The Role of Financial Speculation in Commodity Markets: Harmful or Helpful?

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The Role of Financial Speculation in Commodity Markets: Harmful or Helpful?

A System Dynamics Model to Explore the Effects of Financial Speculation in the Soybeans Market

(Freepik, n.d.)

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Executive Summary

Recent years have shown an increased level of food insecurity: a surge in the level of poverty and hunger in low-income countries caused by higher global food prices. This upward trend of commodity prices was also identified in the soybeans market: soybean prices increased by about 80% between 2020 and 2022. Moreover, the FAO food price index averaged 98.1 points during the year 2020 but increased to 143.7 during 2022. One of the potential causes of the commodity price spikes is the process of financialization, including an increased level of financial speculation in food commodity markets. Because the literature is inconclusive on the exact effects of speculation, this research aims to provide a fresh analysis of the potential impacts of financial speculation on food commodity prices as well as to explore policies that could influence the level of financial speculation. The main question to be answered through this research is:

'What are the likely effects of the increase in financial speculation on the behavior of commodity prices in the current soybeans market, and which policies can be used to regulate these effects?'

First, a literature review was conducted to study sources on the potential theoretical effects of speculation, as well as sources on the current regulatory measures to counter speculation. Next, the system dynamics approach was used to investigate the role of speculative activity in price-setting behavior. The purpose of the system dynamics model was to create a better understanding of the effects of financial speculation on commodity prices and to explain whether or not speculative activity could have contributed to the behavior of spot prices in recent years. Lastly, expert interviews were conducted to validate the behavior of commodity prices as shown in the model, as well as to gain knowledge on policy interventions that could limit the potential negative effects of financial speculation in commodity markets.

From the literature review, it can be concluded that there is still no consensus on the magnitude of the effects of increased speculation, which can be partly explained by the different methods, time periods, and indicators that are used in these studies. Guided by the literature review, three important interacting markets were identified for inclusion in the conceptual system dynamics model for the soybeans market: the market for storage, the cash market, and the futures market. Literature indicates that the market for storage has a balancing effect on spot prices through the law of supply and demand. Spot price expectations determine the level of open interest, which is a relevant indicator of speculation and refers to the total number of futures contracts that is held by investors. When the expected spot price is high (and the market is therefore attractive), this is followed by an increase in the level of open interest in the futures market. An increased level of open interest could theoretically moderate the futures price (and therefore the spot price) because the open interest determines the level of market risk that is perceived by the investor. Lastly, in the literature review, speculators were found to be trend-

following, fast-reacting entities who take on the price risks that hedgers try to mitigate, but who also contribute to strengthening of price expectations and spot prices.

Traditional economic theory, combined with the behavioral process of price expectation forming, created the basis of the model constructed in this research. The conceptual model that resulted from the literature review was converted into a quantitative system dynamics model to assess the quantitative behavior of prices and inventories. The model shows oscillation of the spot price and inventory level: speculators are able to amplify the oscillation, which can be compared to the forming and crashing of price bubbles in a commodity market. This amplification occurs because speculators react faster to changes in spot prices than other market participants (e.g., hedgers). The change in behavior of prices following from increased speculation is permanent, compared to the temporary effects of a change in fundamentals, such as a production shock due to a bad harvest. The behavior that is shown in the model does not completely match the irregular, oscillatory behavior of spot prices that occurs in reality. This could be due to short-term changes in variables that were not captured by the model. While the model is still relatively simplistic, it creates an understanding of the system structure of financial markets that determines spot price behavior.

To link the behavior of the model to real-world policymaking, expert interviews were conducted. It can be concluded that the experts agree on the fact that some kind of policy intervention is required to limit the negative effects of speculation. Developing countries should be protected from structurally higher food prices. However, there is still considerable uncertainty regarding the effectiveness of potential policies in limiting speculation. Policy makers should pay attention to the level of transparency in setting position limits. Information on the calculations and intended purpose of the position limits (how much speculation should this measure prevent?) should be published. Moreover, policy makers should focus on clarifying and explaining the classification of speculators and hedgers. Furthermore, experts indicate that only traders with an active and real interest in the commodity should be allowed to participate in the futures market, so that the number of speculators in the futures market could be reduced. Policy makers should assess the interest that actors hold in the specific commodity, so that only actors with both a financial interest and an interest in (for example) soybeans can participate in the soybeans futures market.

In order to improve the system dynamics model that was created in this research, several recommendations can be given. First of all, the causal direction between the futures and spot price is still much-debated and this critical feedback mechanism in the model can be further investigated. Moreover, experimenting with different types of speculative indicators and the uncertain delays could improve the robustness of the model. Next, future research should focus on the perspective and influence of index investors, who buy a basket of commodities in which each commodity holds a particular weight, and who play a different role in price-setting behavior than futures investors. Furthermore, the way in which expectations are formed by investors should be elaborated upon.

