Modeling of integrated supply-, value- and decision chains within food systems

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Introduction

This paper presents a work in progress with the objective of constructing a mental model of food systems in the form of a causal loop diagram (CLD). The idea behind the current modelling effort is that a generic food system, composed of primary production, processing, retailing and consumption, can be thought of as an integration of supply-, value- and decision chains. Traditionally food systems have been modelled as supply chains but here, in an effort to capture their complex nature as chains of profit driven businesses that have a major impact on their social and natural environment, the system model will be extended to include economic factors. The downstream flow of goods in a supply chain, by way of business transactions between individual agents, results in an upstream flow of money from consumers to suppliers. Decisions about the extent of operating activity for every agent in a chain of businesses are generally made on the basis of profitability. Thus, the downstream flow of goods and the upstream flow of money are interlinked by decision chains. In order to understand how these flows interact, we analyze the feedback structure of a simple supply system specifically focusing on its profit driven nature and the regulating effect of market dynamics.

This research effort forms a part of VALUMICS, the ongoing Horizon 2020 EU funded project on food supply networks. In line with the project objectives, the aim is to further use the integrated mental model resulting from this research as a foundation for a simulation model that can be used to identify policy intervention opportunities, specifically focusing on the resilience, integrity and sustainability of food supply networks.

Methods

The focus of this paper is on the initial system analysis part of an ongoing research effort which leads to the construction of a causal loop diagram (CLD) of a food system. The system conceptualization is induced through system analysis and the resulting dynamic hypothesis will subsequently be used to recreate the dynamics of the system using system dynamics modeling.

Earlier work

Food systems have traditionally been conceived of as supply chains, or series of activities involved in bringing food products from primary production, through processing and distribution, to the final consumer. The complexity of many modern supply systems, including food systems, constitutes, not a chain structure but rather a network structure. In order to model the dynamic relationships of supply-, value- and decision chains we must introduce market dynamics. The laws of supply and demand are fundamental microeconomic theory and have previously been incorporated into models of supply systems (Conrad, 2004; Meadows, 1971). In the current research we draw on earlier work on supply chain modeling using system dynamics, with a specific focus on those that incorporate market dynamics and decision linkage between physical and monetary flows. System dynamic models of supply chains, for food and other products, have mostly been restricted to a simple physical flow of products and information in the form of orders either within a single company or between few companies in a simple supply chain. 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.

