operational policies on resilience, integrity and sustainability of European food value chains.

GOALS

The goal is to develop the functional specifications and design of a hybrid of system dynamics and agent based simulation model to be developed in WP7. The model will be applied to assess the impact of different transformations (policy interventions, demand, supply and trade shocks) in future scenarios towards fairer and sustainable food supply chains. It will focus on exploring opportunistic behaviours related to fair value distribution, and fair relations along the food value chain, and how it impacts the distribution of value added along food value chains.

The work in T5.2 "*Integrated model structure and specifications"* is focused on conceptualisation of an agent-based model (ABM) where decision-making and agents' behaviours are explored in selected food value chain case studies. This includes developing Agent tables, Decision tables, Agent behaviour rule maps and Agent interaction maps. Furthermore, a cognitive map is used to visualise the stakeholder's perception of the system and problem formulation. The work involves participants through the different case studies who ensure the flow of information from other WPs and tasks in the project with the objective to align the work to the needs of the modelling (WP7) and future scenarios (WP8). T5.2 was extended by 3 months to better align the ongoing groundwork in WP4 related to e.g. mass flow and decisions (T4.4/D4.3) and to consider the progress of scenario developments in WP8. Partners UCD and UoI are responsible for involving case study leaders (CSL) and other participants in developing the functional specifications for the ABM. The progress is discussed in WP meetings and dedicated case study (CS) on-line meetings. Furthermore, an internal VALUMICS ABM workshop in Wuppertal on July 11-12, 2019 was held to facilitate the work. The meeting was organised by NUID-UCD as part of Task 5.2, with a view to needs of WP 7. Specifications are to be delivered as internal reports to Task 7.2 on the technical design and further iterated through the technical design leading to coding of the integrated quantitative model.

MAIN OUTCOME

The Functional specifications and design parameters for the implementation of the quantitative modelling includes the following

- Scope, limitations and assumptions
- Problem description and opportunistic behaviours in FVC
- Fairness theory and metrics
- Modelling objectives
- Future scenarios to be modelled
- Information requirements from case studies and What if questions
- Methodological approach - Model content and functionality

The outcome of the work from case study teams is included in **Appendix** to this deliverable.

1. INTRODUCTION

The work in the VALUMICS project centres on the five case study supply chains; Dairy cows to milk, Beef cattle to steak, Wheat to bread, Farmed salmon to fillets and Tomato to canned tomato. The food systems that are the subject of each case study all have a similar structure with products flowing from primary producers through intermediaries to the final consumer. The ongoing work in WP4 and WP5 has, however, revealed some differences in terms of the agent groups present in each system, the linkages between these agent groups, the governance and the way in which the products flow through the system.

The macroscopic structure of a generic food system was described through workshops in WP2 resulting in a generic food value chain causal loop diagram reported in D2.5. Therein, a generic food system was defined as integrated supply-, value-, and decision chains consisting of a downstream flow of products, the associated upstream flow of money and the decision chains that link them. Studies on food supply chains using system dynamics were reviewed briefly in D2.5 (e.g. Georgiadis, Vlachos, and Lakovou (2005); Minegishi and Thiel (2000); Stave and Kopainsky (2015)). These models rarely include the flow of money through the system and in those exceptional cases its impact on decision making and the dynamics of the system are usually neglected. In reality, financial factors have a large impact on decision making and thereby the physical flow of products and services. Therefore, in order to use a model of a supply system to anticipate policy implications, it is beneficial to consider not only the physical flow of products in the system but also the associated flow of funds and the effect it has on decision making. The dynamics of the systems under study, with continuous and discrete elements, as well as the heterogeneity of the agents within them, calls for a hybrid simulation methodology. The product flows can be simulated using system dynamics which is well suited for modelling such flows. The decisions controlling the product flow and pricing, which are the principal part of the model, will however be modelled using agent-based modelling (ABM).

Several properties of ABM make it well-suited for capturing some of the complex features of supply chains such as the behaviours and interactions of agents in the chain (Choi et al., 2001; Higgins et al., 2010). In their review of ABM in agricultural supply chains, Utomo, Onggo, and Eldridge (2017), identified 58 articles published in a variety of journals. Although they all centre on the same subject they originate in fields of research ranging from environmental science and agriculture to computer science and operational research. The majority of the research is focused on the upstream side of single echelon supply chains with agents in the model usually representing producers. The model output data is therefore often related to aspects of production such as yield and produced quantity. Other types of output data include financial factors such as income and wealth and conceptual phenomena such as trust and honesty and cooperation. There seems to be a shortage in the literature of research that focuses on the food supply chain as a whole, from producers to consumers, thereby incorporating the full extent of interaction and feedback within the chain. Furthermore, Utomo et al. (2017), point out that the main advantage of ABM is its ability to model social interactions and could therefore contribute to the study of subjects such as cooperation, competition and collaboration within supply chains.

2. SCOPE

At the VALUMICS plenary meeting in June 2018, it was agreed amongst the project partners that the integrated quantitative model developed in WP7 would focus on fairness issues, especially unfair trading practices (UTPs), in food value chains (FVCs), while the focus of WP8 on scenario development would have a broader focus (e.g. resilience, sustainability and integrity in general). Hence, the specifications in this document focus on aspects of fairness and unfair trading practices in FVCs, and how these can be represented in an agent-based model. The current functional specification will be used as a basis for the model that will be developed in WP7 and further used for scenario analysis in WP8. Therefore, the experimental factors are dependent on the scenarios that will be tested in WP8.

An important requirement of the simulation modelling scope is the definition of a boundary not only related to the main research question on distributive and procedural fair food value chains, but also on the choice of geographical location (country market) and number of agents involved. These limitations are necessary for every simulation model due to technical (computational) and other constraints like level of complexity, timing, access to and availability of relevant qualitative and quantitative data and resources for design and production.

Examples of technical constraints include the following: for reasons of available computational power, the number of tiers in the value chain will be restricted to four (producer, processor, retailer, consumer); and the number of actors (agents) at a given tier will be restricted to a number for which simulations can be carried out in a reasonable time, at a reasonable computational cost. For each case study examined (see Boundaries below), this generic four-tier base FVC will then be extended to capture the particular attributes and characteristics of that case study FVC. This approach will allow the greatest possible amount of reuse of design and computer code, and minimise redundancy of effort.

The scope of the model to be developed in WP7 is determined by prioritised case studies that will be modelled initially, and considering the (1) geographic boundaries (2) the occurrences and relevance of UTPs in respective FVCs, (3) the assumptions regarding fairness metrics applied, and (4) the limitations of the model:

1. **Boundaries**: VALUMICS cases studies are ongoing in different partner countries and those that will be modelled initially have been prioritised[1]
    - *Wheat to bread* (Czech, Germany, France, UK)
      => WP7 ABM model will focus on France
    - *Salmon to fillets (Norway)*
      => WP7 ABM model will focus on Norway to EU
    - *Tomatoes to canned tomatoes (*Italy and Vietnam sub-case study*)*

[1] Results from other geographic areas will be used to compare and understand better the functioning of European food systems and food value chains through different analysis in the VALUMICS project. The results are also used to verify the validity of the model and provide input to scenario developments and analysis. Furthermore, the comparison of the functioning of the food systems and value chains between the countries in Europe will substantiate the overall outcome of the project using a suit of different tools to assess the fairness, sustainability, integrity and resilience.

=> WP7 ABM model will focus on Italy

- *Dairy cows to milk* (Ireland, UK, France, Germany and Vietnam sub-case study)
  => WP7 ABM model will focus on France
- *Beef cattle to steak* (UK, France, Germany, Italy)
  => will not be prioritised

2. **List of UTPs** we will focus on, in order of priority for addressing and modelling

   - The ABM focus on fairness requires the specification of one or more research questions related to the fairness problem. For that purpose, and for the determination of the scope of the model (related to problem definition, agent decisions and interactions), a cognitive mapping technique will be applied. However, the choice of which are the main decisions relevant to the ABM focus on fairness (distributive and procedural) needs to be related to the problem definition (research question) in terms of simulation modelling approach. (In Appendix to this deliverable is documented the work in progress in each case study)

A simulation model's purpose is not to model the entire system and how it is functioning (impossible from a technical and complexity perspective, and not needed) but to model a problem situation within the system with the purpose to explore options for solution. This is also about defining model boundaries and scope

3. **Assumptions** regarding. how we measure fairness

A working document on fairness was developed following discussions in the annual meeting in Bologna (Gudbrandsdottir et al., 2019): to reach consensus among VALUMICS partners on the definition of fairness in food supply chains; and also to suggest how to quantify fairness in food value chains and operationalise this concept in the work of WP7 and WP8. The key outcome is:

- To consider two dimensions of fairness: procedural and distributive fairness. The main focus is on distributive fairness, but procedural fairness issues will also be considered.
- Other types of fairness are acknowledged and will potentially be included in other aspects of the project. This will be explored further, for example by a questionnaire on fairness perceptions.
- In the VALUMICS ABM model it is suggested to operationalise distributive fairness in terms of quantitative metrics, in particular gross profit margin and the Lerner Index for market power.
- Procedural fairness is more difficult to quantify so we suggest operationalising it in the VALUMICS ABM model in terms of observable effects on the distributive fairness metrics.
- What if questions will be used for scenario experimentation and hypothesis testing

4. **Limitations** – what we will and will not do.

It should be noted that where important information is missing, informed assumptions need to be made coming from documented expert opinion or published sources. Also, it should be clear that the purpose of the simulation modelling is not to produce an exact replica of the modelled system but to capture main factors and interrelations among system components on a reasonable level of simplification, to ensure it could be capable to produce insights for the proper analysis of the system behaviour in relation to the main research question.

All modelling is about making informed choices of selection: what to include in the model and what may be (reasonably) safely excluded without significant degradation of quality of results. At each tier, we will model actors (agents) of three categories, small, medium and large, with the number of agents in each category informed by the real-world preponderance together with the technical feasibility of running a computer program instantiating that number of agents. This will allow modelling of the heterogeneity of real-world FVCs. It is expected that, typically, there may be three to five large players at a given tier, with greater numbers of medium and/or small players. Since these limitations will only become clear at the implementation stage, the exact numbers are to be decided in the technical design of the system, D7.2. The characteristics of the different categories of actors will also be required in time for D7.2, and the parameters for which values are needed are listed in Table 5. In cases where the technical limitations do not allow modelling of the full population of actors in a given FVC, the approach taken will be to model a proportion of them as agents, and the rest to be represented by environment variables expressing market and other conditions.

Scenario development as per WP8 will use existing FVC structures (numbers of tiers and types of actors and interactions among them, though possibly changing numbers of actors at each tier) up to 2030. Furthermore, this will be easier for stakeholders to relate to: there is a lot of uncertainty after 2030. If a pathway to a future WP8 scenario depicts specific changes to FVCs (e.g., certain actors join the chain, certain actors leave), we will try to accommodate this in the model, but such efforts will depend on the resources available in WP7, and will defer in priority to more important modelling tasks.

The implication of this is that the integrated model will focus on existing value chain structures, assuming that these will remain valid at least until 2030, and will consider variations of these structures from 2030 to 2050 as time and resources permit.