This research does not show that speculation in food commodity markets is solely harmful, nor does it show that it is completely helpful. It shows how important the right balance between speculation and hedging activities is to reap the benefits of price risk mitigation, while also preventing a surge in prices. While statistical methods have been employed extensively in the field of economics and financial speculation, this research offers a new perspective on the problem of price spikes. It is a first known attempt to incorporate financial speculation into the structure of economic and financial systems through the translation of traditional and behavioral economic theories into a (relatively simple) quantitative system dynamics model. The research shows the feasibility of using the system dynamics approach to provide a holistic (visual) overview of the mechanisms involved in price discovery. The model can serve as a starting point for future modelers in the field of commodity market speculation.

Acknowledgements

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When I approached Servaas Storm to brainstorm about a potential research topic, I immediately became enthusiastic about the recent debate on the effects of financial speculation. While I was not familiar with speculation in commodity markets, the elective package on Economics and Finance had already sparked my interest in the role of financialization in the financial crisis of 2008. Together with my fellow students Suzan van Arkel and Carlotta Breman, we decided to combine our interest in the subject through a thesis circle. While we all approached the topic of financial speculation in commodity markets using different methods, we often sat together to share our knowledge and findings. Moreover, we joined forces during the expert interviews. I would like to thank these girls for their support: I enjoyed our weekly conversations on the topic, which not only improved the thesis itself, but also made the thesis process very pleasant. Moreover, our first supervisor Servaas Storm has been an enormous support throughout the thesis process: his feedback has been very insightful, providing us with the explanations of the difficult economic context. I would also like to thank him for his involvement in the expert interviews, which enabled us to exchange views with very interesting people on the topic of financial speculation.

Without the assistance of my other supervisor, Floortje d'Hont, this research also would not have been possible. When I decided to use the system dynamics approach to explore the system of financial markets, Floortje guided me through the development of the model. Our weekly discussions and her enthusiasm have been helpful and motivating in the modelling process. Lastly, I would like to thank the chairman of my graduation committee, Cees van Beers, for his feedback during the kick-off and greenlight meeting.

In addition to these words of gratitude, I would also like to thank my boyfriend, family, and friends, who supported me throughout the research process. Special thanks to those who read parts of my research to improve its quality.

This thesis marks the end of my time as a student in Delft. I am looking forward to entering a new phase after graduation. I hope you enjoy reading my thesis!

Marise Tabaksblat
Delft, June 2023

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1. Introduction

In the last few years, (food) commodity prices have been increasing considerably. For example, the FAO food price index averaged 98.1 points during the year 2020 but increased to 143.7 during 2022 (FAO, 2023). The higher global food prices contribute to higher food insecurity, poverty, and hunger for millions of poor people in low-income countries. Concerns are growing that the surge in global food prices was partly caused by financial speculation in global food commodity markets. This research aims to provide a fresh analysis of the potential impacts of financial speculation on food commodity prices as well as to explore policies that could influence the level of financial speculation. This chapter describes the societal and scientific relevance of the research and formulates the knowledge gap that leads to the research questions.

1.1 Background

This research introduces a study of the relationship between financial speculation and prices within (food) commodity markets. During the last few years, an upward trend of commodity prices has been identified (Zloty, 2021), for example in the market for soybeans (Figure 1.1). This trend impacts vulnerable populations worldwide: higher prices lead to an increase in global hunger, since commodities form the basis of many food production chains. The number of people facing acute food insecurity has doubled since 2016 (Agarwal et al., 2022). This issue is being addressed by the United Nations (UN, n.d.), for food insecurity has led to an international crisis for many years. Multiple studies have tried to identify the factors which influence this price increase, one of them being the increased level of financial investment in these commodity markets (Robles et al., 2009). Some research shows that financial speculation was the main cause of the sharp peaks of price increases in 2007/2008 and 2010/2011 (Lagi et al., 2011). This phenomenon has everything to do with the process of financialization of the world economy, in which the growth of the financial sector increases relative to the growth of real economy, resulting in the increasing dominance of the financial sector and financial motives (including speculation) (Falkowski, 2011). This dominance could result in a change of the structure of price-setting mechanisms, therefore influencing food security. The global problem of rising prices and food insecurity can be defined as a 'wicked' problem, meaning multiple actors (e.g., farmers, financial actors, regulators) with different perspectives are involved in a problem that is both politically complex as well as technically complex (Rittel & Weber, 1973). Moreover, multiple explanations for the problem can be found in literature, and there is no clear solution that can be tested immediately. However, if not addressed properly, the consequences for society could be negative (e.g., an increased level of world hunger). Before policies can be effectively analyzed and interventions into the system can be implemented, the technical and political complexity of regulations in the system (of financial markets) need to be investigated (Enserink et al., 2013).

While previous research shows a wide range of different investigated markets, this research focusses on one specific commodity type, because this enables us a more detailed and scoped research. The market choice is based on the transparency of the market as well as the number of external variables that could possibly influence price-setting behavior. For example, the market for wheat or oil is highly influenced by developments in the Ukrainian war (IPES-Food, 2022), making it difficult to assess the impact of speculation in isolation. A more 'neutral' commodity can be found in the world soybeans market. Another advantage of this market choice includes the fact that variables around production and inventories of soybeans are well documented by the Food and Agriculture Organization of the United Nations (FAO, 2023).

