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INTERNATIONAL JOURNAL ON FOOD

Int. J. Food System Dynamics 10 (2), 2019, 224-247

DOI: https://dx.doi.org/10.18461/ijfsd.v10i2.14

Defining a Conceptual Model for Market Mechanisms in Food Supply Chains, and Parameterizing Price Functions for Coffee, Wheat, Corn, Soybeans and Beef.

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Received January 2019, accepted March 2019, available online April 2019

ABSTRACT

The contribution of the study presented in this paper is twofold. Firstly, to add to the present body of knowledge of food supply and demand model dynamics and the associated economics, based on system analysis. It describes a new approach for dealing with price mechanisms in models based on causal links and dynamic feedbacks. It has been applied to some main global food commodities, but has also been used for metals and materials in a parallel study. The price mechanism is described in a way to be useful for other modelers dealing with price mechanism, and it enables modelers to make dynamic price endogenous in models. Secondly, it presents price function curves for different food commodities, parameterizing a fundamental property of the commodity trade.

Keywords: market price; market; supply chain modelling; grain; beef; system dynamics.

1 Introduction

At the present, humans know more than ever before and as a result, we live in a more stable world. Humans have not necessarily become smarter, it's rather the fact that over time cumulative knowledge have accrued and models (mental motels and other machine-implemented models) have been formed based on events that took place and fundamental knowledge of what shaped the events that occurred. Of all resources on the globe, food is the single most important for human society. Without food, everything else is redundant, regardless of what it is. Therefore, it is valuable, to model the global food supply at different scales and contexts.

Models allow us to simplify and understand more complex systems and concepts and are useful tools for forecasting. One of the most well-known-model involves supply and demand for a commodity (food in this case). If there is less available to be sold demand goes up, and price as well. If there is too much available the demand (and price) goes down. This known supply and demand model, like all models, is a simplification of the reality. Even so it is instructive and can teach us things about market mechanics (Wagonfoot, 2018).

The literature for economic modelling lacks dynamic simulation of market prices and the underlying base of physical flow of resources, goods, services and people. In traditional economic models, only monetized value (money) is kept track of, often missing a larger part of the value flows in society. The creation of an economic model that takes these aspects into account requires some new thinking in terms of model metrics and selection of parameters and understanding of fundamental causalities (H. Sverdrup and Olafsdottir, 2019). The need for this type of model approach has been pointed out, and was partly realized by Keen, Minsky and Victor (Keen, 2011; Minsky, 1982, 1986; Victor, 2015). However, none of them, started with the physical flow of goods, materials or the actual provision of services. Those physical flows are the actual basis for creating the values that flow as money in their models.

This paper presents an "add-on" to the before known generic behavior of supply and demand that has to do with the role of profit, and price, for the demand and supply curves for food commodities. The paper attempts to explore this new dynamic way to deal with price mechanism in models and presents price curves with prediction capabilities for some food commodities that can be of value for those willing to do further modeling for these commodities. This method has been established and validated for metals in the WORLD6 model. The WORLD6 model is a comprehensive integrated system dynamics model for global industrial dynamics, resource extraction and distribution dynamics, population dynamics, energy system and global economics (Sverdrup, Olafsdottir, Ragnarsdottir, and Koca, 2017) and the WORLD6 economic module has been described in more aspects by Sverdrup and Olafsdottir (Sverdrup and Olafsdottir, 2019). These price curves that are presented in the paper indicate that the method is valid for food commodities in addition to metals. Therefore, they are believed to be a valid foundation for the price modeling aspect for the food supply chains in the WORLD6 model.

Each model is a simplified version of some aspect of reality people want to learn more about (Wagonfoot, 2018). The work presented in this paper seeks to add input to the former market models available. The main contribution is therefore the gained understanding of the dynamics of food supply systems and the associated economics, in addition to the price function curves for grain, corn, soybeans, rice and beef. This work is a stepping stone towards further modelling involving integrity and sustainability of food supply and value chains.

The rest of the paper is organized as follows: first a brief overview of the objectives followed by a description of the methods used. Then a short overview of the theory behind the work is presented followed by a chapter about the data sources and estimations (data tables are presented in appendix). Next the resulting price curves for, coffee, wheat, corn, soybeans and beef is presented, with discussions and conclusions.

2 Objectives and scope

The objective is to be able to understand the dynamics of food supply systems and the associated economics and to add to the present body of knowledge of supply and demand models. To analyse the fundamental aspects needed, in order to be able to model prices endogenously in models with market and supply chain dynamics. The work presented will be used in an integrated model of food supply chains, the associated value chains and the coupled decisions on a global, regional and business-to-business scales. The aim is to develop this from a conceptualized level, covering the fundamental mechanisms involved. This is used to develop a generic price mechanism model that will work over longer periods (1850-2015).

3 Theory

Supply and demand is known to be one of the fundamental concepts of economics and it plays a big role in the market economy. The law of supply and demand is an economic theory that was popularized by Adam Smith in 1759 and again in 1776 (Norman, 2018). The demand function usually presented in current models refers to the quantity of a product that is desired by the buyers. Note that the quantity demanded is the quantity of a product people are willing to buy for a certain price. If the price gets above that price the demand function changes. The relationship between the price and the quantity demanded is known as the demand relationship. Supply represents how much exists in the market. The quantity supplied to the market is based on the willingness of the producers to supply to the market at a certain price. The price, is a reflection, of both the supply and the demand. The correlation between price and the quantity in the market is known as the supply relationship price. In market economy theories, supply and demand theory will allocate resources in the most efficient way possible (Hayes, 2018), assuming a prior all operating agents to be fully conscientious and rational.

There are four different price mechanisms usually used in human markets. These are: (1) **Dynamic market mechanisms** with arbitration over a market table, and relatively equal transparency and availability of information. Normally, this leads to a freely set price in arbitration between supply and demand, clearing the table when supply and demand match. A free market mechanism requires proper surveillance, clearly stated rules and execution of governance (Forlani and Parthasarathy, 2003). (2) **Localized cost-plus-pricing** systems (Forlani and Parthasarathy, 2003). Some markets operate between companies in business-to-business supply chains. The reference price is taken from the regional or global market, and different types of margins are added or subtracted in competition locally, but without real feedback to the regional level. This model is often occurring in business-to-business supply chains. This can be observed to occur between very large firms and their very small sub-suppliers. One example is the gold market where the gold metal price from the London Metal Exchange is the reference price, and prices up and down the manufacturing chain related to this in a systemic way (LBMA, 2018; Sverdrup, Koca, and Ragnarsdóttir, 2012). (3) **Oligopoly market**, (Kenton, 2018) where the price setting in dominated by one or a small group of agents (oligopoles) that dominate in the supply and demand arbitration (Kenton, 2018). This often end up as a "cost plus" model for setting prices. (4) **Command and control markets** (Pearson, 2000), those are sometimes set by governments in a range of situations: (a) Where no market arbitration is not really possible, (b) during times of emergency like under disaster conditions or in wartimes. During times of dictatorship, where there is no intelligent feedback on decisions made, and where power eventually corrupts the powerholder beyond recognitions towards a monster (Fukumyama, 2011). Such systems quickly develop lack of providers, dysfunctional marketplaces and poorly compatible agents. The system normally has severe malfunctions with breakdowns to failure of provision.

3.1 Earlier price modelling

There are two main approaches to price modelling in modern economics simulations:

1. A freely invented time-series of years and prices are fed to the model. This is the most common approach.
2. Equilibrium modelling, using demand versus price and supply versus price lines.

The time-series are sometimes extrapolations of past trajectories, sometimes they are freely invented time-series, with no or limited real foundation. Figure 1 presents a classical representation of how textbooks describe market mechanism and in Figure 2 a causal loop diagrams of the dynamics behind the graphs in Figure 1 is presented.

When supply decreases, the price increase. When demand decreases, the price decreases, when demand increases the price increases. This is used to find the point where the demand lines cross with the supply lines, the equilibrium price point (Figure 1). There are several issues with this. Firstly, businesses operate on profits and not on price. Even if sales are from stocks, still it is driven by profit. Secondly, the feedback curves do not necessarily have these shapes when checked against data. It is difficult to find any supply to price or demand to price relationship in the scientific literature anywhere. Some are available in market blogs and commercial commentaries, but then there is no description of how they were determined. Describing price mechanisms like shown in Figure 1 and Figure 2 does not lead to price predictive capabilities and the price histories cannot be reconstructed. Earlier price modelling cannot be said to have successful, and accordingly, the prevailing practice is to give the standard economic model a premade price over time time-series as input. Where that time series used for model input originally came from is mostly rather unclear and unsubstantiated (Alexandrova and Northcott, 2013).