In relation to the validation of the simulation modelling conceptualisation, a documented procedure for gaining and confirming its legitimacy and rightness is needed, such as group conceptual model building (application of cognitive and agent maps), expert and stakeholders opinion in relation to gaining agreement on the true representation of the system components and their interrelations

Note: Comments from partners are included as footnotes in this report and reflect the ongoing discussion and work in progress to clarify and reach a common understanding among the interdisciplinary team in the VALUMICS project.[2] [3]

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[2] *Comment*: What is the unit of analysis? Measure at the firm level or industry / stage of supply chain level? If firm level will need to control for all the other determinants of gross margins (e.g. firm level effects). Lots of reasons why a firm may have a low profit margin unrelated to fairness (e.g. poor management, technology) *Reply*: we have to measure at the firm level as that is our agent. Unless we can quantify or at least estimate "the other determinants of gross margins" we must simply disregard them and state in the limitations part of Scope that we are deliberately omitting them

[3] *Comment*: As concerns "Distributive fairness", it's not clear if the selected metrics consider as a cost also the unsold products. In other words, if we consider the cost/price per unit for each transaction we may have a fair situation but if we consider the total investment/profit of an agent we may have a different result.
We have seen that several negotiations are affected by the concern of the agent about not selling the whole production in a given period because of several reasons (perishable products, additional stockade costs, etc. *Reply*: if we can quantify waste and include it in the actor's margin, then we can include it as a cost; otherwise we must disregard as in comment to footnote above

3. AGENT-BASED MODELLING APPROACH

Understanding the endogenous and exogenous characteristics of organisational and market complexity, being a source of causal ambiguity, emergent behaviour and self-organisational dynamics (Morel and Ramanujan, 1999) is well advanced by general systems theory (Von Bertalanffy 1968; Andrew 2003) and the system dynamics field of research (Forrester, 1961; Randers 1980; Morecroft 1999; Sterman, 2000; Morecroft, 2007).

A more contemporary method for exploring complex adaptive systems is agent based modeling and simulation (ABM), which in contrast to the system dynamics “macroscopic” perspective takes a “microscopic” view for explaining agents specific emerging systems behaviour (Macal and North, 2010). Agents in such systems behave within an environment, in parallel, interacting and competing for control over resources in an adaptive manner, subject to a condition/action rule pattern connected to a specific behavioural decision-making structure (Holland 1992; Anderson, 1999).

Agent-based modelling, compared to traditional approaches to modelling economic systems, can be a more viable approach when there are reasons to think in terms of agents; for example, when the problem or research question we need to explore is naturally represented by a large number of agents whose decisions and behaviours can be well-defined, which exhibit adaptation and change, which learn and engage in dynamic strategic interactions and relationships with other agents, and which can have a spatial component to their behaviours and interactions (Axtell, 2000). A very important feature of Axtell’s agent-based modelling criteria is linked to the structure of the system which has endogenously emerging mechanisms governing its future evolution and is not dependent only on the past

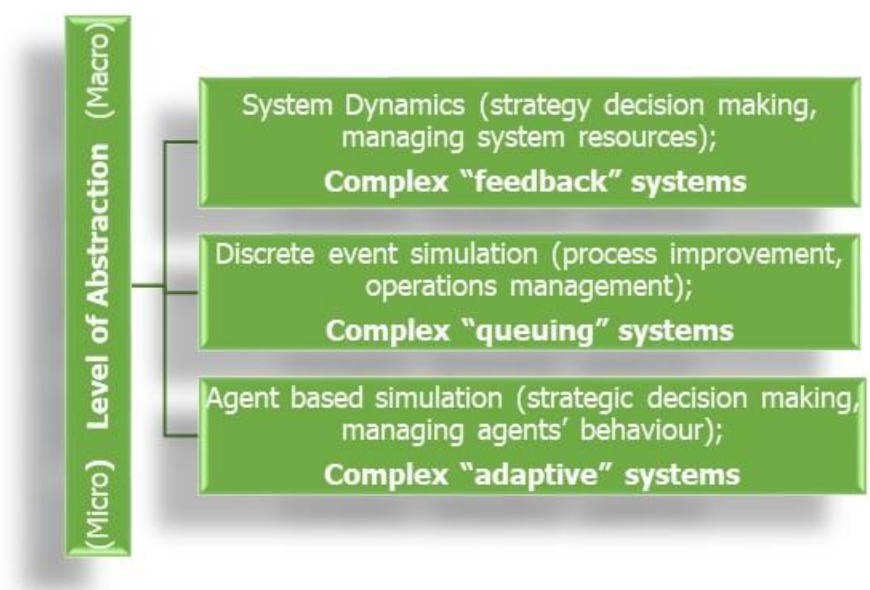


Figure 1 Level of abstraction of different simulation modelling (adapted from Macal and North, 2010)

Considering the initial work that has been done on the project in WP2 (D2.4 and D2.5, Olafsdottir et al.,2018a, 2018b) related to system dynamics conceptual modelling of supply, value and decision chains in (FVC) (Gudbrandsdottir et al., 2018), and our focus on distributive and procedural fairness in food value chains (FVC) from ABM perspective, a hybrid approach has been agreed on. This implies developing stock and flows for financial resources for simulating value distribution along the FVC actors, and linking it with agents' decisions and interrelations (related to price setting and negotiation, and contractual relations) as conceptualized in Figure 2.

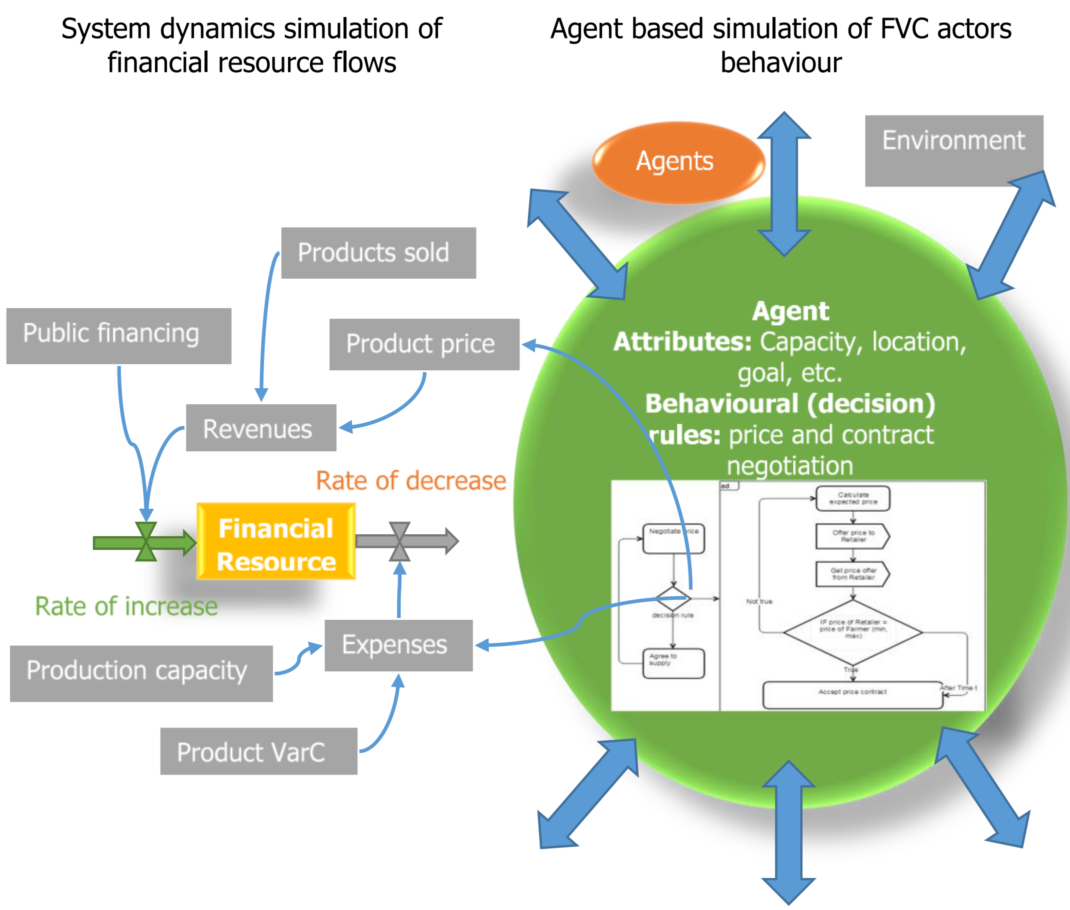


Figure 2 Illustration of the hybrid approach showing the system dynamics modelling of flows on the left and the ABM approach on the right (adapted from Macal and North, 2010)

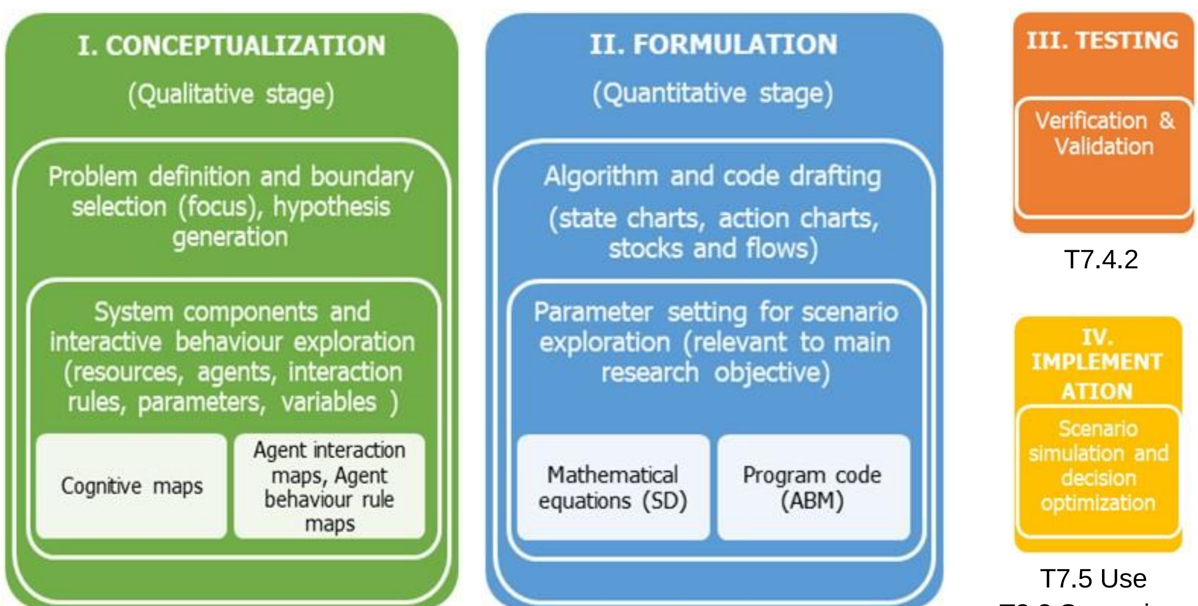
4. FUNCTIONAL SPECIFICATION

A functional specification is a blueprint of the model to be built. It specifies **what** the model will do, while the technical specification specifies **how** the model will do it (how it will be implemented) in terms of module definitions and algorithmic pseudocode. The functional specification will highlight the main relevant decisions of each market actor in each FVC, and their explanation based on procedural and other aspects, including conditional factors and what if questions.

In the following section we go through the steps of developing a conceptual model for the current simulation project. We start by defining the problem and setting the modelling objectives. The inputs, outputs and contents of the model are then put forward based on the problem at hand and the project objectives.

ABM CONCEPTUAL FRAMEWORK

The ABM conceptual framework follows a well-established practice for ensuring design and creation of a valid and robust simulation model capable to provide means for virtual policy experimentation and decision analysis and optimisation.



T7.4.2

T7.5 Use
T8.3 Scenarios

T5.2 Functional specifications

T7.2 Technical specifications
T7.3 / T7.4.1 Implementation/coding

Figure 3 Key stages of the modelling and tasks where the work will be performed in VALUMICS

The modelling process is iterative following five general steps (Sterman, 2000): problem articulation (boundary selection), dynamic hypothesis, simulation model formulation, model testing and policy evaluation. Following Randers (Randers, 1980) guide to model conceptualisation, modelers need to follow a conceptualisation, formulation, testing and implementation stage. Richardson & Pugh (1981) and Roberts (1981) view the model building stages as problem definition, system conceptualisation, model formulation/representation, model behaviour and analysis, evaluation and policy analysis and use.