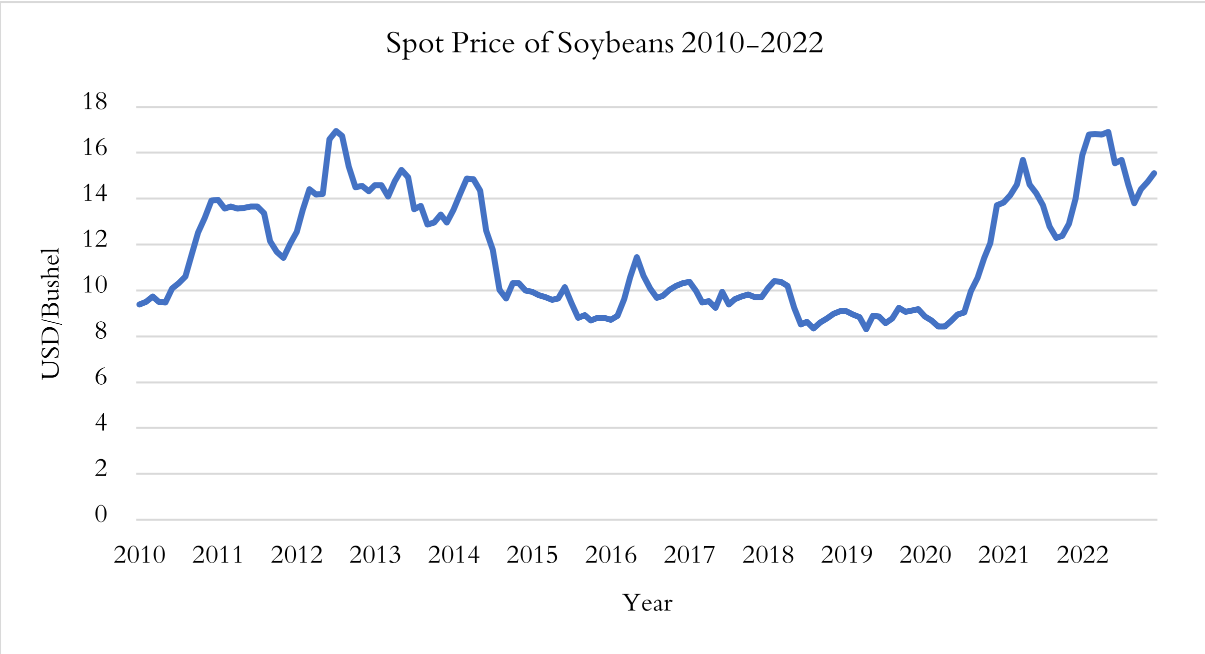

Figure 1.1: Trend in Commodity Prices 2010-2022 (Van Arkel, 2023)

1.2 Societal Relevance

The increasing commodity prices cause a worldwide problem: once commodities become too expensive for more vulnerable (low-income) countries, global hunger increases. Moreover, a price above the market equilibrium reduces demand and increases supply (as can be seen in Figure 1.2), resulting in an accumulation of inventories of different commodities, such as grain. If the impact of increased speculative investment is indeed significant, this has implications for policies regarding the (de)regulation of speculative trade (Lagi et al., 2011). Regulations like the Commodity Futures Modernization Act of 2000 in the United States have been in place for multiple years, ensuring that no interference into certain financial products can take place (Chen, 2022). However, if the evidence of negative economic effects of speculation comes to light, policies can aid in stabilizing the market system of supply and demand for certain commodities (Worthy, 2011). As mentioned before, this research aims to provide a fresh analysis of the potential impacts of financial speculation on food commodity prices as well as to explore policies that could influence the level of financial speculation.