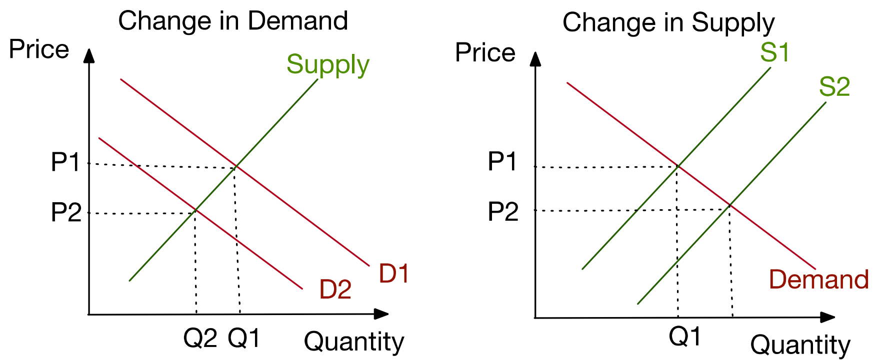


Figure 1. The graphs show how economics textbooks describe how market mechanisms work. When supply decreases, the price increases, when demand decreases, the price decreases, and when demand increases the price increases. This is used to find the point where the curves cross, the equilibrium point; graphs based on Dilts (Dilts, 2004).

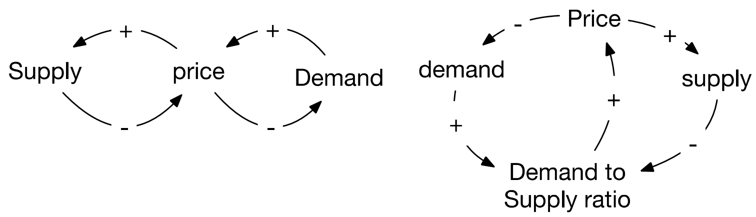


Figure 2. Causal loop diagram representation of the dynamics behind the graphs in Figure 2.

4 Methods

4.1 Modeling method

The standard methods of systems analysis (Albin, 1997; Kim, 1992; Senge, 1990; Senge, Smith, Schley, Laur, and Kruschwitz, 2008; Haraldsson, Olafsdottir, Belyazid, and Svensson, 2018) and systems dynamics was used to do the modelling (Haraldsson and Sverdrup, 2005; Olafsdottir et al., 2018; Sterman, 2000). The system analyses is based on flow charts with box-arrow symbols and causal loop diagrams defining the causal effects and feedbacks in the system. These conceptual diagrams are translated into a simulation format and numerically solved using the STELLA® program. The simulation models are tested against our information available, including quantitative state data or qualitative experiences. To validate model output, the output is compared to historical data. When the model is able to reconstruct observed past (1850-2015) patterns adequately, it is assumed that it is good enough to be used to simulate possible futures (2015-2250).

4.2 Data handling

Data collection occurs simultaneously with the construction of the model, and the system analysis clarifies what kind of data that is needed. The data needed is divided into several different categories: (1) system boundary and initial conditions, (2) system structure data, (3) system parameters settings, and (4) variables describing system states (Sverdrup et al., 2018).

For the system structure data (2), the data is mostly based on gathering information to connect variables based on causation and feedback loops, i.e. to correctly represent the dependency between two variables. The process of this causal mapping in relation to data handling goes back and forth throughout the whole modelling process. The initial conditions (1) and the system parameter settings (3) are used to parameterize the model before the simulations starts. The state variables (4) are not used for model initialization or calibration, but saved and used for evaluation of model performance.

The parameter setting (3) includes the price curves for the food commodities. In order to generate them, data requires an estimate of the reserves and resources for the food commodities presented. The estimates are based on data from different markets (Droke, 2014; Graedel and Allenby, 2003; ICO, 2015; Luke, 2017; Macrotrends, 2018; MLA, 2014; OpenStax, 2017; Roser and Ritchie, 2018; Semmelroth, 2015; Sterlite Industries. 2008/9; USDA, 2014, 2015, 2018) most are derived from commercial information channels. Few of the data sources can be considered as permanent as no data was found in the scientific literature

The parameters and information from categories 1-3 are only varied within the margin of error when the model is initialized. A major feature of the system analysis and system dynamics methodology is to map how well the embedded understanding actually reproduces the observed development in systems states, and where the actual deviation brings an important message. It is not the objective through extensive calibration of parameters to get a maximum likeness to the system output.

5 Conceptual market and supply chain model

Figure 3 shows how in a supply chain with many actors in every step, adaptive market mechanisms are at work. It should be noted that a market is nothing more or less than the locus of exchange, and therefore it is not necessarily a place, where buyers and sellers come together for transactions (Dilts, 2004). Then a price will be set in the system of many suppliers and many buyers in an arbitration process known as market demand.

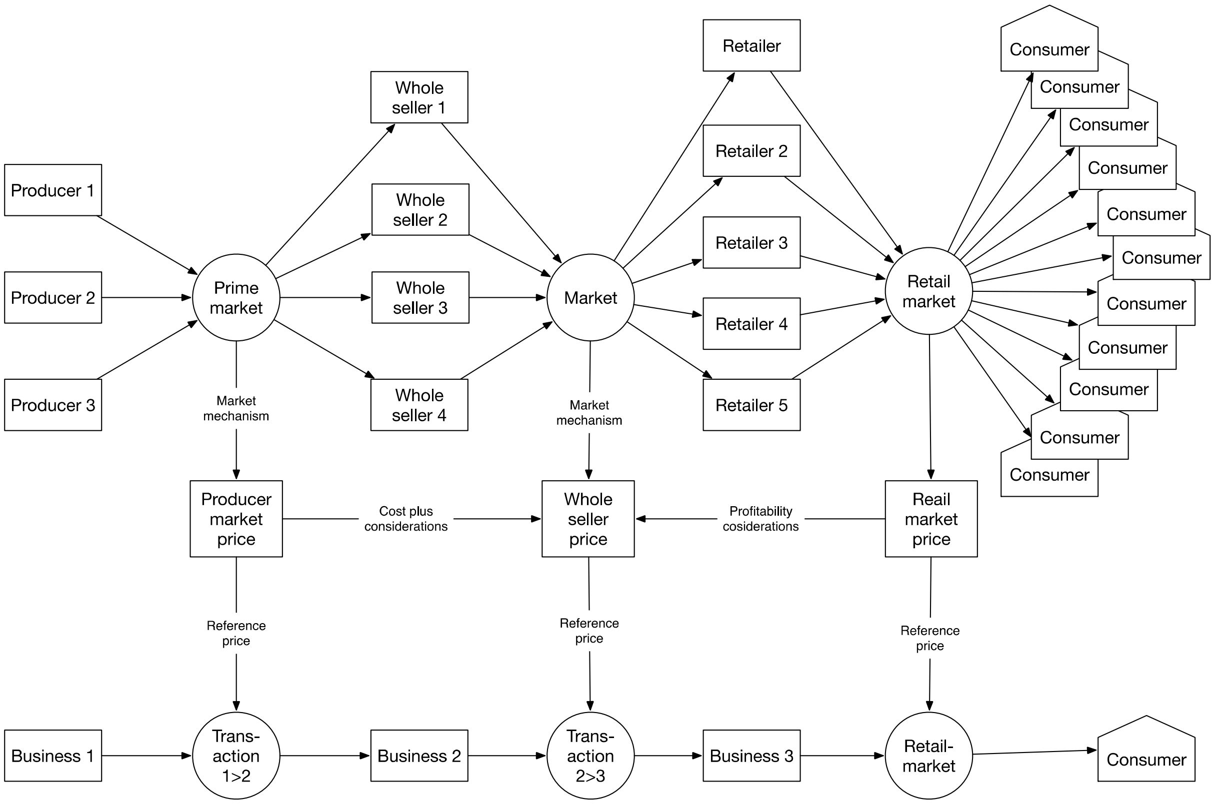


Figure 3. A flow chart of a product in a supply chain with many actors in every stage where adaptive market mechanisms are at work. A market price will be set in the system with many suppliers and many buyers in an arbitration process. In a lower systemic level view with business-to-business supply chains, the price is taken as a reference from the regional level with many-actors involved. The picture shows a single regional linear supply chain.

A market demand curve is simply an aggregation of all individual demand curves for a particular commodity (Dilts, 2004). On a lower level business-to-business supply chain, the price is taken as a reference from the regional level with many actors involved.