According to Randers (1980) classification, the first “conceptualisation” stage need to account for the modeler´s conceptual understanding of the system components and how they are influencing each other’s behaviour. In system dynamics, main components are resources, flows, variables and feedback resource interrelations. In ABM, the main components are agents, their attributes and behavioural rules, and agent interrelations (Macal and North, 2010). This aim is addressed using qualitative techniques like cognitive maps, agent interaction and agent behaviour rule maps, which help the modeler also to frame the main research question, explore the model boundary and generate dynamic hypotheses for simulation testing.

The next “formulation” stage is linked to the quantitative model building, meaning that normally a stock and flow formal diagram need to account for the system structure and for the proper mathematical interrelations among the model variables, while in ABM this is related to the coding of agent behaviour in the model. The next “testing” stage is about model calibration and verification, having the purpose of proving the proper quantification of the simulation model. The “implementation” stage is associated with the simulation application to policy evaluation by doing what if scenario simulations in order to test previously identified hypotheses and find how variation in key input variables influences the behaviour of the whole system.

In Figure 3, all stages relevant to the simulation modelling of FVC have been defined. The work in task 5.2 includes the qualitative stage of defining the functional specifications and the model conceptualisation. In the “Conceptualisation” stage the focus is on, problem definition and boundary selection (focus), including hypothesis generation need to be performed. For this purpose, Agent decision tables, Cognitive maps, Agent interaction maps and Agent behaviour rule maps have been applied for the elicitation of System components and their interrelations (resources, agents, interaction rules, parameters, variables).

The technical specifications are part of task 7.2 and this is the quantitative stage or the “Formulation” stage where algorithm and simulation coding will be performed (T7.3 and T7.4.1) through state charts, action charts, stocks and flows charts. The next stages are about “Testing” (verification and validation) which will be performed in task 7.4.2 and “Implementation” through Scenario simulation and decision optimisation research in tasks T7.5 and T8.3.

4.1 Problem Description

Unfair trading practices – Opportunistic behaviour

Unfair trading practices within food supply chains are of increasing concern to European Union (EU) and member states' policy makers (DG IPOL, 2015). Findings indicate that their negative impact on SMEs in the EU food sector is affecting the competitiveness of the industry as a whole (Wijnands et al., 2007). Although UTPs can arise in any market or sector of an economy, they have the potential to be especially problematic in food supply chains, as agricultural producers may be placed under undue pressure and have limited bargaining power in negotiations with larger purchasers, such as supermarkets or retailers, given the lack of alternative buyers (Duffy et al., 2003, Falkowski et al., 2017). As a counter measure, the recent EU Directive (2019/633) on UTPs aims at protecting weaker 'suppliers', primarily farmers, including their organisations (e.g. cooperatives) against their buyers, as well as suppliers of agri-food products which are further downstream (European Parliament, 2019). The Directive addresses aspects of procedural fairness which have a direct effect on distributive fairness as the fairness of procedures influence the resulting outcomes; The new Directive constitutes practices that

> *"…grossly deviate from good commercial conduct, be contrary to good faith and fair dealing and be unilaterally imposed by one trading partner on the other; impose an unjustified and disproportionate transfer of economic risk from one trading partner to another; or impose a significant imbalance of rights and obligations on one trading partner"*
>
> (European Parliament, 2019).

The Directive prohibits 16 specific unfair trading practices and distinguishes between "black" and "grey" practices[4]. The black unfair trading practices are prohibited, whereas the grey practices are allowed if the supplier and the buyer agree on them beforehand in a clear and unambiguous manner. The rules ensure e.g. that farmers are paid on time, do not have their orders cancelled at short notice, and do not have to pay for wasted food. Short order cancellations by the buyer for orders of perishable products are no longer possible. Suppliers can ask for written contract and the buyer cannot threaten them with commercial retaliation when they file complaints.

Prohibited practices summarised

1. Payments later than 30 days for perishable agricultural and food products
2. Payment later than 60 days for other agri-food products
3. Short-notice cancellations of perishable agri-food products
4. Unilateral contract changes by the buyer
5. Payments not related to a specific transaction
6. Risk of loss and deterioration transferred to the supplier
7. Refusal of a written confirmation of a supply agreement by the buyer, despite request of the supplier
8. Misuse of trade secrets by the buyer
9. Commercial retaliation by the buyer
10. Transferring the costs of examining customer complaints to the supplier

[4] https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/brochure-utp-directive_en.pdf

The concept of fairness in the context of transactional relationships is closely connected to power. The more powerful party in a business relationship is in a position to misuse its power and thus treat their business partner unfairly. Earlier, manufacturers and suppliers generally had the upper hand in their relationship with retailers, giving ground to research on supplier power and associated fairness issues (Brown, Cobb, & Lusch, 2006; Griffith, Harvey, & Lusch, 2006; Kumar, Scheer, & Jan-Benedict, 1995). Now, the balance of power in these relationships has mostly shifted due to the emergence of mega retailing formats, through mergers and acquisitions and the formation of horizontal alliances (Kumar, 1996).

In VALUMICS the work in WP3 resulted in a categorisation framework for the different European Union (EU) policies, laws and governance actions identified as impacting upon food value chains in the defined areas of: fairer trading practices, food integrity (food safety and authenticity), and sustainability collaborations along food value chains. The D3.3 report concludes by exploring in more detail how the themes of fairness and of transparency are being handled in the policy activities presented. Highlighted are the ways that both fairness and transparency can be extended within the existing frameworks of EU policy activity. The findings provide an important context for further and detailed research analysis of the workings and dynamics of European food value chains under the *VALUMICS* project (Barling *et al.,* 2018).

Due to the topicality and policy relevance of fairness in FVCs there is value in exploring its dynamics through simulation modelling. Increasing fairness in food supply chains is important and even more so as pressure on the system increases with rising population numbers and sustainability concerns.

THEORY OF FAIRNESS

In fairness theory, fairness is often defined along two main dimensions as distributive fairness and procedural fairness. In addition to distributive and procedural fairness, interpersonal and informational fairness have been defined (Liu et al., 2012). Interpersonal fairness and informational fairness are based on people's reactions and social interactions and are sometimes collectively referred to as interactional fairness (Bies & Moag, 1986; Greenberg & Cropanzano, 1993).

Distributive fairness deals with the fairness of outcomes, or in a supply chain context, how benefits and burdens are distributed between partners. In FVCs, the price received by an actor will be the most important outcome considered (Busch & Spiller, 2016). Examples of distributive fairness issues are: *unfair pricing* (e.g. retailers using their purchasing power to drive down suppliers' prices to uneconomic levels, sometimes even using threats), *unfair cost burden* (e.g. suppliers having to bear unforeseeable costs and costs that were unjustly forced upon them, and *unfair risk burden* (e.g. suppliers having to bear risk that does not result in a larger share of profits) (Duffy et al, 2003; Kumar, 1996).

Procedural fairness deals with the ways (e.g. procedures) in which outcomes are achieved. Fair procedures are those that incorporate generally accepted principles such as consistency, bias suppression, accuracy, correctability, representativeness, and ethicality (Leventhal, 1980). Examples of potential procedural fairness issues are unequal power (as a result of different firm strategies related to e.g. transaction costs, market growth, capacities, entry barriers) among partners to define prices, unequal access to relevant information and the inequitable treatment of different partners in a supply chain on behalf of a powerful party (Busch & Spiller, 2016; Kumar, 1996). These examples describe situations where agents could potentially act procedurally unfairly. However, the opportunity to act unfairly does not necessarily result in procedurally unfair behaviour.

Regardless of the power structure, perceived distributive and procedural fairness of the weaker party have been found to have a positive impact on satisfaction in supply-chain relationships (Brown et al., 2006; Griffith et al., 2006; Kumar, 1996; Kumar et al., 1995). Procedural fairness has been considered to have a greater effect on satisfaction than distributive fairness (Kumar, 1996; Maxwell, Nye, & Maxwell, 1999) and is indeed a prerequisite for distributive fairness as procedures influence resultant outcomes. However, in their research, Brown et al. (2006), found that the positive effect of procedural fairness was only present when associated with high levels of distributive fairness.

The degree of fairness in inter-firm relations is a perception and therefore it is necessary to define quantifiable indicators to be used for the simulation model. The operationalisation of distributive fairness through economic indicators will be the main focus of the simulation modelling. As it will be difficult to measure procedural fairness directly within the model, the concept will be operationalised through the development of experimental factors used to explore how structural aspects, such as access to information and power asymmetry, affect distributive fairness.

PROBLEM FORMULATION

The food systems studied and chosen case studies comprise a large and complex system: these can only be interpreted from a limited viewpoint both because of the modellers' need to select and simplify, and the lack of availability of complete and exhaustive information on the system: thus many simplifications and assumptions are needed. In formulating the problem, we regard the model developed as a laboratory for experiments and simulations. Our main problem and lack of insight to be addressed by the integrated quantitative model can be summarised as:

> *How may trading practices be made fairer (under environmental sustainability constraints to be specified)?*[5]

The emergent pattern of interest to us is the observed distribution of gross profits, adjusted to take account of EU subsidies. A desired emergent pattern is a fairer distribution of gross profit. We wish to explore if and how regulatory interventions and changes in individual actor behaviour may drive overall system behaviour.

The basic structure of the model is determined by the following:

- Who are the actors in each FVC?
- How many at each tier?
- Are they homogeneous or heterogeneous (e.g., large / medium / small retailers)?

[5] *Comment*: While the ABM focuses on fairness, it has to do so while considering other specific constraints related to sustainability – that are not be modelled per se, but that are considered as external constraints from the environment. Otherwise, it might well be the case that a way to make FVC fairer is simply to continue depleting our environment / externalise the costs of social regulation to the environment (as is already the case in many FVCs, where farmers simply "pass on" to the environment the constraints they receive from downstream players.

4.2 FAIRNESS METRICS

UNDERLYING COMPONENTS OF UNFAIRNESS AND WHAT CAN BE MODELLED QUANTITATIVELY

Agent-based simulation models are typically built from the bottom up by identifying agents in the system and defining their behaviours, including how they interact with other agents and their environment. The behaviour of the system as a whole emerges out of multiple concurrent individual behaviours. In the VALUMICS ABM the behaviour of agents will be defined in terms of decision rules executed upon special events 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 FVC. To be able to quantitatively measure fairness in the system we therefore need to define fairness metrics. We can also use the model to assess how the fairness of procedures or structural aspects governing individual decision making in the FVC affects the fairness of outcomes.

DISTRIBUTIVE FAIRNESS METRICS

When examining quantitative metrics for distributive fairness we take into account the importance of price, on both input and output markets, for agents in the FVC in their effort to maximise their profit or utility. Furthermore, the influence of market power with respect to creating opportunities for misuse of power in the form of UTPs, is considered to be of relevance.

The recent definition of UTPs in food supply chains by the European Parliament emphasises the links between bad commercial conduct and imbalances in market power, which can lead to the imposition of additional risk, an extra cost burden and obligations on one actor or group of actors. Supply chains are made up of a series of actors performing activities involved in bringing products from primary production, through processing and distribution, to the final consumer. Products move through the system by way of business transactions between sellers and buyers. The **price** negotiated in each transaction is therefore the central mechanism by which the different echelons of the supply chain are interlinked. In addition, the price of a product is of great importance to both parties involved in the negotiation process as they strive to maximise their profit or utility and is considered to be one of the most important factors that will increase the fairness perceptions of FVC actors.

Price transmission is the measure of how changes in price at different levels of the supply chain materialise in other parts of the chain. Perfect transmission occurs when a change in the producer price instantaneously causes the same change in the retail price. Imperfect and/or asymmetric price transmission can be present in supply chains without perfect competition, often where one or more agents are in a position of market power and can use it to their advantage. Asymmetric price transmission can possibly be an indication of market power and where market power is present there is a possibility for unfair trading practices as more powerful agents may misuse their powerful position. (Falkowski et al., 2017). However, although, market power may make UTPs more likely, it is not a necessary precondition for UTPs to occur. Small-scale players without market power also cheat.