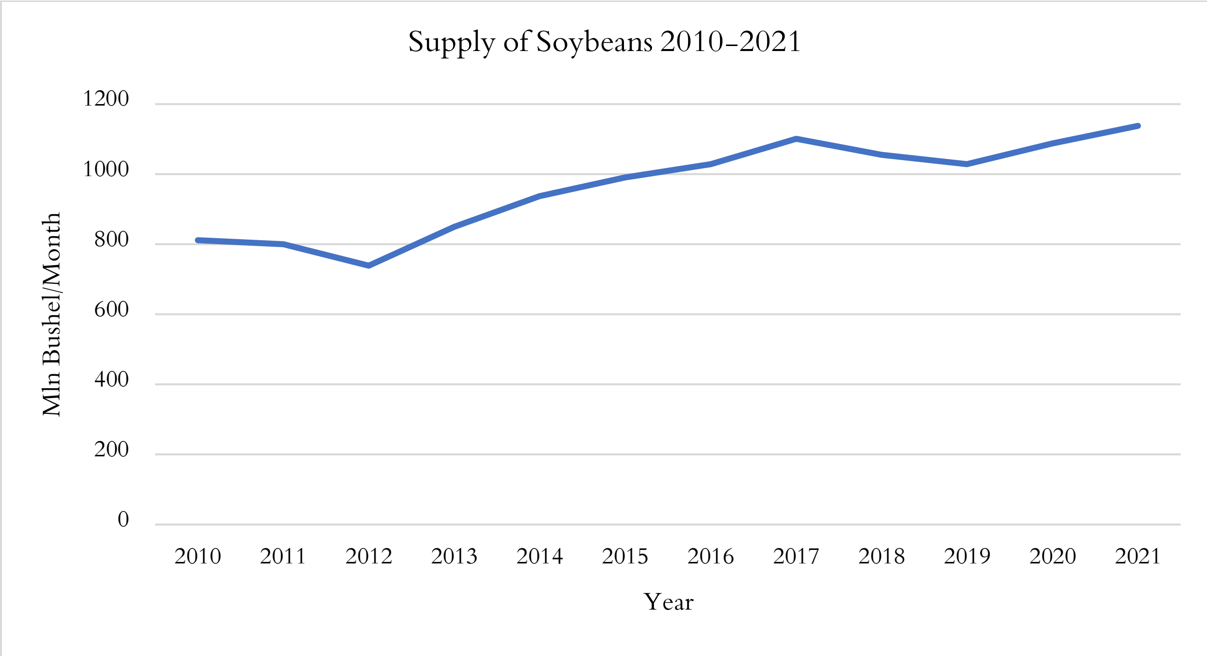

Figure 1.2: Increased Monthly Supply of Soybeans (Van Arkel, 2023)

1.3 Scientific Relevance

Recent years have shown an even higher level of financialization of the economy (indicated for example by the volume of credit and assets relative to GDP) than before (Gimet et al., 2019). A limited number of quantitative studies of the effect of financialization on commodity pricing in more recent years is available. However, the literature on the impact of financial speculation on food commodity prices is inconclusive. Many theoretical models have been proposed, for example by Basak & Pavlova (2016) and Clapp & Isakson (2018b). However, previous overviews of the empirical literature both deny speculator effects (Dwyer et al., 2012; Fattouh et al., 2013; Kilian & Murphy, 2014; Will et al., 2016; Mayer et al., 2017) as well as affirm the effect of speculation on prices (Algieri, 2013; Lagi et al., 2011; Zloty, 2021). An overview of the investigated literature can be found in Appendix A.

Moreover, the (quantitative) methods used differs widely. One example by Bos and Van Der Molen (2013) investigates the impact of futures speculation on spot coffee pricing by using a non-parametric, flexible empirical model. While most changes in coffee pricing are the result of shifts in demand and supply, Bos and Van Der Molen (2013) conclude that speculation explains the 'spiky' behavior of coffee prices significantly. They substantiate their findings by addressing the fact that most previous research only accounts for linearity in their models, whilst the transmission from futures to spot price could be non-linear. This shows how findings in previous research are often dependent on the method and assumptions that are applied, and on the indicators that are used.

This research therefore introduces another point of view: to investigate the workings of financial markets, the approach of system dynamics can be applied (Nair & Rodrigues, 2013). System dynamics is an approach that has been adopted to determine influences on price changes for many different industries (Keilhacker & Minner, 2017). It provides researchers with a tool to investigate highly complex and dynamic systems, in which many components interact and produce behavior that cannot be explained through the analysis of the individual components (Zeng et al., 2017). The commodity pricing market represents such a system: it is influenced by many economic factors, including fundamental factors such as real incomes and technology determining demand and supply, demand for storage, speculation levels, but also more general economic concepts such as price elasticities of demand and supply (Knittel & Pindyck, 2016). Abaunza & Aramburo (2009) investigated the factors influencing the world coffee market, considering the feedback loops created by investment. However, no study has been published which specifically addresses the influence of speculation on the behavior of the commodity pricing system by applying the approach of system dynamics. While statistical (correlational) methods have been employed extensively, these methods do not provide an overview of the influence of financial speculators to get a more thorough understanding of the working of the price-setting system. Moreover, these methods do not specifically account for possible feedback loops, accumulation of inventories, or delays in the system.

This research not only adds to knowledge on financial systems that facilitate exchanges of funds (Investopedia, 2019) but also to the general application of system dynamics in economic systems. According to Radzicki (2009), economists have been criticizing system dynamics models because these models often generate counterintuitive behavior that is inconsistent with the dynamic hypothesis coming from traditional economic theory. However, in recent years, other economists have realized that the system dynamics approach can be used as a tool to capture non-traditional ideas of the workings of economic systems (Radzicki, 2009). Specifically, the school of behavioral economics has been applying system dynamics as a tool to understand how human beings employ irrational (economic) behavior (Lane & Rouwette, 2023). Radzicki (2009) identifies different ways of translating existing economic models into system dynamics models, which will be further discussed in Chapter 2.