Figure 4 shows how the market mechanism is presented in the model. The market model applied in the WORLD6 models is a free market model. Describing prices like this has proved to lead to price predictive capabilities and the price histories can be reconstructed and in that sense allows the validation of the presented causal links (Sverdrup, Koca, and Ragnarsdottir, 2013; Sverdrup, Koca, and Ragnarsdottir, 2014; Sverdrup, Koca, and Ragnarsdottir, 2015; Sverdrup, Koca, and Ragnarsdottir, 2017; Sverdrup, Koca, and Schlyter, 2017; Sverdrup, Olafsdottir, and Ragnarsdottir, 2017; Sverdrup and Ragnarsdottir, 2014, 2016a, 2016b; Sverdrup, Ragnarsdottir, and Koca, 2014; Sverdrup, Olafsdottir, Ragnarsdottir, and Koca, 2017; Sverdrup et al., 2012; Sverdrup and Olafsdottir, 2018; Sverdrup, Olafsdottir, Ragnarsdottir, and Koca, 2018). Supply is here defined as "the quantity being supplied to the market"; this is an action representing a flow of commodity per time unit. "Market" is the quantity on the market table, the quantity being available and ready for immediate transaction. "Demand" is defined as the delivery of commodity wanted from the market, before any restrictions are considered. "Modified demand" is the demand after the delivery price has been considered. "Delivery" is what actually can be delivered. Under regular circumstances, "delivery" and "modified demand" are the same. "Delivery" is an action that moves the commodity from the market to society. The relationship between "profits" and "supply" to the market is shown in graph 1 in Figure 4. The effect of "price" on "demand" in order to make "modified demand" is shown in graph 2 in Figure 4. The relationship between the market quantity and price is shown in graph 3 in Figure 4. The relationship between disposable income and demand is shown by graph 4 in Figure 4.

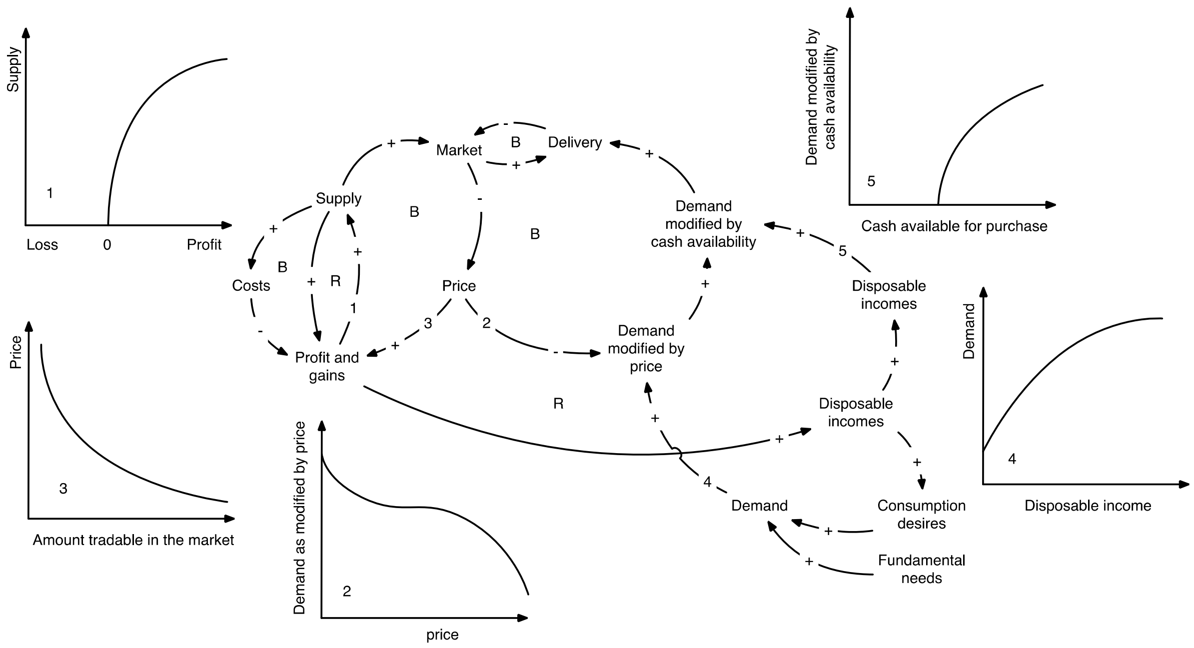


Figure 4. The market model applied in WORLD6 models. B is balancing loops, balancing the reinforcing loops (R) and slowing them down.

In Figure 5, a causal loop diagram of some of the main loops in in the supply chain modelling is presented on a generic base. The model includes a capacity loop, production loop, a profit loop, investment loop, supply loop and consumption loop. The main driver in this system is the profit.

The causal loop diagrams in Figure 4 and Figure 5, show how production rate is driven by demand from society, and promoted by commodity price and production profit to generate supply to the market. This part of the model generates market prices inside the model and eliminate the need for externally supplying guessed price curves. The price is determined by how much commodity is available in the market. A high commodity price will stimulate the production rate and increase supply to the market, and limit demand. But more supply to the market will increase the quantity of commodity available and may potentially lower the price. The profit is affected by the production cost and how that is modified with raw materials. Profits are transferred to income from supply when the quantity is supplied and paid at once into the commodity exchange warehouse. The price is strongly correlated to the market quantities.

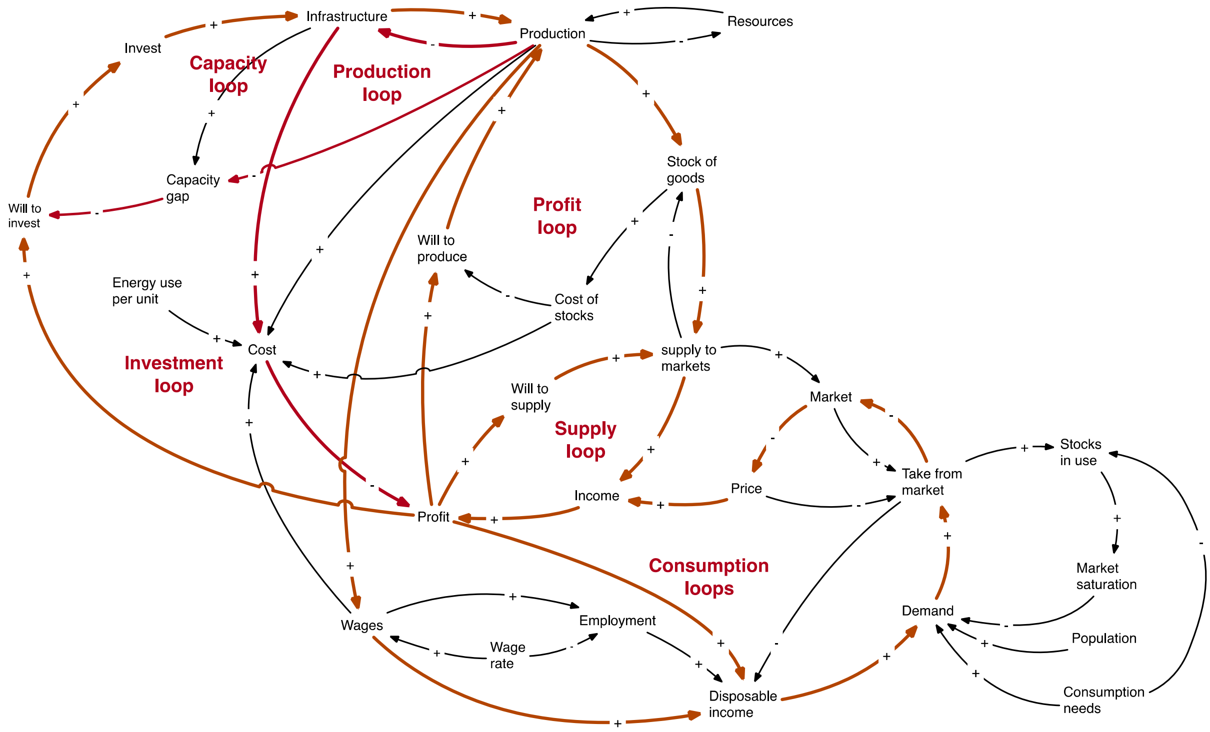


Figure 5. The causal loop diagram showing the market mechanisms and their effect on production, supply, demand and actual delivery from the market.

5.1 Conceptual model for grain

A simple grain supply model based on the generic causal loop diagram (CLD) in Figure 4 and Figure 5 is demonstrated in figures 6 and 7. Figure 6 presents the flow chart for a dry, storable food commodity and figure 7 the CLD for the worlds grain market. The model consists of 4 stocks: grain in field, that is harvested and pulsed (supply variable) to the market stock every half year (Northern and southern hemisphere). From the market, the grain is either put into storage in granaries or sold to consumers. At consumers, it is lost through consumption.

What is left in the granary at years end is “ending stocks”. The quantity in the market is “market quantity”. It is apparent that the ending stocks are only indirectly related to price. In this simplest version, the producer stock is omitted. Ending stocks at the end of each year tend to be in the range of 200 million tons, while the world’s consumption of cereals is about 700 million per year (CBOT, 2018). The grain is harvested at the end of the season and passes via markets into different types of granaries. In the last centuries these were largely state administrated. Today they are to a large extent privatized In Europe and America while elsewhere in the world the state system persists. For some countries, the state organizes that harvests to be delivered mainly straight to state granaries at fixed prices.

From the granaries, the grain is portioned out to the market over the year, based on policy, prices and needs. Excess grain stays in the granaries as a reserve for the following year. At present, the global granaries seldom maintain more than 1.5 years of grain demand at the end of the harvest season of the Northern Hemisphere. It should be noted that even that losses have not been considered there are sometimes significant quantities (in the order of 20-40%) lost along every transport and in every storage (i.e. the stock variables, “grain in field”, “market”, “granaries”, “consumer stock” and the transport between them). These loss terms can be seen on the flow chart but in order to reduce complexity they are not shown in the CLD.