Closely linked to price transmission is the eventual **profit margin** obtained by the various actors across food value chains[6]. Overall, it is a reasonable hypothesis that price movements threatening the margin of firms being able to exert market power are transmitted faster than price movements that improve it (Falkowski et al., 2017). Testing this relationship necessitates the use of at least two measures – one on **economic margins** (either gross or net), and another concerning the degree of **market power**. With regards to the latter, a very widely adopted metric that will be considered in the VALUMICS project is the **Lerner Index for output market and relative mark-down index for input market**. The Lerner Index provides an estimate of market power in an industry, measuring the price-cost margin through the difference between the output price of a firm and the marginal cost divided by the output price (Elzinger & Mills, 2011). The index ranges from a high value of 1 to a low value of 0, with higher numbers implying greater market power. For a perfectly competitive firm, L=0 and such a firm does not exercise market power; equally, when L=1, a firm has monopolistic power. Analogously, we can define mark-down index for input market. Both indexes can be used as measures of the departure from perfect competition and as such they can be considered as good measures of fairness according to economic theory.

The Lerner index will be calculated using the estimate of the first derivative of the input distance function and stochastic frontier analysis approach. In this case, we exploit the duality relationship[7] between the cost and input distance function to get the information on the marginal costs. The duality relationship is used because we can work with quantities instead of prices which are hardly accessible on the firm level. The same approach will be used for input market. That is, the relative mark down will be calculated based on the estimate of the first derivative of the output distance function which is dual to the revenue function (see details in ANNEX I from Lukas Cechura, CZU).

Given the difficulty in obtaining the necessary financial information to determine net margins, the VALUMICS project will use **gross** rather than net margin as the economic indicator relating to fairness. Although, gross margin is not really a measure of fairness per se it can be used to compare the economic performance of agents in the chain and thus address how equally are benefits and burdens distributed. The aim will not be to determine an absolute measure of fairness using these indicators, but rather to ascertain transitions towards fairer outcomes. This approach is in keeping with the European Parliament's depiction, which, rather than providing a strict value measure of UTPs, emphasises the presence of gross deviations away from good commercial conduct.

*In conclusion, the VALUMICS project will use the **gross profit margin** and **Lerner index** to measure distributive fairness in the simulation model. When calculating gross profit margin, revenues will include any subsidies and support, including environmental public financing (e.g. direct payments under CAP (Gudbrandsdottir et al., 2019).*

[6] *Comment*: Price strategies are not necessarily aiming to maximise profit margin in the short-term. Some actors may adopt below-cost pricing strategies as expansion strategy. Or they may adopt a limit/predatory pricing within a procedural unfair practice to push competitors out of the market. This is particularly relevant and complex for multi-product processing companies or retailers

PROCEDURAL FAIRNESS AND WHAT-IF QUESTIONS

Procedural fairness concerns the procedures leading to outcomes. The outcomes can be perceived as fair or unfair (i.e. distributive fairness) but the procedures leading to these outcomes can themselves also be considered fair or unfair (i.e. procedural fairness). The procedures in place certainly affect outcomes, although a high level of procedural fairness does not automatically lead to high levels of distributive fairness.[8]

Procedural fairness question can inform the selection of what-if questions that are used to test how different levels of procedural fairness (e.g. the implementation of some parts of the Directive on UTPs) affect the fairness metrics already discussed. Such what-if questions could address different procedural fairness issues, including unequal power among partners to define prices and unequal access to information resulting from the way in which the individual FVC are governed (e.g. producer organisations and price auctions). Examples of a what-if questions relating to procedural fairness could then be[9]:

> *What-if there was no reference price in the price auctions in the tomato value chain?*
>
> *What-if retailers would take part in the price auctions in the tomato value chain?*

The Directive on UTPs lists prohibited practices in business-to-business relationships. These include customs which can be considered to be of a procedural nature e.g. relating to payment terms and other elements of contractual relations. Following are examples of potential what-if questions that can be used as experimental factors within the model:

> *What is the effect of payments later than 30 days for perishable agricultural products and later than 60 days for other agricultural products on the gross profit margin of farmers? (i.e. what would be gained by prohibiting late payments?)*
>
> *What is the effect of short-notice cancellations of perishable agri-food products on the gross profit margin of farmers? (i.e. what would be gained by prohibiting short-notice cancellations?)*

These are examples of how procedural fairness can be implemented in the ABM model, since we will not have procedural fairness metrics as these are difficult to quantify. To be able to include procedural fairness in the model regardless we suggest to use procedural fairness as experimental factors that we use to run the model. These What-if questions should then concern some

[8] *Comment*: - As concerns "procedural fairness" the "time" factor has a great relevance not only with respect of the payment but also in relation of the times of the negotiations, especially if we consider agents selling perishable products
- We are focusing a lot on fairness in a "vertical" perspective of the value chain, should consider also horizontal relationships among the same type of agents. It would be very difficult to find metrics for this type of relationship but maybe we should consider it as a possible cause that has consequences on vertical relationships. In the North Italy tomato case study one example could be represented by the issue of farmers' overproduction. In general, in any sector in which an actor doesn't respect the shared rules, the consequences may fall on agents also in other steps of the value chain *Reply: clearly an important real-world situation, but unless we can quantify the effects, I think we need to rule it out of scope*.

[9] *Comments*: These are only examples from the tomato chain, but in many agri-food industries contractual relationships exist with no reference price. Each case study will define their own questions that they want the model to answer. An added value of VALUMICS is to learn from each other chain governance. Thus some what-if questions may come from the findings from the governance of the CS analysed so far.

procedural fairness issues. We then “ask” the model: what happens if late payments are banned and punishable? What then happens to the factors being measured by the model e.g. the distributive fairness metrics.

In terms of food supply chains, the literature on fairness has often been very much focused on consumers and how they perceive fairness in the supply chain and the effect that has on their purchasing behavior (e.g. Fairtrade) (Briggeman & Lusk, 2011; Busch & Spiller, 2016; O'Connor, Sims, & White, 2017). Two studies focused on the effect of perceived fairness on food supply chain relationship quality (e.g. Sun et al. (2018), Duffy et al. (2003). These are procedural aspects of fairness that are difficult to model and are grounded in actor perceptions. However, given their potential incidence and impact on distributive fairness, in particular the outcomes in a supply chain context there is a need for studies that evaluate perceptions of UTPs across food supply chains, including the perspectives of all actors. In this context, Gorton et al (2015) proposed a framework to study relationships between buyer-seller power, buyer trustworthiness and supplier satisfaction / performance. The model draws on an organizational supply chain perspective of power and was verified using data relating to dairy farmers’ relationships with their main buyer in Armenia. Furthermore, the VALUMICS project has suggested to study fairness perceptions of agents in the chains by surveying actors across the FVCs and asking for perceptions on fair compared to actual gross margins, as well as analysing responses to a series of statements on the distributive and procedural components of UTPs according to a conceptual model on fairness in sustainable supply chains (IIED/Oxfam, 2012).

Governance and fairness as perceived by stakeholders

Findings from earlier work in the VALUMICS project on governance in European food value chains and the view of stakeholders on fairness was reported in Deliverable 5.1 (Barling and Gresham, 2019) and summarized here below:

“Studies on each of the five case studies: liquid cow’s milk, beef steak, farmed salmon, processed tomato, and bread from wheat evaluated the governance of the value chain through the different stages of production, processing and retail, following the transformation from farmed/grown commodity to final food product. The case studies are situated within broad regulatory frameworks of state-led policies at the European and national level, while also encompassing governance initiatives originating from corporate and societal actors.

The findings from the studies confirm that the nature of governance in value chains covers inter-firm relations but also includes private governance initiatives and public policy and regulatory interventions.

The nature of each food value chain has its own particular features and characteristics more specific to that sector. There are important structural features in each value chain that set boundaries within which the dynamics of governance take place. The actors at key stages of each value chain may be in a better structural position than others, which can give them an advantage in the negotiations and bargaining over contracts.

Stakeholders’ views on fairness are focused on price setting and the means by which pricing decisions are made. [*This was a visible concern raised by milk and beef producers as sellers.*

Conversely, the processors, as the buyers, raise a range of factors that they have to take into account to ensure profit to their own business when negotiating the buying price. For example, the processors' profitability is impacted by the need to use of the rest of the beef carcase, or the volatility of world milk prices and the low, loss leader pricing of milk by the supermarkets].

It was notable that the interviewees very rarely mentioned the types of unfair trading practices, as defined and laid out in the Directive on unfair trading practices in the agricultural and food supply chain. Rather, it was the subjective experience of price setting (and related volume agreements, for example) in their particular value chain and sector where concerns around fairness and transparency were most explicitly articulated.

There is subjectivity in the views of stakeholders over issues such as price negotiations that must be considered when assessing fairness in value chains. The need for industry, and more particularly for policy makers, is to find the most appropriate mechanisms and interventions (such as interbranch organizations, producer organizations, cooperatives, voluntary codes of practice, mandatory legislation) that will achieve fairer trading and working conditions, and greater transparency and information flow in food value chains. These interventions and mechanisms need to be suitable for each respective agricultural and horticultural sector as well for the agri-food industry as a whole. At both the sector level, and across all food value chains, the important structural features and their impacts on intra-chain bargaining must be taken into account" (Barling and Gresham, 2019)

4.3 WHAT-IF QUESTIONS

"What-if" questions capture the hypotheses the model is intended to address and test. These can be referred to as experimental factors or input (see Table 6),

More work is currently ongoing in the respective case studies on identifying potential procedural fairness related to what-if questions. Furthermore, it should be noted that although it is proposed here to use what-if questions to incorporate procedural fairness in the modelling work, it is by no means suggested that these would be the only what-if questions. Certainly, the what-if questions relating to the scenarios in WP8 will be of major importance no matter whether they relate to procedural fairness issues or not.

On top of the generic hypotheses that the WP8 team proposes to explore for all food chains (see below, section 4.4), case study leaders are required to list "what if questions" that are be more specific to their case studies and that would not be relevant to other case studies (see Appendix).

Further questions include: What is the link between the degree of market/bargaining power of FVC actors to the observed UTP? What other factors (for example, financial markets, reference price negotiation) could have effect on fair value distribution? By observing to what extent gross margins vary in different what if experiments, can we indicate when the FVC is becoming more or less fair (provided that we know what is regarded to be an acceptable min, max range for a fair profit in the FVC).

In order to test the scenarios developed in WP8 in the simulation model they need to be translated into what-if questions that can be tested in the model. The scenarios are on a macroscopic level while the model is on a more detailed level. These what-if questions are then translated into either quantitative or qualitative experimental factors (as described above).

There should be made a linkage between (a) an existing or potential opportunistic behaviour and (b) an intervention that might address it. Here, priority means the order in which the modelling effort should address these questions, given limitations on WP7 resources.

The Wuppertal workshop in July 2019 had a discussion on what-if questions. Some questions will belong to WP8 and some to WP7 and some to both. What-if questions are to be ranked in order of priority so that the most important are addressed first as time and scope permit.