1.4 Knowledge Gap and Research Questions

The introduction has shown that the subject of financialization in commodity markets is a much-debated subject. Results of previous studies are clearly dependent on the method, the scope of the system, and the indicators used to arrive at a conclusion. Furthermore, most research on speculation in food commodity markets is focused on the time period around the crisis in 2008. This shows the need for further investigation into recent changes in commodity markets. Moreover, the approach of system dynamics offers a different quantitative perspective on financial markets.

As long as the effects of speculation remain unclear, there is uncertainty on how effective the implementation of different policies to improve food security will be. Therefore, the following research question will be addressed:

RQ: 'What are the likely effects of the increase in financial speculation on the behavior of commodity prices in the current soybeans market, and which policies can be used to regulate these effects?'

This question is divided into four sub-questions:

S1: 'What is the theoretical role of speculation in commodity pricing?'
This question will be answered by a thorough literature review of theories around financialization and price-setting. These theories will be synthesized, providing a dynamic hypothesis and a first (conceptual) system dynamics model, which will show the relationships between different economic variables (such as supply, demand, and spot and futures prices).

S2: 'What policies are currently in place to deal with the effects of increased speculative activities?'
To answer this second question, current regulations to organize financial markets need to be reviewed. Most scientific research on the role of speculation describes the state of the art with regard to policies in financial markets. The investigations will be used to answer the second sub-question.

S3: 'To what extent does speculation influence the behavior of commodity prices in the soybeans market?'
The formalization and evaluation of the system dynamics model will be useful in answering this third question, which also requires an inspection of recent data regarding investment, demand, and supply in the soybeans market. The model created for sub-question S1 will be extended and used to assess the influence of speculation and the model will be validated using different types of tests, such as extreme conditions tests.

S4: 'Which policies could be effective in addressing the effects of speculation in commodity markets?'
The last sub-question identifies the different policy options that could deal with the effects of financialization in commodity markets. To identify these policies, literature on regulatory measures in financial markets will be studied. Moreover, expert interviews are done to gain more knowledge on potential policies and their impact.

1.5 Thesis Outline

The next chapter discusses the research approach and research methods. Chapter 3 reports on the literature study that was performed and the conceptual model that was created. In Chapter 4, a short history of regulations in the field of financial speculation is discussed, after which Chapter 5 gives an overview of the validated system dynamics model. This is followed by Chapter 6 on the experiments and results. Chapter 7 discusses potential policy interventions that were considered in the expert interviews. Next is the discussion of the research results in Chapter 8, which is followed by Chapter 9, in which answers to the research questions are formulated and recommendations are done. Lastly, Chapter 10 contains a reflection on the scientific relevance of the research and the research method.

2. Research Approach

This chapter describes the research approach: it relates the formulated sub-questions to the research design and shows the methods which are used for data analysis, interpretation, and validation.

2.1 Research Design

To investigate the relation between speculation and commodity pricing, three different modes of inquiry are used, which means the research is based on a mixed methods design as proposed by Creswell & Creswell (2018). More specifically, the research proposes an exploratory sequential design: it starts with the creation of exploratory knowledge using qualitative methods, and this knowledge is used in further quantitative modes of inquiry (Swanson & Holton, 2005).

The first phase of the research starts with the use of qualitative evidence synthesis, in which existing evidence of the relationship between speculation and commodity markets is investigated as well as current regulations. This inquiry answers the first and second sub-question regarding the theoretical role of speculation and regulation. This phase is followed by the quantitative simulation inquiry, which imitates the real-world system of economic and financial markets. The next phase requires quantitative observation and evaluation, which show whether the simulated model successfully identifies the role of speculation in commodity markets. The model behavior will be validated through different validation tests, including expert validation. The two modes of inquiry of the second and third phase provide an answer to the third sub-question, showing to what extent the relationship between speculative activity and food commodity (soybean) prices is present when looking at empirical evidence.

The last phase of the research again goes back to the synthesis of qualitative evidence: a short literature review is be supplemented with knowledge on policies in financial markets, gained through expert interviews. Policies that could limit the negative effects of speculation are discussed during semi-structured expert interviews, which are used to address the fourth sub-question.

2.2 Research Methods

The first sub-question (*'What is the theoretical role of speculation in commodity pricing?')* and second sub-question (*'What policies are currently in place to deal with the effects of increased speculative activities?')* can be answered through a systematic literature review. The first part of this review investigates the influence of speculative behavior that has been identified in previous research. Moreover, a more general overview of (other) factors influencing commodity pricing (including supply and demand conditions) is necessary in order to assess the influence of speculation in the last sub-questions. The second aim of the literature review is to assess the current state of art regarding regulations in financial markets. The theoretical framework resulting from the literature review provides a first, conceptual model, which is used as input for the second phase of the research.

The last two sub-questions (*'To what extent does speculation influence the behavior of commodity prices in the soybeans market?'* and *'Which policies could be effective in addressing the effects of speculation in commodity markets?')* are answered by using a system dynamics model, containing the factors that were identified in the previous phase of qualitative research. The model is simulated with the simulation software Vensim Pro (version 9.4). The model is evaluated by using for example behavior-anomaly tests and expert validation, which show whether the modelled system behavior corresponds to the behavior of the real system (Forrester & Senge, 1980). Model evaluation infers the model's validity and provides insights in the fitness for purpose of the model.