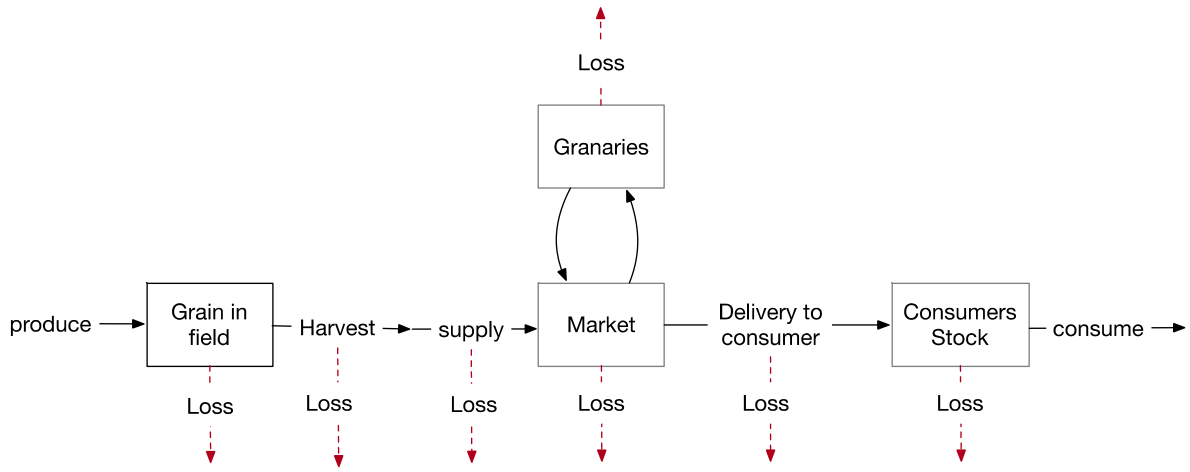


Figure 6. A flow chart for a dry storable food commodity like grain based on the very simple grain model for the worlds grain markets in figure 7.

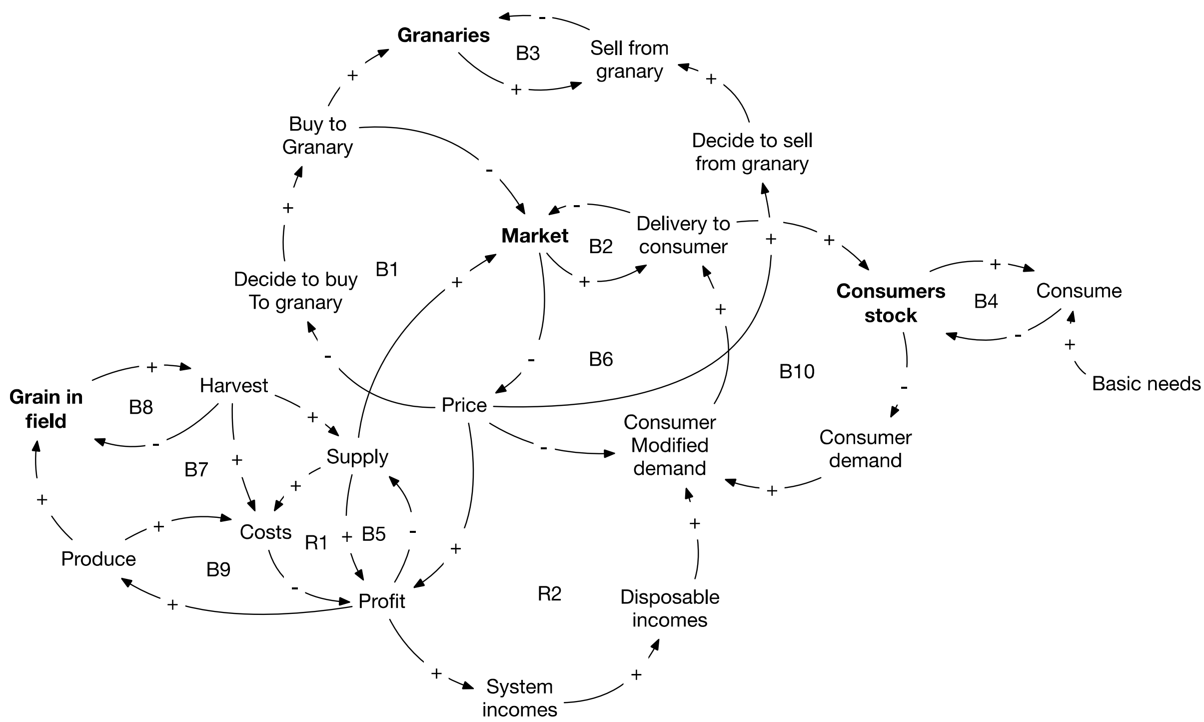


Figure 7. A simple conceptual model for the worlds grain represented in a CLD. Consistent with the flow chart in figure 6.

5.2 Conceptual model for meat

Figure 8 and figure 9 show the flow chart and corresponding CLD for meat with limited time before it is spoiled. In this study beef has been chosen.

Beef has a limited storability as fresh meat, but a substantial one when frozen. Beef is tenderized for about 30-40 degree-days in commercial production, mostly as vacuum packed product (privately or locally, one may rather do tenderizing under drying conditions for 40-60 degree-days). Part of the tenderizing occurs during cooled transport to the final destination along the supply chain. This means that the meat has 10-14 days of tendering on its way when properly cooled. Then beef has a shelf-life of another 3 weeks before it must have been sold. In total, after 4-5 weeks the meat is either frozen or lost. At that junction, it is decided whether it will be frozen or sold on a sale. Frozen beef goes to a different market, the frozen beef market, that has lower prices. It may be frozen as is or reprocessed to minced meat, sausages or other less defined products. This is also a junction where cheats in the system may arise. The meat may be repacked and relabeled and re-dated. The losses have not been integrated in the CLD, but there are substantial losses along every transport, transaction, processing step and in every storage site, sometimes in significant quantities. Some losses are considered in the flow chart. Losses are in the order of 20-40% along the supply chain for meat.

One flexibility beyond freezing is considered in the system. Because of the short lead time, a part of the meat will be kept stored as live animals. This is the safest way of storing them for longer times. They can then be slaughtered on demand. The system requires high quality logistics and a high degree of system discipline.

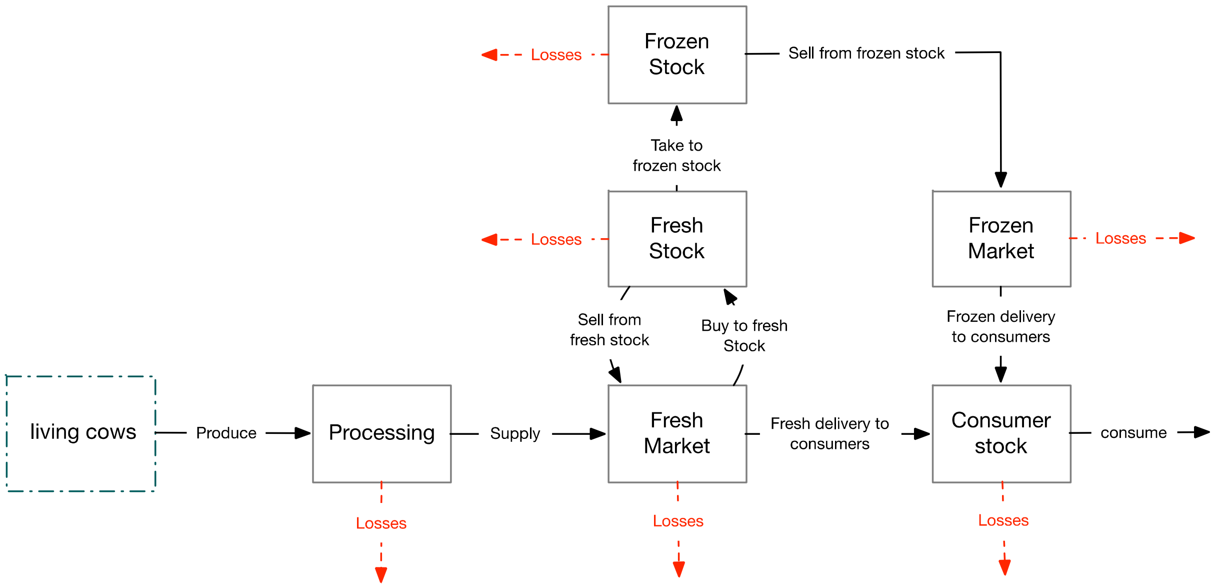


Figure 8. Flow chart for meat from living animals to human consumption.