From the perspective of WP8 the most important questions will be about changes in demand and supply. The model will need estimates from WP8 on the changes over time in these parameter values, from 2020 up to 2030 and/or 2050, and will assume a linear trend in the change from start of period to end of period, unless there is evidence or other strong reason to believe otherwise. WP8 will provide values for the expected demand and supply (production, consumption, import and export) for the case studies examined, under each scenario analysed[10]. Modelling objectives

The VALUMICS project considers a variety of factors in the context of food value chains. These include sustainability, resilience and integrity. The simulation model that will be made in WP7 has

[10] The values will be obtained by using the EAT-Lancet scenario and collaboration with Marco Springman, by using a rerun of the IMPACT model for a set of food commodities (wheat, dairy, salmon and tomato) and countries under study within the scope of the VALUMICS project.

a narrower focus, concentrating on fairness in food value chains. The concept of fairness in the context of transactional relationships is closely connected to power. The more powerful party in a business relationship is in a position to misuse its power and thus treat their business partner unfairly. The governance structure of the food value chains that are the subjects of the VALUMICS case studies have been analysed thoroughly in Task 5.1. The results of this work give indication of the power structure in these value chains and thus possible sources of unfair market conditions. Building on the work already performed in the project an overarching research question for the simulation model has been suggested:

> *How does governance structure affect profit distribution in food value chains (under specific environmental sustainability constraints)?*

FUTURE SCENARIOS (INPUT FROM WP8)

In the WP 8 of VALUMICS, alternative futures for the European food systems in 2050 will be described to explore a broad range of characteristics that would make FVCs sustainable, more resilient, fairer and efficient. The aim is to cover the whole transition space in three contrasting paradigms that differ in the institutional frameworks, governance and market approaches that dominate in them. A qualitative description of the sort of broad socio-political strategies through which the European food system – and in particular the governance of European food value chains therein – could be transformed towards 2050.

Three broad strategies have been proposed by the WP8 team :

- A **global / market led strategy**, where trade levels are 50-70% higher compared to 2020. Food, feed and inputs are produced in regions with comparative advantage and traded globally highly processed to recycle residues locally. Governance is based on market-led mechanisms and consumer transparency, and sustainability is incentivized economically and based on consumer information and identity-differentiation
- A **regional / state led strategy**, where trade levels are comparable to the levels of 2020. Public institutions have a strong role in regulating and supporting the food production in EU. Food consumption is based on agricultural production in Europe and aquaculture and fisheries products from the European region (currently imports are 60% of the total consumption). The responsibility of creating fair, resilient and sustainable food system is handed over to the governments and other public institutions that ensure their function with strong regulatory frame.
- A **local / civil society led strategy**, where trade levels are 50-70% lower compared to 2020. Civil-society has a leading role in shaping local food production and consumption practices. Community supported agriculture (CSA), urban farming and fishing are focal parts of food production based on local resources. Local co-operatives across the food value chains including food producers and consumers are governing production and consumption tightly together, proximity and transparency are the key aspects of this cooperation.

Under each of those paradigms, food system narratives at the EU level will be developed and specific food chains scenarios, based on the VALUMICS case studies, will be explored. Four case studies are considered at this stage: Salmon in Norway and export to EU, Milk and bread in France, and Tomato in Italy. The extent to which full scenarios will be developed for all the chains is still to be determined

> *These scenarios are not predictions and they do not seek the truth following the pathways of current trends, but instead explore the entire transition space to offer contrasting visions that are meant to reveal a broad range of options and means for stimulating, provoking and communicating a desirable future.*

Each paradigm encapsulates, in essence, a set of "generic" hypotheses of how the overall governance of European food chains will evolve. The impact of these hypotheses specifically on fairness will be explored using the ABM developed in WP7 under the form of "what if" questions. In other words, these hypotheses will be translated into changes in the environment of the food chains modelled to examine their impact on the structure, the governance and, ultimately, the level of fairness of the chains. Depending on the "strengths" of the ABM developed, the two dimensions of fairness – i.e. distributive or procedural – will be explored. Indeed, while the proposed hypotheses are meant to impact (mainly) upon procedural fairness they can in turn affect the way in which the valued added / mark up is distributed along the chains, hence the level of distributive fairness.

In the WP8 scenarios, food consumption is based on raw commodities - wheat, milk etc. The WP8 hypotheses will cover, for each raw commodity within the chosen jurisdiction for it, how much is produced, demanded by consumers, exported, and imported. For example, a dairy factory can produce yogurt, liquid milk, powdered milk etc. - similarly for other raw commodities - and the product mix chosen by a producer will depend on economic advantages of different end products.

For each raw commodity dealt with in a case study, at the agent-based model will treat it as follows

> - one end product (the one specified in the case study) is treated in detail by the agent model, for a particular jurisdiction
>
> - other end products are treated as boxes, into which a proportion of raw commodity goes, out of which some money comes (there may be threshold values for each end product). Waste must also be quantified.
>
> - in ABM terms, these boxes will form part of the environment (affecting agent behaviour, but not affected by agent behaviour).

"WHAT IF" QUESTIONS FOR THE THREE PARADIGMS- HYPOTHETICAL INTERVENTIONS

A set of preliminary hypotheses is listed below, that will need to be further explored to be fully operationalised by the WP 7 team – this will ultimately depend on the final structure of the model.

Hypotheses of changes underpinned by the "**Global & market-led**" scenario

- At the producer stage: CAP subsidies are reduced/removed
- Trade barriers (either tariffs or non-tariffs ones) are fully removed, exposing producers and processors to tougher international competition / direct expositions to competitors
- Competition rules are made tougher, in the sense that vertical and horizontal integration are even more strictly regulated. In particular, producer organisations and Interbranch organisations are banned; further merging between retailers are not allowed, hence the growing concentration at the retailing stage stops.
- New technologies are adopted, e.g., blockchain, intelligent packages incl. access to production and labour facilities

Hypotheses of changes in the "**Regional, Public/ State-led"** scenario

- Producer organisations and Interbranch organisations are generalised (e.g. by being made mandatory?) to simultaneously strengthen bargaining capacities of farmers and overall coordination between farmers / processors in the face of powerful retailers
- Price transparency is made mandatory along FVCs, following / strengthening the project of regulation put on the table by the DG AGRI (http://europa.eu/rapid/press-release_IP-19-2629_en.htm)
- The UTP directive is fully implemented and made even stronger by constraining to a greater extent the mandatory content of any contracts between buyers and suppliers (e.g. setting pluri-annual contracts)
- Public procurement policies are strengthened and contains new clauses with regard to the social conditions of productions (e.g. living wages for producers, others…)

Hypotheses of changes in the "**Local / civil society-led"** scenario

- All tiers predominantly local, the value proportion of some tiers will drop out (e.g. packaging, processors?)
- Cooperative decision-making across FVC actors, including consumer cooperatives

Other aspects to be developed / explored, not necessarily specific to a given scenario:

- Change in transportation costs? (collaboration with the logistics model) -> change in agents' costs?
    - Increase in fuel price
    - Government support on rail transportation?

4.4 INFORMATION NEEDED FROM CASE STUDY TEAMS

This section outlines the major information on functionality needed from case studies. These will be gathered using formal tools such as cognitive maps and agent decision tables, described in detail later. The following is an inventory of relevant elements. For more details of this approach, see (Nikolic et al book on ABM, of which the following is a summary).

- Explicitly identify physical and social entities of the system and the links between them
- Make a list of all relevant elements, issues, factors, worries and explanations (cognitive maps)
- Choose important time frame(s): the longest and shortest time periods relevant for the system.
- Specifically identify:
  - Relevant concepts
  - Actors or objects
  - States or properties
  - Relevant behaviours
  - Interactions or flows (continuous or discrete)
- All the system components that cannot be influenced by the other subcomponents are grouped together to form the external world or "environment". These are exogenous variables.
- Everything that is not influenced by the actors within the system but that does affect them is a part of the environment.
- Extremely slow processes (relative to chosen time frame) are also part of the environment.

These findings are then used to identify the components of the agent-based model (ABM, described in more detail in the later section on Methodological Approach).

- Consider actors and objects with useful boundaries (physical, organisational and functional).
- Entities capable of independent decision making are the agents; all others are objects. Agents can have or interact with objects (such as processors owning facilities, or a farmer harvesting a crop).
- Within the entities defined:
  - identify properties and actions that describe and specify the agents. These are states.
  - search for interactions with agents or objects outside, both incoming and outgoing. These are interactions.
  - identify state changes that are caused by interactions or by other state changes, and state changes that lead to interactions or other state changes. These are behaviours.
- Identify which agents, interactions and behaviours are dynamic and which are static, and with respect to which time frame?

Then the functional specification (what the simulation model will need to do) needs to define answers to the following questions:

- Main focus and problem definition of the simulation model
- Main agents, agents' attributes and agents' behaviour rules
- Main agents' interrelations and environmental variables

- Main resources and resource flows
- Main parameters and variables, related to modelled agents (attributes, decision rules, conditional factors) and resources
- Main hypothesis (what if questions for scenario experimentation)

INITIAL LIST OF INFORMATION NEEDED FROM CASE STUDY TEAMS

These are important data that will allow setting of model parameters.

- What is the usual start up investment to build capacity and then to maintain business operations per year (production costs) for each FVC actor,
- What is the min, average, max output capacity per year for each FVC actor,
- Is there market data regarding consumer demand per year and price elasticity,
- What is the min, average, max price per unit for each actor,
- What is the level of the integration and ownership among the actors along the supply chain,
- What is the min, average, max price mark up for each actor in the food value chain,
- Are there any available market statistics regarding price and value distribution including comparable indicator for economic return or ROI for each actor,
- Are there price evolution and sales data along the FVC,
- Is there any direct or indirect price regulation in the main local and EU market (min price, reference price, fixed mark up, …),
- What unfair trade practices (due to market power or other) are observed in the FVC influencing value distribution among all actors,
- What is the usual agreement between each supplier and buyer regarding timing of the contract, supply and payment, and regarding any fluctuation or variation in demand including return of unsold product,
- Can you describe the price setting and price negotiation process between the supplier and buyer,
- What are the main influencing factors regarding price setting, negotiation and decision making along the supply chain,
- Are there interproducer, interbranch etc trade organisations and what is their role in market regulation,
- What factors influence consumer demand,
- Is there product differentiation regarding health indicators, ecological farming etc.

In addition to these, for each actor, the model will require data on actors of different sizes (small, medium, large), to allow for a heterogeneous ABM. The agent parameters for which the model will require values in time for D7.2 are listed in Table 5, for traditional and "green" (non-traditional) producers. If an exact value cannot be provided for a given parameter, then a range of indicative or reasonable values should be.

5. METHODOLOGICAL APPROACH

At the Wuppertal modelling workshop held in July 2019, the ABM methodological approach was described in detail, and the work performed on agents' maps and decision tables linked to the case studies on tomatoes, wheat, salmon and dairy. Furthermore, the aim of the joint practical workshop was to work together on problem structuring and problem definition using cognitive maps, agent behavioural rule maps and interaction maps as well as analysing specific "what-if" questions. A crucial aspect was to increase understanding among the modelling team of the needs of WP8 and other "customers" (what we want) and the availability of case study knowledge and data (what we have). In short, the model then tries to derive what we want from what we have. The key steps of the ABM methodological approach as discussed in Wuppertal are described in this report to ensure common understanding of the modelling team and the case study participants.

The model content is part of the conceptual model framework (Figure 2) and represents the qualitative approach to define the functional specifications in task 5.2. The main steps include defining the agents of the system and collecting and organizing the information on agent decisions in decision tables. Agent mapping and cognitive maps are applied to further describe agent rules and their interactions. In WP7 the technical specifications for the model will be defined, also, model coding and further experimentation on WP8 future scenarios or hypothetical interventions (solutions) will be part of WP7 in the implementation phase.

The modelling effort adopts the following conceptual approach. ABM is a method/approach which examines the interactions of "entities": FVC actors in our context. It is constructed to discover possible emergent properties from a bottom-up perspective. It describes the actors and observes how they interact, to explore system's possible states. The ABM uses a complex adaptive systems perspective where actors are modelled by autonomous agents. An agent could be a producer, processor, retailer, consumer: any food value chain (FVC) actor. An agent is: "encapsulated … situated in some environment, and … capable of flexible, autonomous action in that environment in order to meet its objectives" (Jennings, 2000).