2.2.1 System Dynamics

The system dynamics approach is suitable for the problem at hand for multiple reasons. Firstly, while most statistical methods are suitable to show (before-after 'Granger') causality, system dynamics is more effective in exploring the system of price-setting mechanisms. System dynamics has the advantage of being able to account for feedback loops as well as accumulation of inventories (Gary et al., 2009). Both are present in the economic system: speculation could influence price and vice-versa, resulting in feedback loops. Moreover, higher prices can stimulate supply (with a delay), but discourage demand for commodities (almost instantaneously), resulting in accumulation of commodity inventories. These causal relations can be presented in a system dynamics model and can provide the researcher with a tool that is useful in communicating the workings of the economic system to policy makers (Onggo, 2021). Moreover, as expert A argues in the expert interview, in statistics, one often assumes linearity. This means economists should be careful with the interpretation of the results of statistical approaches in systems where non-linearity occurs. Conversely, the approach of system dynamics can account for possible non-linear behavior.

Secondly, the approach of system dynamics specifically enables modelers and policy makers to include time delays in the model (Sterman, 2000). An example of such a delay can be found between the effects of price on production and demand. The time it takes for inventories to adjust to price changes is called a material delay. This type of delay is different from an information delay, which involves adjustments of beliefs to information. An example of this second type of delay can be found in the time it takes for speculators to adapt their expected price changes in case of a change in spot prices. The approach of system dynamics can account for these delays.

Lastly, in case data is limitedly available, the system dynamics approach does not require high-quality data in order to provide decision-makers with useful insights regarding price-setting mechanisms (Onggo, 2021). The approach is less data intensive than other modelling approaches and does not produce less useful results.

The purpose of the model is to create a better understanding of the effects of financial speculation on commodity prices and to explain whether or not speculative activity would have been able to cause the behavior of spot prices in recent years. The model is not used to predict behavior of prices, for the approach of system dynamics is unsuitable for prediction. As Forrester (2007) states: *"An effective forecast for conditions at a future time can be made only as far as the forecast time horizon, during which past continuity still prevails. Beyond that horizon, uncertainty is increasingly dominant."* (p. 366). These uncertainties make that it is considered unwise to use system dynamics as a forecasting tool to predict future behavior of prices.

2.2.2 Model Development

In developing the conceptual and eventually quantitative system dynamics model, different steps are taken to show the working of economic and financial markets. The steps follow the modelling cycle as described by Martinez & Richardson (2011). Firstly, the problem at hand needs to be identified. This is already partly done in the introduction, but the knowledge on the problem situation is further extended through the literature review.

The literature review also adds to the second step, which is the conceptualization of the problem. The conceptualization shows the different sub-models. Firstly, more traditional theories of prices, supply and demand are considered in the development of a simple supply and demand model (Gale, 1955). This model shows the feedback loops that results in spot price discovery through changes in production, demand, and inventories. The article of Knittel & Pindyck 2016) is used as a starting point to formulate this part of the model. Secondly, investigations of literature on the working of the futures market provide knowledge on the sub-model that sets the futures price. The futures price also forms the connection with the supply and demand model. Lastly, speculation is incorporated into the model. By reviewing the literature on the theoretical effects of speculation, the futures market is specified in such a way that speculative effects can be evaluated. Feedback loops that strengthen or moderate price expectations are identified and incorporated in the model.

After the conceptualization phase, a quantitative model is formulated, by translating the conceptual model into equations that correctly describe the loops, causal relations, and delays. When information on specific values for parameters or relationships is missing, assumptions are made and validated. The verification and validation process that evaluate the model structure and following behavior show whether the model is fit for the purpose as described in section 2.2.1. This evaluation phase also includes experiments with speculative activity in the model. Potential irrational behavior that follows from adding speculative activity is assessed by reflecting on the dynamic hypothesis and the consequences for policy makers.

The last phase of the modelling cycle is the phase of policy testing. However, due to lacking knowledge on the quantitative effect of policies on the number of speculators, this phase is only considered in the reflection on the model and interview results.

When following the modelling cycle, the three ways of translating existing economic models into system dynamics models by Radzicki (2009) will also be considered. The first way involves the conversion of an existing economic model into the format of a system dynamics model, which enables the comparison of assumptions, structures, and behavior. The second option is to build the economic model from the ground up while following the principles of the system dynamics approach. This second approach usually creates more realistic, but counterintuitive behavior. Since both approaches can be valuable, this research employs a combined approach: first, the traditional theories of demand and supply are translated into a system dynamics model. The model is then modified by adding behavioral processes (e.g., price expectation forming) according to the system dynamics guidelines (e.g., by using different orders of delays). Both approaches are therefore used to create the conceptual model and formulate the dynamic hypothesis.