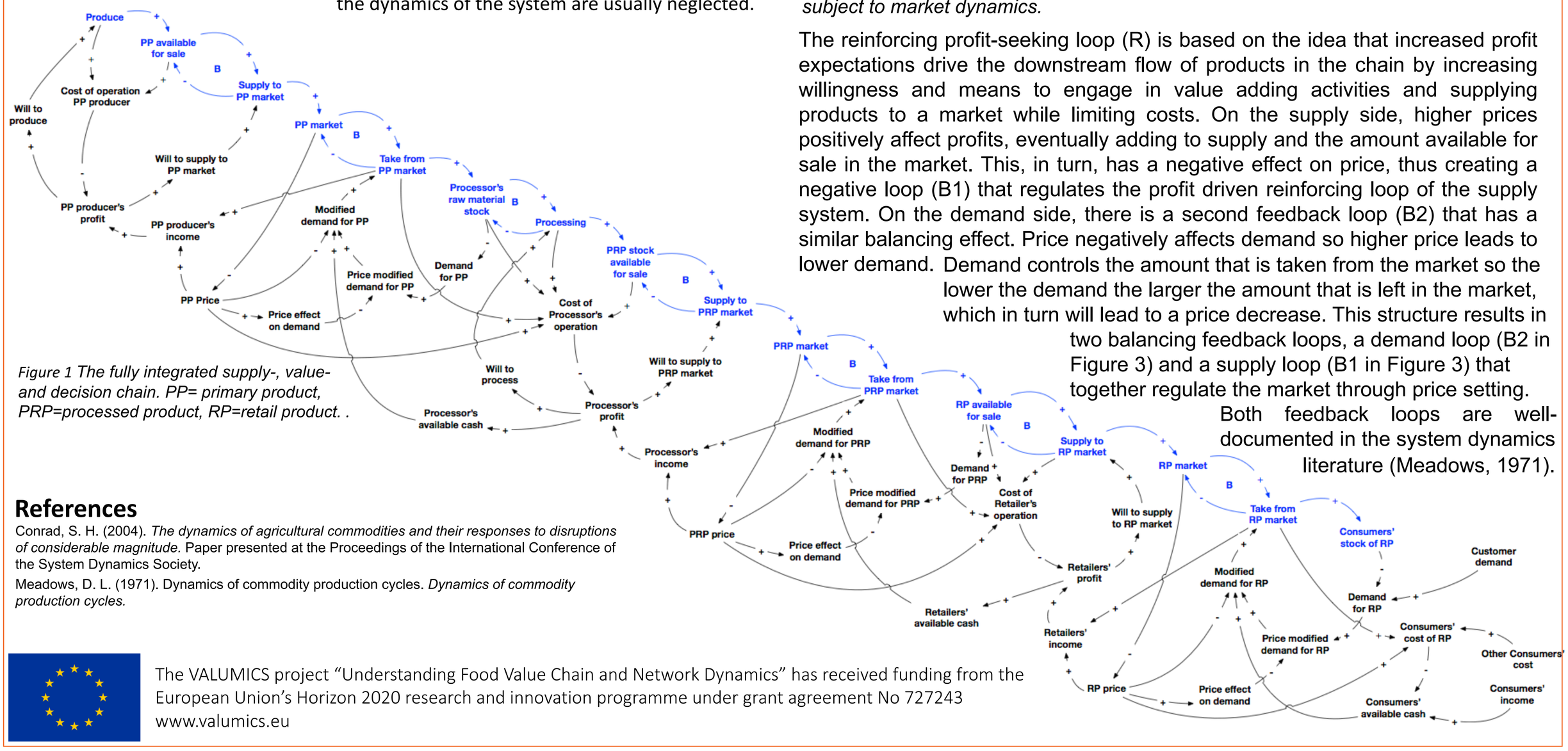

Figure 1 The fully integrated supply-, value- and decision chain. PP= primary product, PRP=processed product, RP=retail product. .

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The model is developed in layers (Figure 1). The core layer is the physical product flow. Additional layers are attached to this core layer to introduce market- and price mechanisms that influence decision making. Physical products flow through the system from the primary producers to final consumers. Individual agents are only present in the model as parts of aggregated groups. Products flow between agents by way of business transactions. These transactions take place on the micro level but are subject to market dynamics that take place on a larger scale where multiple agents trade in a market. To incorporate these transactions on the aggregated industry level we introduce markets between agent groups (Figure 2).

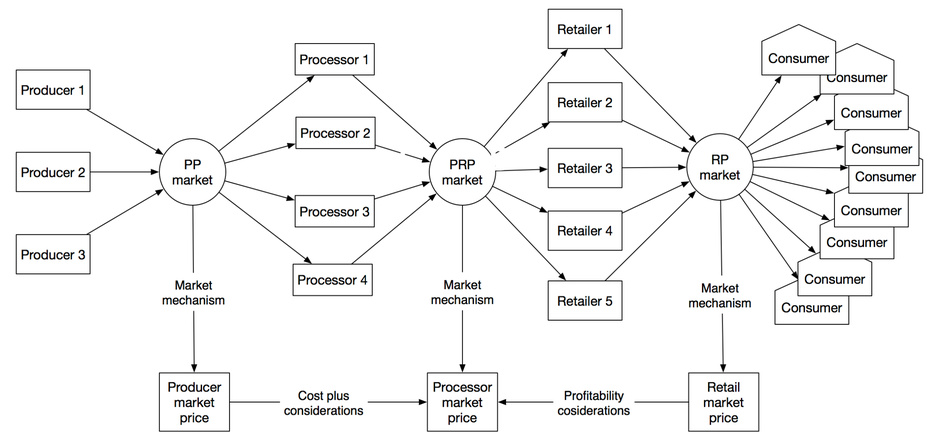

Figure 2 A simplified illustration of the supply chain on an aggregated level with markets between agent groups. The price generated on the macro level is the reference price in micro level business transactions. PP= primary product, PRP=processed product, RP=retail product.

The downstream physical flow of products is associated with an upstream flow of money. Money flows between agent groups in the form of costs and revenues. Revenues increase profit while costs decrease profit. The flows of products and money are controlled by decisions made by agents in their effort to reach their objectives. We presume that the businesses in the supply chain and thereby the supply chain itself are profit driven. This means that decisions are mainly based on expected profit. Figure 3 shows a simplified model of the main drivers of the integrated supply system. The feedback structure presented in this simplified model is repeated for every supplier/customer relationship in the supply system. It features a reinforcing profit-seeking loop (R) and several balancing feedback loops, two of which (B1 and B2) regulate the market through price setting.

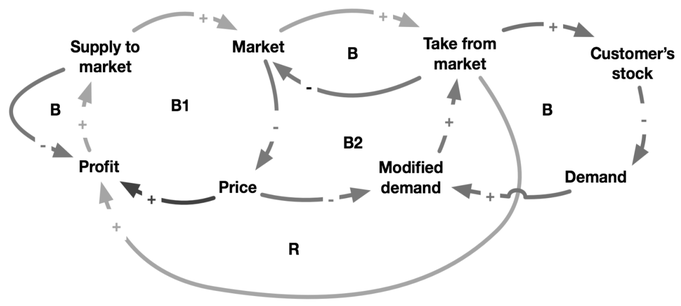

Figure 3 The reinforcing and balancing loops driving and regulating a supply system subject to market dynamics.

The reinforcing profit-seeking loop (R) is based on the idea that increased profit expectations drive the downstream flow of products in the chain by increasing willingness and means to engage in value adding activities and supplying products to a market while limiting costs. On the supply side, higher prices positively affect profits, eventually adding to supply and the amount available for sale in the market. This, in turn, has a negative effect on price, thus creating a negative loop (B1) that regulates the profit driven reinforcing loop of the supply system. On the demand side, there is a second feedback loop (B2) that has a similar balancing effect. Price negatively affects demand so higher price leads to lower demand. Demand controls the amount that is taken from the market so the lower the demand the larger the amount that is left in the market, which in turn will lead to a price decrease. This structure results in two balancing feedback loops, a demand loop (B2 in Figure 3) and a supply loop (B1 in Figure 3) that together regulate the market through price setting.

Both feedback loops are well-documented in the system dynamics literature (Meadows, 1971).

References

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Meadows, D. L. (1971). Dynamics of commodity production cycles. *Dynamics of commodity production cycles.*

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