Each agent:

- is autonomous: has control both over its internal state and over its own behaviour
- has predefined goals: it attempts to solve a problem, or achieve objectives (maybe optimise, maybe satisfy requirements)
- has behavioural routines (senses environment, decides and acts within constraints, responds to actions of other agents, regulations, flows of goods, money, information, etc.) which are driven by its goals
- can perform actions on itself and other agents, receive inputs from environment and other agents, because it consists of
    - a **state**: all of the relevant information about what this agent is at this moment
    - and (behaviour/decision) **rules** subject to if-then decision-making structure: how states are translated to actions or new states

- has resources or other objects (e.g., a processor agent may have a factory and stock of goods) and competes for limited valuable resources in an imperfect competition and regulatory environment

The modelling effort applies techniques including cognitive mapping and agent behaviour mapping for system analysis and agent rules definition, to determine the model content. The goal of this qualitative agent modelling approach is to support the conceptual, functional and technical specification for the quantitative modelling phase. The behaviour of each of the agents can be captured in a story/narrative which explains which agent does what with whom and when.

Having identified the system and the agents, as well as their states, relationships, behaviours and interactions, our next step is to formalise these concepts. Formalisation is needed because even though the identified concepts may seem well-defined to the stakeholders, they may be far more context-dependent or specific than the stakeholders realise - and models and computers cannot deal with ambiguity and context dependency. That is, our model of the world needs to be made explicit, formal, and computer-understandable (as well as being human-understandable). Once formalised in pseudocode, this can then be implemented as a computer simulation. These formal modelling tasks are the content of WP7.

DEFINING SYSTEM COMPONENTS

Describing the model contents involves identifying the physical and social elements of the system and the links between them. Here the contents of the model are defined which involves identifying and thoroughly describing the **components** that make up the system as well as defining the modelling scope.

This will require detailed input from the subject matter experts of the case study teams, to define agents and their decisions, behaviours and interactions. A useful high-level approach to this is to consider what actors there are in a particular value chain and, for each one, think of how that actor (agent) will behave in practice:

- What happens in ”a day in the life” of this actor - what does he/she do?
- What decisions does he/she make (that relate to fairness, e.g. pricing decisions)?
- Focus on agent decisions relevant to the ABM’s focus on fair value and UTP.
- What influences these decisions (prices, regulations, other environmental factors)?
- What interactions has he/she with other actors, whether in same tier or not (which agent rules affect which other agent rules)?
- What interactions has he/she with the environment?

Cognitive maps will be used to capture what influences what, and decision tables will be used to identify the decisions together with what influences them and their other characteristics. These are described in detail below.

THEORETICAL FRAMEWORK BEHIND CONCEPTUALISATION TECHNIQUES APPLIED

Cognitive mapping (Ackermann & Eden 2010; Eden & Ackermann 2001) is related to mapping individual and group mental models about a research question and to Cognition theory (Kelly 1995; Eden & Huff 2009). A recent example of joint application of Cognitive mapping and ABM is the paper of Elsawah et al. (2015) “A methodology for eliciting, representing, and analysing stakeholder knowledge for decision making on complex socio-ecological systems: From cognitive maps to agent-based models”.

Authors of the paper apply an approach to ABM design supported by cognitive mapping technique. They use cognitive mapping to capture and analyze qualitative information from stakeholders on the issue of viticulture irrigation in Australia, and further to inform a better approach for capturing agents’ decision making procedure. Their paper demonstrates how cognitive mapping brings advantages for ABM design and parameterisation:

> “*The action oriented nature of concepts in the map makes it explicit about “what action is taken”, and “by whom”. Therefore, the structure and flow of decision making becomes explicitly represented in a cognitive map. Thus, the cognitive map allows for capturing behaviour rather than just attributes of agents, as well as the interactions between actors' perceptions, states of their worlds, and choice states*.”

Agent interaction mapping (AIM) and Agent behaviour mapping (ABM) are techniques, associated with the cognitive mapping technique but with a different aim related to analysing agents, agents’ rules and interrelations. The design purpose and theoretical framework of the cognitive and agent mapping techniques are presented in Table 1.

Table 1 Cognitive and agent mapping techniques

Mapping technique	Design purpose	Theory
Cognitive Map (CoM)	Mapping key market resources, agents, influencing factors and variables and eliciting feedback interrelations; Analysis of market structure and feedback dynamic;	Cognitive mapping theory (Kelly 1995; Eden & Huff 2009) RDT (Pfeffer & Salancik 1978; Hillman et al. 2009);
Agent Interaction Map (AIM)	Analysis of agents’ interactions and influencing dynamics; Mapping agent interactions including identifying each agent’s key behavioural decision rules and key influencing factors;	BDT (Kahneman & Tversky 1982; Gigerenzer 2000; Kahneman & Tversky 1979) Stakeholders Management mapping concept (Ackermann & Eden 2011)
Agent Behaviour Map (ABM)	Mapping each agent’s behavioural decision rule in more detail through an agent behavioural map; Analysis of agent decision rules and behaviour;	BDT (Kahneman 2003; Kahneman & Tversky 1982)

Cognitive maps, Agent interaction maps & Agent behaviour maps

Main outcome of the cognitive mapping for problem structuring and definition is related to the following insights:

- The researched problem of fair value distribution and fair procedural interrelations among food value chains agents is not isolated but is connected to the overall goals of making food value chains economically, environmentally and socially sustainable and resilient
- Exploring the fairness problem need to account for interconnected effects between distributional fairness and procedural fairness, and effects of related and unrelated regulation
    - How fair or unfair interrelations are affecting fair or unfair value distribution
    - How bargaining power is affecting distributional and procedural fairness
    - How related and unrelated regulations are affecting the degree of fairness in value distribution and procedural interrelations
- Gross margin and Lerner index can be used as measures (indicators) for fair value distribution and connected degree of bargaining power

Examples of cognitive maps, agent interaction map and agent behaviour map which are generic for food value chains are shown here from the EURO conference June 2019 in Dublin, as presented by Rossen Kasakov and Sean McGarraghy. In an Appendix to this deliverable are cognitive maps and work in progress on developing maps for the VALUMICS case studies.

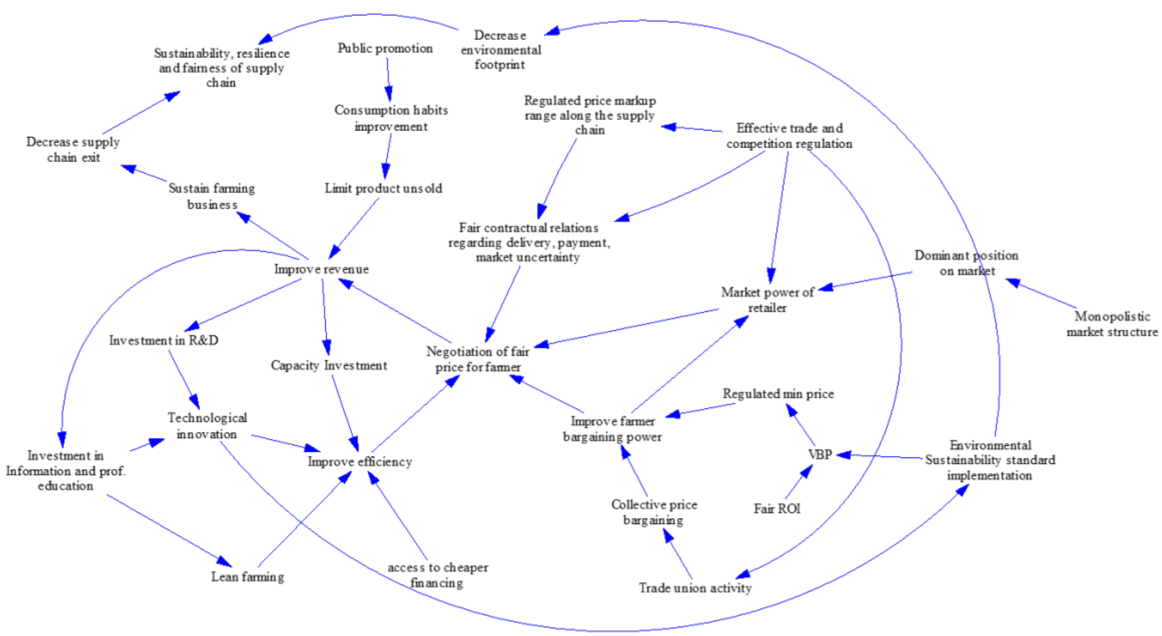


Figure 4 Example of cognitive map for price negotiation of farmer and buyer (retailer) (From: McGarraghy et al., 2019)

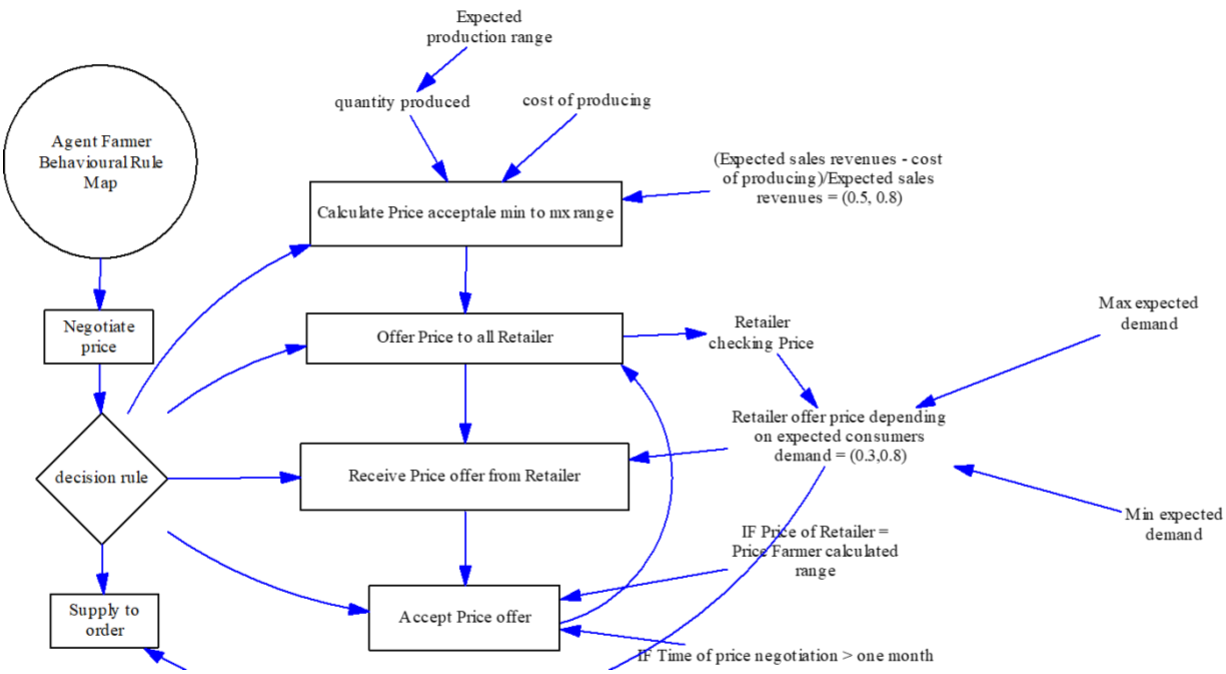


Figure 5 Example of an agent behavioural rule map (From: McGarraghy et al., 2019)