2.2.3 Expert Interviews

Expert interviews are performed for two different purposes. First, the behavior of the model is validated by experts. The question is whether or not they recognize the behavior that results from an increased level of speculation. The mental models, or the knowledge these experts hold on the behavior in economic systems (Schumacher & Czerwinski, 1992), are compared to the behavior produced by the model. The second purpose is to gain insight into the mental models of experts on the effects of speculation and the use of financial regulations in commodity markets. How realistic is it to assume that certain policies could be implemented, and how would these policies limit speculation? These experts could link the research to actual real-world politics. Some general open-ended questions regarding speculation effects, price-setting mechanisms and current financial regulations are prepared in advance. These questions can be found in Appendix G. The interviews are therefore semi-structured (Adams, 2015). The experts that are approached are mostly academic researchers within the field of (political) economics and/or global development and trade (see Appendix H for the expertise). To protect the identities and personal data of the experts, they are referred to as expert A/B/C/D/E. While the interviews are mostly discussed in Chapter 7, some interesting comments during the interview are already included in other chapters, for example within the introduction in Chapter 1 and the description of the conceptual model in Chapter 3.

2.3 Data Sources

The cleaned datasets that are used in this research follow from Van Arkel (2023). This includes data from the Commodity Futures Trading Commission (CFTC, 2023) on open interest and futures prices in the soybeans futures market. Moreover, the datasets contain data from the Food and Agriculture Organization of the United Nations (FAO, 2023) on soybean production levels, and from the International Monetary Fund (2023) on soybean spot prices.

The discussion regarding the interval of the data (monthly or daily) has been addressed by different researchers, among which Von Witzke & Noleppa (2011), who claim that using daily price data leads to unexplained fluctuations. Daily data would be affected by so many different idiosyncratic, technical factors, that the use of monthly data is preferred. Monthly data are already smoothed: while this research uses monthly price data to assess the relationship between speculation and price fluctuations, the model could also be used to assess the sensitivity to higher order exponential smoothing (with different orders of delays). The purpose of higher order smoothing is to find the model structure that generates the behavior that is (nearing) the price-setting behavior observed in the real world.

3. Literature Review and Conceptual Model

The empirical literature on speculation in commodity markets is vast. This chapter will review the key contributions. Firstly, the role of financialization will be addressed, followed by a discussion of the commodity futures market. A comparison between the traditional and non-traditional speculative theory is made in order to show the current stance in literature on the effects of speculation. Secondly, the workings of the soybeans futures market and the role of supply and demand changes will be investigated to formulate a conceptual model.

3.1 Speculation in Commodity Markets

Before addressing the speculation in the context of the soybeans market, the theoretical role of speculation in commodity markets is discussed. How can an increased level of speculation be identified, and how does previous research define the role of speculation?

3.1.1 Financialization of Commodity Markets

To understand the potential role of the process of financialization in commodity pricing, it is important to first address this concept in itself. According to literature, financialization involves the increasing dominance of the financial sector within the global economy, including the expansion of financial motives and financial actors within different markets (e.g., Falkowski, 2011). The comparative growth of Finance, Insurance, and Real Estate (FIRE) has enabled profit making through complex financial assets (Clapp & Isakson, 2018a). Revenues of the non-financial economy (the 'real' economy, where production of non-financial goods and services takes place) have been transferred to the financial sector.

The role of financialization within global commodity markets has changed since early 2000s, when a large inflow of financial investments occurred (Falkowski, 2011). This process was strengthened even further during the financial crisis of 2008: after the collapse of mortgage and stock markets, data show how investors shifted away from mortgage-backed and asset-backed securities towards commodity futures markets for alternative investments (Lagi et al., 2011). Moreover, evidence showed an existing negative relation between commodity returns and stock returns (Greer, 2000). This negative correlation can be explained through the correlation of commodity and stock returns with the rate of inflation: while commodity returns are expected to rise with rising inflation, stock returns are expected to decline with rising inflation (Greer, 2000). Since commodity markets were clearly behaving differently than the stock market, these commodity markets became an opportunity for investors to diversify their investment portfolios to achieve higher returns. Thanks to the deregulation that took place in for example the US since the 1980s, the commodity markets became more open and accessible to (index) investors (Clapp & Isakson, 2018b).

3.1.2 Speculation in Commodity Futures Markets

Tang & Xiong (2012) discuss one of the most popular strategies in commodity investment: investing in commodity indices. The investor buys a basket of commodities in which each commodity holds a particular weight. The most popular indices are the S&P GSCI and the DJ-UBSCI. Next to index investment, the futures market offers speculators a more direct investment opportunity to enter commodity markets. A futures contract is a standardized, exchange-traded contract in which a particular commodity is bought or sold at a specific time in the future at a predetermined price (Lioudis, 2022). Futures are different from options, which give the speculator the right, but not the obligation to go through with the transaction at the time the contract expires. Since futures and options markets include different price-setting mechanisms (Hull et al., 2013), and since the impact of the options market is *"closely related to the impact of futures contracts"* (Knittel & Pindyck, 2016, p. 90) this research focusses on the bigger futures market.