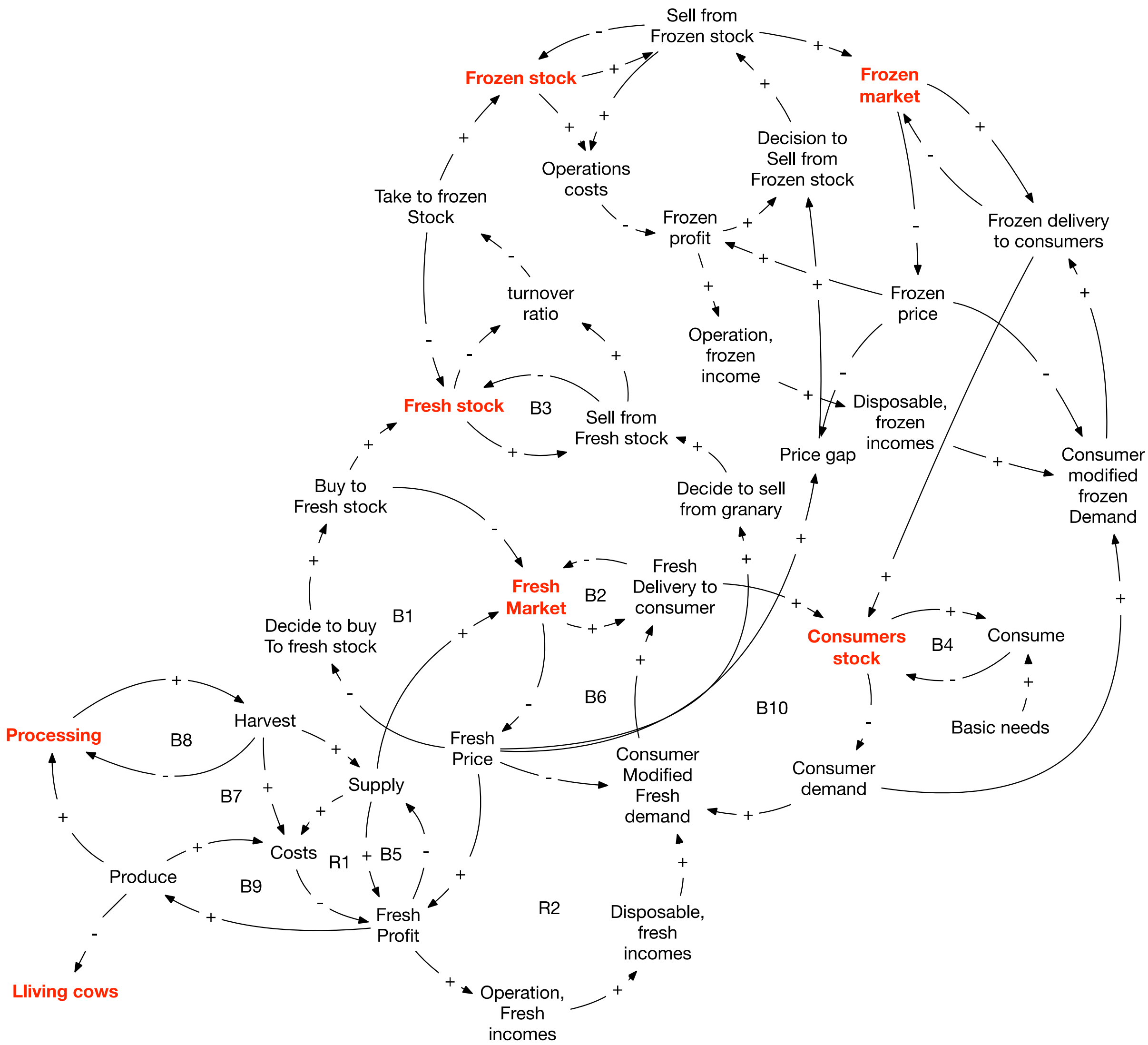


Figure 9. Causal loop diagram for meat based Gudbrandsdóttir et al., 2018.

6 Parameterization for commodity market analysis

Parameterizations in the model that describes the basic market mechanisms for setting the price for commodities has special relevance for model use. It is a goal of the study to generate prices within the model avoiding the use of time-series for generating future price expectations which may have no or little basis in reality. The causal loop diagram in Figure 4 implies the following equation:

$$Price = k * (Market\ stock)^n \quad (1)$$

with k a constant and n an exponent that are determined empirically by determining the quantity of immediately tradeable commodity in the market and the global price at the same moment.

Examples for various commodities suggest that the price curves over time have a generic shape and allow a very similar parameterization. On this basis it may be legitimate to use generic price curves for materials where there is not enough data available to determine the price curve empirically. In this case, one data point might be considered sufficient for creating a price curve for a commodity that fits equation 1.

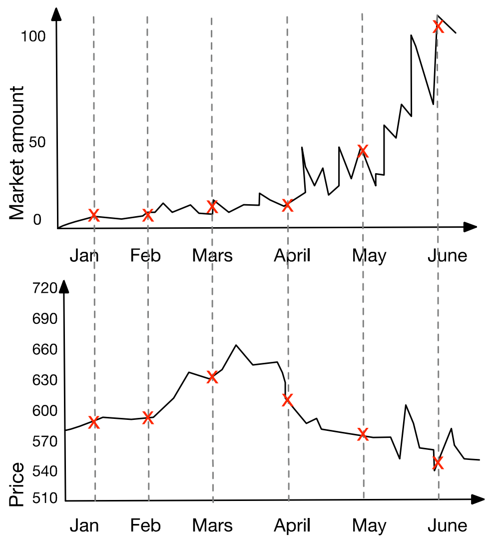
With market stock, it is assumed that the quantity available in the market for immediate transaction includes both, ownership transfer and if necessary, physical supply. This excludes derivatives trade, hedging and forwards, which are not counted as immediately physically deliverable.

There is potential for exponential growth when the resource exploitation is unrestricted and dynamic market price mechanisms that can limit demand are mechanistically incorporated in our process-oriented models.

The market stock estimates were related to the market price and used to generate the approximate price response curves. During related studies with metals, it was discovered that the price mechanism for coffee had the same shape and level as for metals (H. Sverdrup and Olafsdottir, in review). This led to the realization that the curves depended less on the commodity traded and more on human psychology and the transaction mechanisms of the actual trading arena. The learning outcome from modelling the trade in metals, fossil fuels and materials formed the basis for dealing with the same market mechanisms for food commodities.

The following sections present the data that were extracted for parameterization in the models of selected food commodities. This method of data extraction is used to get a hold of the data that is publicly available that happen to be in the forms of diagrams not data bases. For assuring full transparency, the process of extracting data from the diagrams is presented in detail for wheat as an example.

Figure 10 is presented to showcase the method of data extraction when the only data available is presented in graphs. The Figure does not show the real graphs used to extract data, those can be found at the CME Group website (CME Group, 2014).



	Market amount	Price
Jan	10	580
Feb	9	580
Mars	12	630
April	13	600
May	40	570
June	100	540

FIGURE 10. This figure presents hypothetical data to showcase the data extraction method. Market quantities (above) and prices (below).

The same procedure was applied to the other food commodities that were investigated. The resulting data tables are presented in this paper. Market quantities were used whenever they were available, but if these were lacking an estimate was made based on proxies like year ending stocks, total stocks or, for fresh food, monthly supply (for beef, assuming beef can be stored fresh about one month as maximum). Resulting price curves are presented in section 7. Table 1 shows an overview of the data available for this study and what types of proxies were used when needed.

Table 1.
Overview of data used to develop the market mechanism price curves.

Commodity	**Market tradable quantity**	**Market tradable quantity proxy**	**Years ending stocks**	**Years ending stocks proxy**
Coffee	Yes	-	-	-
Wheat	Yes	-	Yes	-
Corn	Not found	-	Yes	-
rice	Not found	-	Yes	-
Soybean	Not found	-	Yes	-
Beef	Not found	Monthly supply	Not found	Frozen beef

All the relevant data tables for the food commodities are stored in appendix. It it noted that the data is not for analysis but for specification of the price curve and are, therefore kept in the initial units.

For wheat, there is some data available for market quantities and prices. The data were obtained from the Chicago commodity exchange published by the Chicago Board of Trade (CBOT) as presented in table 2 for wheat.

Table 2.
Market quantities, prices and stocks for wheat
(data obtained from the Chicago Board of Trade (CME Group, 2014), and the US Department of Agriculture (USDA, 2014)

Time	**Market quantity,** Million ton	**Price,** $ per ton
Aug ‘13	**5.4**	720
Sept ‘13	**12.0**	685
Okt ‘13	**8.7**	730
Nov ‘13	**10.0**	750
Des ‘13	**9.0**	745
Jan ‘14	**22.0**	680
Feb ‘14	***26.8***	*628*
Mars ’14	***51.0***	*587*
April ‘14	***57.0***	*580*
May ’14	***40.0***	*550*
June ‘14	***68.0***	*528*
July ‘14	***50.0***	*560*
Aug ‘14	**83.0**	520

Table 3.
Market quantities, prices and stocks for wheat
(data obtained from the Chicago Board of Trade (CME Group, 2014), and the US Department of Agriculture (USDA, 2014)

Year	**World ending stocks,** Million ton	**FOB US, $** per ton
2007	130	410
2008	160	300
2009	205	225
2010	197	350
2011	195	310
2012	175	360
2013	187	315
2014	220	265
2015	235	220
2016	262	190
2017	269	185

Similar data were found for corn (maize) from the Chicago Commodity Exchange (CME Group, 2014) and for world markets from the USDA (USDA, 2014). For obtaining the price curve for corn, the data were extracted from the diagrams as demonstrated with Figure 10. The same procedure was carried out for rice using data from the US Department of Agriculture (USDA, 2014) (Table 2 in appendix). Market quantities were derived from the global ending stocks (in million tons).