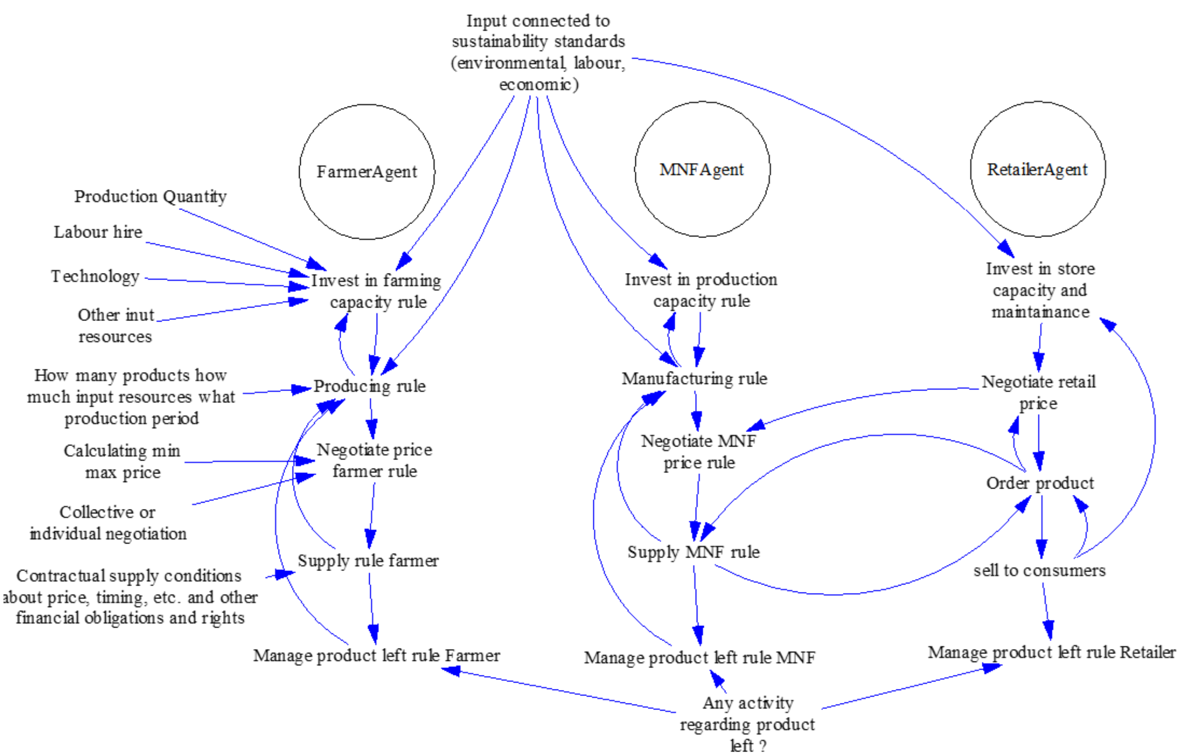


Figure 6 Example of agents interaction map (From: McGarraghy et al., 2019)

AGENT DECISION TABLES

Agent decision tables are tools for collecting and organizing qualitative and quantitative information of the main agent decision routines identified through the cognitive and agent mapping techniques.

Each agent decision routine for each FVC needs to be clearly explained in relation to the following:

- Main goal (decision routine purpose),
- Detailed procedural description of each food value chain agent decision routine,
- Level and timing of the decision,
- Any quantitative parameters associated with the decision routine,
- Main related factors (endogenous and exogenous variables) conditioning the decision routine,
- What if questions (hypothetical changes in the system) that can have effect on agent decision routine.

For each of the case studies the physical and social elements of the food system are listed up. These elements can be agents capable of independent decision making or stocks, flows or controls (the SD elements). The agents, which are the main components of this particular simulation model, are listed up in an agent table (Table 2) and further defined in terms of the properties that define them (agent attributes), the behaviours that cause state changes (decisions) and the interactions resulting from these behaviours (activities). The decisions are further broken down in decision tables (Table 3), with more detailed information about each decision type for the agents in the different food value chain. The decisions of each agent listed in the decision column in Table 2 make up the 1st column in the decision table (Table 3). Here, we use the agents of the generic food supply chain and the decisions of food processor in Table 3. Furthermore, the information requirements are explained in Table 4.

The structure of the model is based on the problem at hand (fairness issue) and the objective of the modelling (test fairness improvement options with different experimental factors based on scenarios). Therefore, the agents that will be part of the model and the agent decisions that are relevant for the modelling are selected based on the problem statement and the modelling objectives.

Table 2 An example of an agent table (generic food supply chain)

Agent group	Attributes	Decisions
Producers	Production capacity, production cost, risk aversion, min margin, number of customers, number of suppliers	Initial investment, capacity planning, raw material sourcing, raw material price negotiation, production planning, store or sell (to who?), internal (own product) price setting, price negotiation
Collectors	Handling capacity, production cost, min margin, number of customers, number of suppliers	Decide on own product price, offer price to a producer, sell to whom?
Cooperatives		
Primary processors	Processing capacity, production cost, min margin, number of customers, number of suppliers	Initial investment, source commodity, process, offer price to seller, process, increase/decrease capacity, supply to market, decide on own product price, accept/decline price offer from customer
Secondary processors	Number of suppliers, number of customers, production cost, min margin, capacity	Offer price to seller decide on own product price
Food service	Number of suppliers, production cost, number of customers, min margin, capacity	Offer price to seller, decide on own product price
Retailers	Retail capacity, min margin, liquidity, cost, number of customers, number of suppliers	Source processed product, offer price to seller, decide on own product price,
Consumers	Socio-demographic, diet preferences, willingness to pay, demand	want to buy product, accept/decline price of product

Table 3 Decision table example processor

Decision	Goal	Description	Decision level	Time	Quantitative parameters	Conditional factors	What-if Qs
Initial investment							
Capacity planning							
Raw material sourcing							
Raw material price negotiation							
Production planning							
Internal (own product) price setting							
Price negotiation							
Sell (to who) or store decision							

Table 4 Information requirements (qualitative and quantitative data in decision tables)

Qualitative data (descriptive)	**Quantitative data**
Categorisation of FVC actors in each tier	By revenues (for example) or size
Agent attributes (agent specific parameters)	Production capacity, number of agents, product quality indicator, other relevant
Agent decision pattern, for example, related to investment, production capacity, price setting, price negotiation, contractual agreement	expected …% profit margin; acceptable price range; acceptable terms and conditions in contract (payment time delay period, amount of further expenses for product waste, marketing promotion, other); Company financial reports
Agent decision pattern related to UTP	UTP conditional parameters (threshold values related to price of rival buyers or suppliers, …% decrease in market share, other)
Conditional factors and threshold variables influencing agents' behavioural pattern	…% increase or decrease in demand, payment delay period, other
What if questions (hypothetical changes, interventions related to agents and agents' environment)	…% change in important variables

SUMMARY OF INFORMATION COLLECTED & WORK PERFORMED ON THE CONCEPTUALISATION

This document further presents information related to the work done on the simulation modelling conceptualisation stage, which outcome is the functional specification, necessary for the next quantitative formulation stage.

As mentioned, the functional specification (what the simulation model will need to do) needs to define answers to the following questions:

- Main focus and problem definition of the simulation model,
- Main agents, agents' attributes and agents' behaviour rules,
- Main agents' interrelations and environmental variables,
- Main resources and resource flows,
- Main parameters and variables, related to modelled agents (attributes, decision rules, conditional factors) and resources,
- Main hypothesis (what if questions for scenario experimentation).

For the above purpose, the following activities have been performed, described in more detail in in an Appendix to this deliverable and further working documents are being iterated to be used in task 7.2 for the technical specifications:

- Cognitive mapping for problem structuring and definition common to all FVC (provide map),
- Cognitive mapping of market functioning related to each FVC (example with wheat),
- Agent interaction mapping for framing key agent interrelations in each FVC (tomato),
- Agent behavioural rule mapping for each FVC,
- Design of agent decision tables specifying and collecting main qualitative and quantitative data requirements,
- Questionnaire for collecting main quantitative and qualitative parameters.

These tables and the maps explained earlier are used to develop the simulation models with input from the case studies in the VALUMICS project. The information needed is gathered through task work in the different WPs, some of which have already been completed and produced relevant information and others where work is ongoing. The tables and maps for each respective case study are developed as part of the work in the individual case studies and the results are presented and stored in working documents. In the **Appendix** to this deliverable is a summary from case studies on the work in progress towards developing the ABM simulation model and linking to ongoing work to further substantiate the overall outcome of VALUMICS.

6. A GENERAL HYBRID SD AND ABM SIMULATION MODELLING ARCHITECTURE

A general hybrid of system dynamics (SD) and agent based (ABM) simulation modelling architecture (prototype conceptualisation) applicable for all FVC is presented in Figure 7.

All main system components relevant to research focus (problem definition and boundary selection) are taken into consideration, including their interrelations (between financial resources and production resources and between agents and agents, and agents and resources).

Main financial and production resources and variables are presented as two interlinked modules on the left side (system dynamics), while relevant ABM components like agents' decisions and agents' parameters are presented on the right side. Agents' parameters generic for all FVC are included in an excel table where all corresponding values need to be found from statistics and financial reports, and included for simulation parametrisation and initialisation.

The idea is to design a simple enough sufficient ABM architecture capable to capture the common for all FVC and agent level and categories system components (in connection to main focus on fair value and fair contractual relations) and their interrelations, and then to adjust and fine tune it to every specific FVC, including exploration of connections to the anticipatory scenarios and transition pathways.

There are three modules for each agent category in each FVC and agent level, related to production inventory (for traditional and ecological production), financial resources balance and agents (attributes and behaviour). Production inventory module is related to the quantities of products planned, supplied and adjusted according to demand (orders), capacity to produce and average rates of utilisation, including time to produce and time to supply to buyer.

Financial resources module is related to the financial balance for each agent, dependent on revenues (connected to product price and quantity bought, time to get payment and public financing) and expenses for production (dependent on variable costs for production, and any additional expenses agreed or coming from unfair trading behaviour).

Production variable costs are connected to monetary values of production input resources, energy needed for production, labour needed for produced quantities and other like production licenses or ecological standardisation taxes or equipment. In order to differentiate between traditional production and ecological production, we need to have monetary values for traditional and ecological input resources, traditional and renewable energy and payment rate per worker including social security and health care taxes.

In order to parameterize the production inventory and financial resources modules, we need to have average or min to max values for product quantities produced every production period (once or more times per year), and euros received and spent per production volume per relevant time period (every month or three months or per year or other).

In relation to agents' module, we need to clearly define agents' attributes (parameters like name and number of agents in each category and values related to main variables in production and financial resource modules), and agent decision routines controlling (managing) variables from the above modules.

All the above variables and agent decisions are taken as endogenous to the modelled system and will produce the emergent behaviour of the whole system. Other variables (factors) like stock exchange prices, global supply and demand, macroeconomic indicators relevant, market regulation are exogenous to the modelled system and we need to know their influence on the system components (on agent decisions related to price setting and negotiation, UTP, production quantities etc.).