The data for coffee comes from the International Coffee Organization (ICO, 2015)._Coffee was included to show that nearly all commodities show the same behaviour when there is a functioning trade market. This data was transferred from a figure to Table 3 in appendix and then used to construct the diagram shown in Figure 15.

For soybeans, market quantity data was not available. Thus, the work presented is with proxies for the quantity available in the markets as tradable commodity. Annual ending stock for corn was used as a proxy. This is not the same as immediately tradable quantities, but it may be argued that it is related to it. These were used to plot the price curves for soybeans. Table 4 in appendix shows the data generated for soybeans from the diagrams.

For beef, both prices and stock data for the United States is available (USDA, 2018). Frozen beef makes up about 14% of the total market quantity, see Table 5 from appendix for data extracted.

7 Results for price curves

If price curves can be combined with data on actual tradable quantities available in the market for a commodity, the price curve for that commodity can be made. Food markets show great volatility in the price, both depending on global weather conditions, human endeavours and the effects of globalization and of speculation. The global food production is large. These flows are among the largest physical flows arranged by man on the planet. Sufficient data for an initial determination of market price mechanism curves that possibly may serve as proxies for this for 7 different types of foods will be presented:

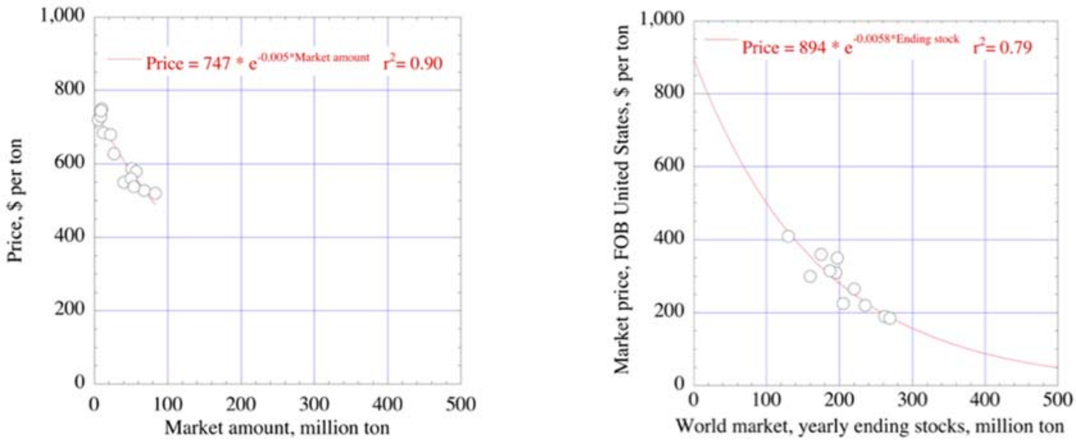
1. Grains: Wheat, Corn, Rice
2. Beans: Coffee, Soybeans
3. Protein: Beef

The various graphs presented in this chapter confirm that the curves all have similar shapes for the price functions.

7.1 Grains

7.1.1 Wheat

Figure 11 shows the market price curve obtained from the Chicago commodity exchange for wheat grain (USDA, 2014). The Chicago market is coordinated with other markets, but reflect only a part of the market volumes in the world. The correlation to the curve is $r^2 = 0.9$, which is good considering the uncertainties and that this is actual market data. An exponential function gave the best fit, but with a very small margin to a power function. Wheat prices from 2007 to 2017 were used where matching price data was available.

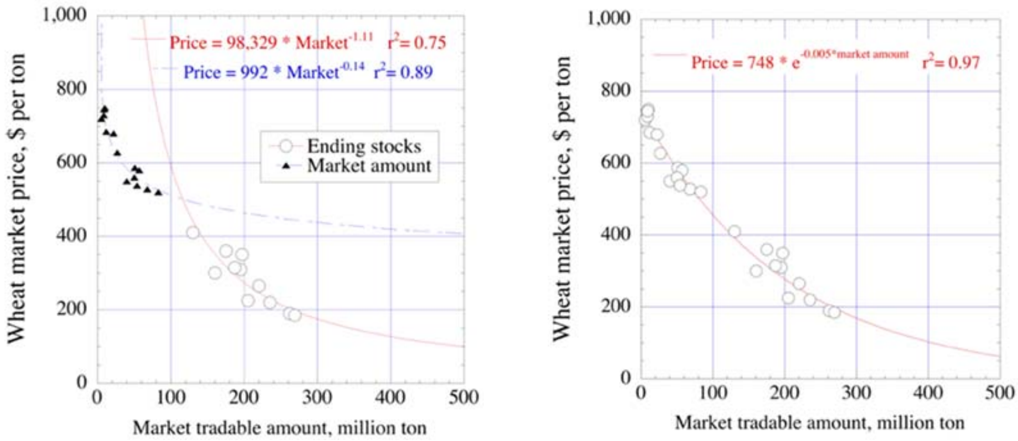


a) b)

Figure 11. Wheat. (a) shows the price curve obtained from the Chicago commodity exchange for wheat grain (b) shows the global yearly ending stocks related to the annual average price that year.

Figure 12a shows the difference between a curve based on ending stocks and the price at that time, and the curve derived from using market quantity. Ending stocks is assumed to be some type of proxy for market quantity. All the data from the year with wheat ending stocks and the Chicago trade exchange market quantities was pooled together in figure 12b, resulting in the following price equation:

$$Price = 748 * e^{-0,005*(Market\ amount)}, \quad \text{with } r^2 = 0,97 \qquad (2)$$



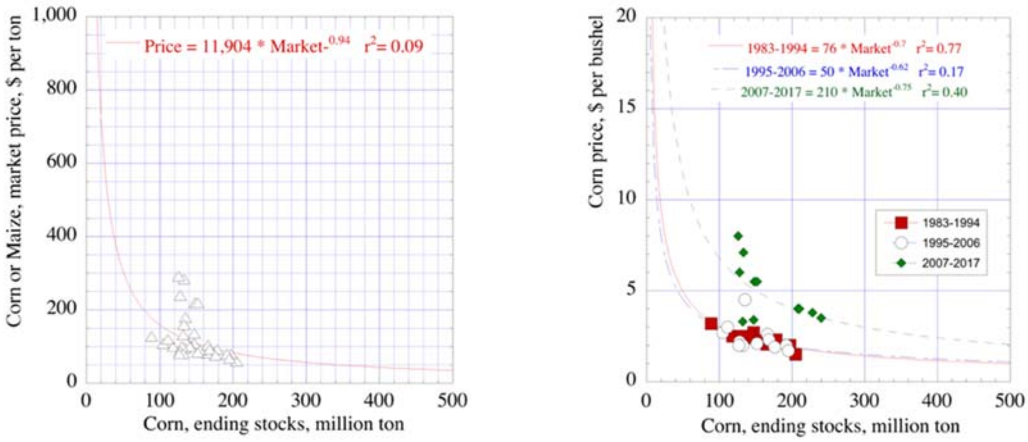
a) b)

Figure 12. Wheat. The price curve for wheat obtained from the data. (a) shows the difference between a curve based on ending stocks and the price at that time, and the curve derived from using market quantity. (b) We have pooled all the data from the year wheat end stocks and the Chicago trade exchange market quantities where we have data available.