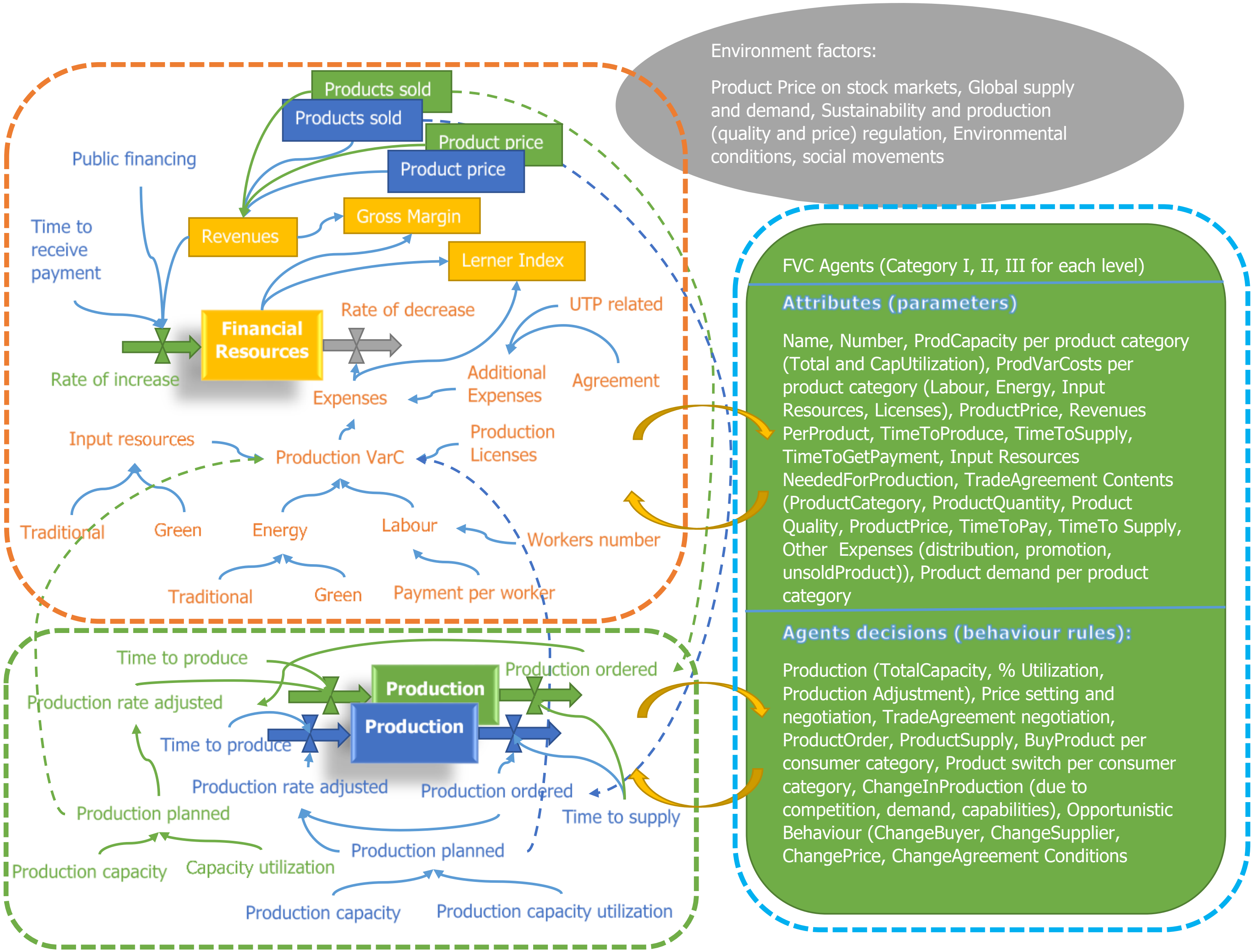


Figure 7 A hybrid of SD and ABM simulation modelling conceptualisation

7. DATA REQUIREMENTS

Table 5 shows agent parameters for which the model will require values in time for D7.2. Here, a "green" producer should be thought of as a producer using an alternative or non-traditional production approach (for example, organic, bio, eco). Units need to be defined.

Table 5 FVC agent parameters (to be adapted to each case study)

Agent parameters (for each FVC)	Small	Medium	Large
Number (Traditional producers)			
Number (Green producers)			
Production capacity (traditional product)			
Production capacity (green product)			
Avg % capacity utilisation (traditional product)			
Avg % capacity utilisation (green product)			
Production expenses for traditional product (Total)			
Production expenses for green product (Total)			
Input resources for traditional product in Total (feed, seeds, water, chemicals, etc.)			
Input resources for green product in Total (feed, seeds, water, chemicals, etc)			
License for traditional product			
License for green product			
Labour (Total)			
Workers number			
Workers pay (per worker)			
Energy product (Total)			
Energy traditional production			
Energy green production			
Price traditional product			
Price green product			
Price of product premium quality			
Price discounted quality			
Revenues (Total)			
Revenues green product			
Revenues traditional product			
Time to produce traditional product			
Time to produce green product			
Time to get payment from buyer			
Time to supply product to buyer			
Production quantity traded (avg) per traditional product			
Production quantity traded (avg) per green product			
Other expenses in agreement (as avg % of sales revenues)			
UTP related expenses (as avg % of sales revenues)			
Avg demand for traditional product			
Avg demand for green product			

Public financing			
Market share goal (as a % of total market share)			
Profit margin goal (%)			

For the purpose of data requirement and scenario experimentation the understanding of , "input", "content", and "output" terminology is useful to complement the simulation modelling architecture as illustrated in Figure 7. Table 6 presents information related to main variables and agent decision routines for variation and scenario generation, relevant for each FVC (input), main system components which behaviour will be simulated (content), and key variables which are related to the main research questions and need to have their behaviour observed (output). The information related to Table 6 need to be defined together with WP8 team working on scenarios and will be connected to the main what if questions, hypothetical interventions and transition pathways

Table 6 "Input, Content, Output" Framework

FVC	Input Experimental factors What-if	Content Components of the model	Output
	Explanation of main variables and decision routines, selected for variation	Explanation of agents and resources for each FVC	Selected variables which behaviour to observe (related to main research questions), like production level, revenues, gross margin, Lerner index, price, energy, workers, UTP
Tomato			
Wheat			
Dairy			
Salmon			

8. DISCUSSION & CONCLUSION

Main insights from the ABM conceptualisation (cognitive and agent maps) are:

- All FVC which will be simulated have common features in relation to the ABM focus on distributive and procedural fairness
- These common features relate to key factors like reference price, which influence trading prices and price negotiation, production seasonality and production inventory planning and adjustment according to orders and demand, financial resources management connected to sales revenues, public financing and product variable costs including additional costs related to unfair trading practices
- Also there are common macroeconomic factors that affect commodities prices like global supply and demand, energy prices, trade tariffs and quotas

The above common factors give opportunity for designing a generic ABM production inventory and financial resource and resource flow structure, which components can be modelled from the perspective of system dynamics, while main actors' decision and actions related to managing these resources will be modelled from agent based modelling and simulation perspective. This approach will allow for the hybridisation of the two simulation perspectives with the main application of ABM due to its technical capability to capture the behaviour of large number of agents in complex adaptive systems like food value chains, having hundreds of actors on each different level along a food value chain.

Main agent decisions and decision heuristics related to the management of product inventory and financial resource flows are also common to all food value chains. However, there are differences in connection to market competition structure and regulation in every FVC, and in connection to timing of production, supply and demand, including differences in consumption patterns, which will need to be reflected in actors' decisions.

Key aspects of quantitative metrics for distributive fairness:

When examining quantitative metrics for distributive fairness we take into account the importance of price, for agents in the FVC in their effort to maximize their profit or utility. Furthermore, the influence of market power with respect to creating opportunities for misuse of power in the form of UTPs, is considered to be of relevance. Price movements threatening the margin of firms being able to exert market power are transmitted faster than price movements that improve it (Falkowski et al., 2017). Given this, the VALUMICS project will integrate quantitative economic indicators into its ABM to gain enhanced understanding of distributive fairness in the aquaculture and agricultural FVCs. First, the gross profit margin obtained by the various actors across the FVCs will be assessed. Second, the degree of market power will be investigated by using the Lerner Index, which provides an estimate of market power in an industry, measuring the price-cost margin through the difference between the output price of a firm and the marginal cost divided by the output price (Elzinga & Mills, 2011). The aim will not be to determine an absolute measure of fairness using these indicators, but rather to ascertain transitions towards fairer outcomes. This approach is in keeping with the European Parliament's depiction, which, rather than providing a strict value measure of UTPs, emphasises the presence of gross deviations away from good commercial conduct.

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ANNEX I MARK-UP MODEL

FIRM OPTIMISATION

The optimisation problem for the output market is analogous to the input market. In this case, the profit function of processor (i) is given by:

(1) $\pi_i = p \cdot y_i - C(\mathbf{w}, y_i, t)$

where p is a price of output, y_i is the output of processor (i), **w** is a vector of input prices, and C(w,y_i,t) is a cost function of processor (i) and time trend (t) for capturing technical change.

The demand or inverse demand function, respectively, is:

(2) $y = f(p, \mathbf{d})$ or $p = f^{-1}(y, \mathbf{d})$

where **d** is a vector of demand shifters and y is the total demand for food.

Given (1) and (2), the first-order condition for profit maximisation is:

(3) $$\frac{\partial f^{-1}(y, \mathbf{d})}{\partial y} \cdot \frac{\partial y}{\partial y_i} \cdot y_i + p - \frac{\partial C(\mathbf{w}, y_i, t)}{\partial y_i} = 0$$

Relation (3) can be rearranged as:

(4) $$p \cdot \left(1 + \frac{\Omega}{\varepsilon_p}\right) = \frac{\partial C(\mathbf{w}, y_i, t)}{\partial y_i} \quad ,$$

where $\varepsilon_p = \frac{\partial y}{\partial f^{-1}(y, \mathbf{d})} \cdot \frac{p}{y} < 0$ is a demand elasticity of the final product and $\Omega = \frac{\partial y}{\partial y_i} \cdot \frac{y_i}{y}$ is a conjectural elasticity capturing the degree of oligopolistic market power. The parameter is in the interval $\Omega \in [0;1]$. $\Omega = 0$ indicates competitive behaviour and $\Omega = 1$ characterizes monopolistic power. That is, a positive value of $\Omega \in (0;1)$ indicates the presence of non-competitive behaviour in the output market. In particular, the higher is Ω, the greater is the degree of oligopolistic market power, or the degree of non-competitive behaviour in general.

It follows from (4) that:

$$p \geq \frac{\partial C(\mathbf{w}, y_i, t)}{\partial y_i} \quad \text{for} \quad \Omega \in [0;1].$$

This relation can be expressed as:

(5) $$\frac{p \cdot y}{C} \geq \frac{\partial C(\mathbf{w}, y_i, t)}{\partial y_i} \cdot \frac{y}{C} = \frac{\partial \ln C}{\partial \ln y} = \frac{\partial \ln D^I}{\partial \ln y} \quad ,$$

where the last equality comes from the duality of the cost (C) and input distance (D^I) functions.

ESTIMATION AND IDENTIFICATION OF THE MARK-UP

Inequality in (5) can be transformed into equality by adding a non-negative one-sided term, u:

(6) $$\frac{p \cdot y}{C} = \frac{\partial \ln D^I}{\partial \ln y} + u \ , \quad u \geq 0 .$$

Assuming that the input distance function has a translog form:

(7) $$\ln D^I = \alpha_0 + \alpha_t t + \frac{1}{2}\alpha_{tt} t^2 + \alpha_y \ln y + \alpha_{yt} \ln yt + \frac{1}{2}\alpha_{yy} (\ln y)^2 + \boldsymbol{\alpha}_x{}' \ln \tilde{\mathbf{x}} + \boldsymbol{\alpha}_{xt}{}' \ln \tilde{\mathbf{x}} t + \frac{1}{2} \ln \tilde{\mathbf{x}}' \mathbf{A}_{xx} \ln \tilde{\mathbf{x}} + \ln \tilde{\mathbf{x}}' \mathbf{A}_{xy} \ln y$$

where $\tilde{x}_j = x_j / x_J$ for j = 1,…,J.

Then

$$\frac{\partial \ln D^I}{\partial \ln y} = \alpha_y + \alpha_{yt} t + \alpha_{yy} \ln y + \boldsymbol{\alpha}_{xy}{}' \ln \tilde{\mathbf{x}} + u + v \quad .$$

Consequently, it follows from (6) and (7) that the function to be estimated has the form:

(8) $$\frac{p \cdot y}{C} = \alpha_y + \alpha_{yt} t + \alpha_{yy} \ln y + \boldsymbol{\alpha}_{xy}{}' \ln \tilde{\mathbf{x}} + u + v \quad .$$

Since we define the relative mark-up as:

(9) $$\varphi = \frac{p - MC}{MC} \quad .$$

It can be estimated via:

(10) $$\varphi = \frac{u}{\partial \ln D^I / \partial \ln y}$$

That is,

(10´) $$\hat{\varphi} = \frac{\hat{u}}{\alpha_y + \alpha_{yt} t + \alpha_{yy} \ln y + \boldsymbol{\alpha}_{yx}{}' \ln \mathbf{x}} \quad .$$

Finally, the Lerner index can be easily calculated from relative mark-up as:

(11) $$L = \frac{\varphi}{1+\varphi} \quad .$$

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