7.1.2 Corn and rice

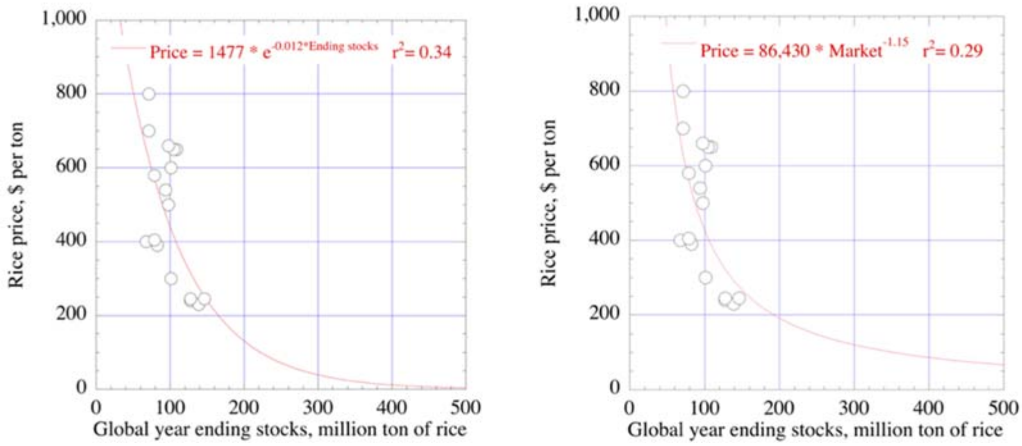
Figure 13 shows the price curve for corn using the data in Table . When all the data is taken combined, a very low correlation is obtained (figure 13a). However, if it is stratified according to time period, it changes the picture. The data was stratified into 1983 to 1994, 1995 to 2006 and 2007 to 2017, is shown in figure 13b:

- 1983-1994: $Price = 76 * e^{-0,7*(Market\ amount)}$, with $r^2 = 0,77$, (3)
- 1995-2006: $Price = 50 * e^{-0,62*(Market\ amount)}$, with $r^2 = 0,17$, (4)
- 2007-2017: $Price = 210 * e^{-0,75*(Market\ amount)}$, with $r^2 = 0,4$, (5)



a) b)

Figure 13. Corn. (a) The obtained price curve for corn, using the data given in Table 3. (b) The data gave more meaning (higher correlation coefficient) when stratified according to time periods. Year ending stocks was used, which are a crude proxy for market quantity.



a) b)

Figure 14. Rice. The obtained price curve for rice., testing an exponential function (a) and a power function (b). The correlation coefficient is low for both relationships, thus not really valid for saying one is better than the other. Year ending stocks was used, which are a crude proxy for market quantity.

Figure 14 shows the obtained price curve for rice, using the data presented in table 4. The curve fit is less good for rice than other cereals (r^2=0.34 for an exponential function and r^2=0.29 for a power relationship), depending on the noise in the available data. However, the general pattern is there as with the other grains.

7.2 Beans

7.2.1 Coffee

Figure 15 shows the obtained price curves for coffee, expressed in the original data format (Figure 15a) and when converted to million ton of coffee and $ per ton of coffee (Figure 15b) and the price curve obtained when converted to million ton of coffee and $ per ton of coffee (Figure 15c). For coffee, a power relationship seems to give the best fit even if an exponential fit gives almost the same correlation (r^2=0.77). It is assumed that a bag is 60 kg on the average.

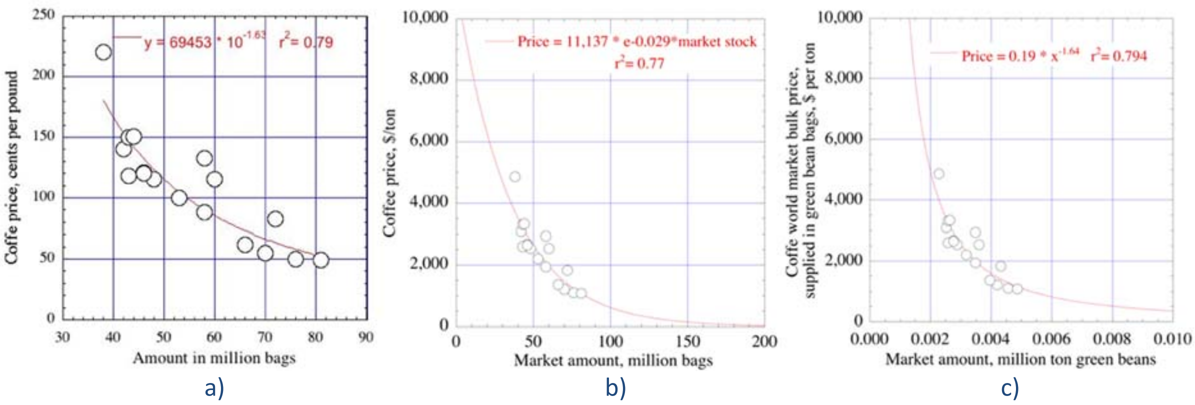


Figure 15. Coffee (a) The obtained price curve for coffee, expressed in the original data format using equation (4) and (b) when using Equation 5 (b). (c) The price curve obtained when we converted to million ton of coffee and $ per ton of coffee. This will be used in a model for the supply chain of coffee from Guatemalan plantations to Iceland.

7.2.2 Soybeans

Figure 16 shows the obtained price curve for soybeans based on data from Table . The correlation is good, r^2=0.83 for using year ending stocks combined with average annual price and r^2=0.86 when using end of year pricing. Going further back than 2012 proved to be difficult with the data available at present. When ending stocks before 2012 was related to market price, no sensible correlation was found. It is apparent that the price stayed nearly constant between 1974 and 1995, giving us no price gradients to work with.

Thus, the price to quantity relationship is too weak to detect in this kind of data. Real market estimates of instantly tradable quantities is necessary. By combining all the data, we get the diagram in figure 16b.

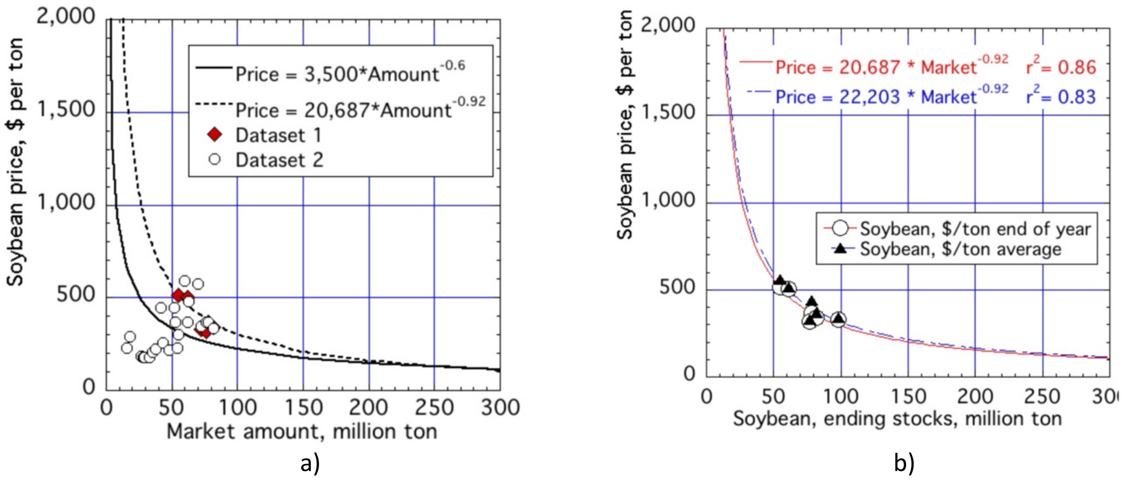


Figure 16. The obtained price curve for soybeans. For soybeans using years ending stocks (b) and market quantities (a) yielded qualitatively the same result. The data has too little spread to really secure proper statistical relationships.

7.3 Protein

7.3.1 Beef

Figure 17 shows the obtained price curves for beef, using the data in Table . Market quantity is not available, but stock quantities for different aspects of beef (fresh cut, frozen whole beef, live animals) was used. The spread in the data is too narrow to yield proper statistical relationships, and the correlations only appear as being good.

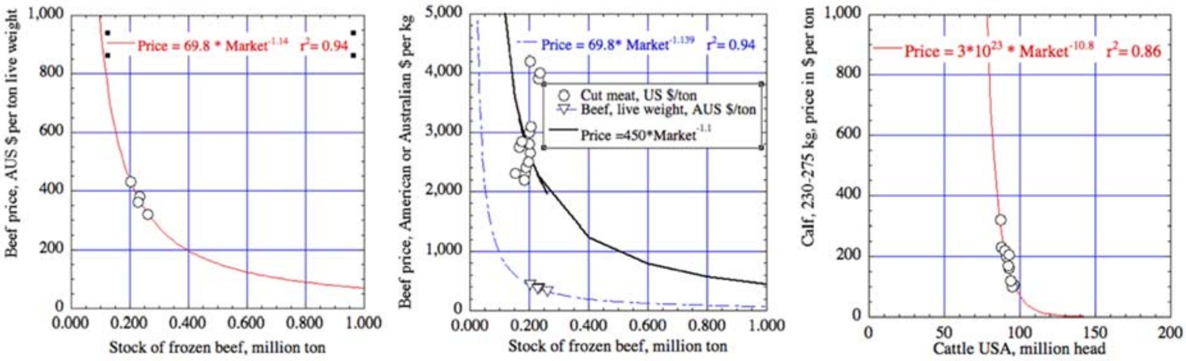


Figure 17. The obtained price curve for beef, using the data given in Table 7. Market quantity is not really available, and we have used stock quantities.

8 Discussions

In a way it is true that modelling is part an art and part science, based on multiple assumptions. One can argue that the process of building a model can be endless, i.e. one can always rethink parts and make new ones based on new information or new data to make the model reflect the real-world system better. The model and modeling method presented in this paper is no different. The model will keep on evolving with better data and gained understanding about the system. There is a consistency in the results presented, and the same type of curve shape was found as has been discovered for metals and materials (H. Sverdrup and Olafsdottir, 2018). This indicates that it is possible to estimate price curves in general.

There were plenty of obstacles and difficulties encountered when interpreting databases using variables proxies, this is due to a lack of connected data. There are several issues that come from that with some of the curves, but they do make it possible to start with modelling, and they show what kind of expression should be used. For only a few commodities could real market data be found, i.e. Coffee and wheat.

8.1 Limitations

The biggest limitation for the study is insufficient data. A number of assumptions must be made to be able to use the limited quantity of data available. The data needed is not always recorded, and for it to be useful for the study it must be extracted from other data, i.e. the data from the plots that has been listed in the tables in the paper. The data used has been scrutinized by auditors of annual accounts and annual reports, but it is noted that it is not scientifically peer-reviewed data. It is an open question, which kind of scrutiny that is better, or if there are any substantial difference. This implies that the findings are preliminary. That they are preliminary is still far better than doing nothing, which would leave the question unanswered.

It is also noted that the authors do not have ownership of all the plots used to extract data from, and therefore, only data extracts made by the authors is published.

8.2 Further work

Hopefully a better data will be available on market quantities in the future to update this work. The data certainly exists with all demands on traceability and data being gathered by both companies and authorities. Getting a hold of it may still be a challenge because of fierce market competition and that large part of the data is privately owned.

It is noted that market data is available for sugar, ethanol and cotton, suggesting that there is more data available for those that have the right access to databases (see Table 3 for a list with some suggestions).

Table 3.
Overview of further commodities where data probably exist and would be of interest for model development. Crosses suggest where data indications has been found during.

Commodity	Market tradable quantity	Market tradable quantity proxy	Years ending stocks	Years ending stocks proxy
Sugar	x		X	
Milk	x	x		
Butter	x	x	X	
Palm oil	x		X	
Soy oil				
Olive oil	x			
Cod, fresh	?	Weekly supply		Frozen
Cod, dried	x		X	
Pork	?			Frozen
Mutton	?	x		Frozen
Potatoes	x	x		
Black Pepper	x		X	
Oranges	?	x		
Orange juice	?	?	X	
Apples	x	?		
Apples juice	?	x	X	
Salads	?	Weekly supply		
Eggs	yes	Weekly supply		

9 Conclusions

The preliminary results presented in this paper have a methodological contribution both in the form of the conceptual modelling of the food supply chains presented with special regards to the price mechanism and the price curves. The main contribution lies in the methodological way to make the required parameterization of supply chain models. The resulting price curves for coffee, wheat and reasonable proxies for corn, rice, soybeans, and beef give a good enough fit to be tested in the WORLD6 model.

Table 4 presents a summary of all the price curve parameters found. It is concluded that, the work presented serves as a good platform for further modeling work to be done, and that with better data, the method described can be used to do a better parameterization of supply chain models.

Table 4.
Summary of price curve parameters conforming to Equation (1).

Commodity	**Production 2015** Million ton	**Market inventory** Million ton	Granary stock location	k	n	r^2
Coffee	30	3.5	Producers, Wholesalers	63,459	-1.63	0.79
Wheat	700	100	Wholesalers, State	992	-0.14	0.89
Corn	1,100	130	Wholesalers, State	76	-0.70	0.77
Soybean	700	70	Producers, Wholesalers	20,200	-0.92	0.86
Rice	400	75	Wholesalers, State	86,430	-1.15	0.29
Beef	90	30	Producers, Wholesalers	70	-1.14	0.94

Acknowledgement

The VALUMICS project titled "Understanding food value chains and network dynamics" leading to this publication has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 727243. The work presented here is derived from the initial conceptualization work in the VALUMICS project, for system dynamics modelling of food supply-, value and decision chains, and is the authors own initiative to apply the WORLD6 model to model price for different food commodities. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Appendix to the paper: *Defining a Conceptual Model for Market Mechanisms in Food Supply Chains, and Parameterizing Price Functions for Coffee, Wheat, Corn, Soybeans, Beef and Salmon*

All the relevant data tables for the food commodities are stored in this appendix. It is noted that the data is not for analysis but for specification of the price curve and are, therefore kept in the initial units, f.x. bushels. One unit of bushel, is about 27.2 kg, used for soybeans or corn. The data was taken from the diagrams as was done and demonstrated with Figure 10 and the corresponding prices.

Table 1.
Data for corn was extracted from diagrams from the USDA and CBOT, (CME Group, 2014, CBOT, 2018, USDA, 2014).

Year	Ending stocks, million ton	$ per bushel	$ per ton	Year	Ending stocks, million ton	$ per bushel	$ per ton
1983	89	3.2	128	**2000**	176	1.9	76
1984	118	2.5	100	**2001**	152	2.1	84
1985	178	2.3	92	**2002**	128	2.2	88
1986	205	1.5	60	**2003**	105	2.7	108
1987	197	2.0	80	**2004**	132	2.0	80
1988	147	2.7	108	**2005**	127	2.0	80
1989	134	2.4	96	**2006**	111	3.0	120
1990	142	2.5	100	**2007**	132	3.3	132
1991	141	2.5	100	**2008**	148	5.5	220
1992	165	2.1	82	**2009**	147	3.4	136
1993	130	2.5	100	**2010**	128	6.0	240
1994	155	2.3	90	**2011**	133	7.1	284
1995	135	4.5	180	**2012**	126	7.3	292
1996	166	2.6	104	**2013**	152	5.5	220
1997	168	2.3	92	**2014**	208	4.0	160
1998	192	2.0	80	**2015**	210	4.0	160
1999	195	1.7	68	**2016**	240	3.8	152

Table 2.
Rice grain. Data generated for rice. The data for ending stocks and market price was taken from the US Department of Agriculture website (USDA, 2014).

Year	Ending stocks, million ton	Price, $ per ton	Year	Ending stocks, million ton	Price, $ per ton
2000	127.50	240	2009	78.75	580
2001	138.75	230	2010	93.75	540
2002	146.25	245	2011	97.50	500
2003	127.50	245	2012	101.25	600
2004	101.25	300	2013	108.75	650
2005	82.50	390	2014	105.00	650
2006	67.50	400	2015	97.50	660
2007	78.75	405	2016	71.25	700
2008	71.25	800	2017		

Table 3.
Data for coffee market quantities and price per weight unit. The data for coffee was taken from the International Coffee Organization website (ICO 2015).

Year	Million bags	Million ton	$ per ton	Cents per pound weight
1998	58	0.00348	2,936	133.00
1999	60	0.00360	2,539	115.00
2000	72	0.00432	1,832	83.00
2001	76	0.00456	1,104	50.00
2002	81	0.00486	1,082	49.00
2003	70	0.00420	1,214	55.00
2004	66	0.00396	1,369	62.00
2005	58	0.00348	1,943	88.00
2006	53	0.00318	2,208	100.00
2007	48	0.00288	2,539	115.00
2008	46	0.00276	2,671	121.00
2009	43	0.00258	2,605	118.00
2010	42	0.00252	3,091	140.00
2011	38	0.00228	4,857	220.00
2012	43	0.00258	3,311	150.00
2013	46	0.00276	2,649	120.00
2014	44	0.00264	3,333	151.00

Table 4.
Soybean. Data generated for soybean from CBOT (CBOT, 2018).

Year	Market quantity Proxy. Ending stocks	Soybean price, $/ton	
		End of year	Soybean, $/ton average
1995	18		
1996	16		
1997	27		
1998	28		
1999	29		
2000	33		
2001	35		
2002	43		
2003	38		
2004	48		
2005	54		
2006	63		
2007	52		
2008	42		
2009	60		
2010	70		
2011	53		
2012	55	514.71	558.82
2013	62	503.68	514.71
2014	78	367.65	441.18
2015	76	319.85	330.88
2016	82	341.91	367.65
2017	72	330.88	341.91

The abbreviation cwt, also known as the term "hundredweight" refers to a unit of 100 lb.

Table 5.
Data generated for beef from diagrams from (Semmelroth 2015, USDA 2018) .

Year	**Ending stock, Frozen beef,** Pound	**Ending stocks, frozen beef,** million ton	**US** cwt $ per kg	**All US cattle** Million heads	**Calf 230-275** kg $ per cwt
2001	332	0.152	2.30		
2002	405	0.185	2.30		
2003	400	0.183	2.20		
2004	415	0.190	2.40		
2005	365	0.167	2.75		
2006	441	0.202	2.65		
2007	438	0.200	2.80		
2008	435	0.199	3.00	96	105
2009	430	0.197	2.50	95	100
2010	385	0.176	2.85	94	120
2011	448	0.205	3.10	93	160
2012	505	0.231	3.90	92	170
2013	515	0.235	4.00	91	200
2014	410	0.203	4.20	87	320
2015	480	0.233		88	230
2016	490	0.262		90	220
2017	455	0.229		93	205