Within futures markets, speculation relates to the buying, holding, and selling of futures in order to profit from price fluctuations. Another type of market activity is called *hedging*, and the difference with speculation relates to the level of risk-aversion (Robles et al., 2009). An example: a risk-averse hedger could be a farmer, holding an inventory of soy. If the farmer expects the price of soybeans to fall in the future, he or she will hedge by selling the soybeans for future delivery at the current price (short selling). The other way around, a producer of soymilk could be aware that he needs a certain number of soybeans in the future to produce the milk, so that when he expects a rise in soybean prices, this risk can be hedged by buying the soybeans for future delivery at the current price (long buying). Instead of hedging risks, a speculator accepts certain price risks in order to make a profit. The commodities are normally not directly handed to the speculator because the contracts are closed out before they expire, meaning a new contract is entered with further expiration maturity. Speculators bet on price changes to spread the risk on their portfolios.

Knittel and Pindyck (2016) mention the difference between spot prices, which are the current prices for immediate delivery, and futures prices, which are prices stated in futures contracts. Speculators selling and buying futures contracts influence futures prices (Ready & Ready, 2022), but the question is whether or not speculation also influences the spot prices. This has been investigated by Lagi et al. (2011): by asking individuals at the US Department of Agriculture how spot prices were determined, the writers found that *"the futures market serves as the starting point for spot market prices"* (p. 12). In theory, the primary price-setting mechanism of spot prices is thus determined by futures prices, specifically by the Chicago Board of Trade futures exchange. This price discovery role of futures markets emerges from the fact that futures markets generally react more quickly to changes in supply and demand (Belke et al., 2013). However, the empirical causality between futures and spot prices is still much disputed. For example, Irwin et al. (2009) argue that long-term equilibrium prices are set in the spot market instead of the futures market.

3.1.3 Theories of Speculation

The advantages and disadvantages of speculation relate closely to the different theories around speculation. The traditional speculative theory claims that speculation stabilizes financial markets (Algieri, 2012). This relates to the previously discussed concept of hedging: speculators enter the market and fill the imbalances that occur through hedgers' demand and supply. By taking opposite positions, speculators take on the risks that hedgers try to mitigate, while also providing liquidity to the market. They allow producers and consumers to continue their real work without having to worry about price changes (Ghosh, 2010). Therefore, research by Kim (2015) but also by Irwin & Sanders (2010) suggests that limiting speculation could deprive the commodity markets of liquidity and price efficiency in times of higher demand. Kim (2015) even shows how the futures market actually reduces spot price volatility, and therefore argues that regulatory changes to limit speculative activity would not improve the situation in commodity markets. Boyd et al. (2018) also advise policymakers to look carefully at the empirical evidence of negative aspects of speculation before interfering in a potential well-functioning, efficient commodity market.

Supporters of the non-traditional theory claim that an increase in speculative activity has resulted in destabilized markets (Algieri, 2012). This theory states that excessive speculation distorts the market by driving prices away from the values that would occur through changes in fundamentals, potentially resulting in market bubbles. According to Masters & White (2008), speculators are dangerous to market systems, driving up (spot) prices beyond levels warranted by (actual) levels of demand and/or supply. From 2003 till 2008, the money spent towards commodity index investing has grown from $13 billion to $317 billion. The ability of producers and consumers to determine prices has weakened, and the price discovery function becomes distorted. Masters & White (2008) therefore argue that stronger regulations to limit excessive speculative activities are necessary. The International Panel of Experts on Sustainable Food Systems (IPES-Food, 2022) also concludes that excessive speculation could result in high upward swings that are not caused by changes in supply and demand, affecting the poorest people worldwide, like in 2007-2008. Lastly, Kornher et al. (2022) argue that excessive speculation becomes problematic once it causes prices to deviate from the aforementioned market fundamentals, influencing price volatility. They therefore suggest the implementation of regulations with high levels of market diagnostics and transparency, and a limited amount of high-frequency trading. This is consistent with the statement made by the G7 Agriculture Ministers (G7 Germany, 2022, pp. 2-3): *"we will not tolerate artificially inflated prices that could diminish the availability of food and agricultural products. We will also fight against any speculative behaviour that endangers food security [...] Therefore, we are closely monitoring markets affecting the food system, including futures markets."*

3.2 The Soybeans Market and Behavior

This section describes the characteristics of the soybeans market. Moreover, the role of fundamental demand and supply changes will be discussed, as well as the role of speculation in price changes and expectations. Each section adds information on the conceptual model that is created at the end of this chapter.

3.2.1 Characteristics of the Soybeans Market

In the soybeans futures market, soybeans are the underlying commodity for the futures contract (Hill, 2016). It is a popular commodity, because it is a widely used product: it is used for livestock feed, or as a meat substitute. Most of the soybean production is based in the U.S., Argentina, Brazil, China, and India. China is also the biggest importer of soy, importing more than 50% of all production. The soybeans futures contracts market consists of two types of contracts:

- Mini-sized soybeans, with a contract size of 1000 bushels (outside of the model scope)
- Regular/Standard soybeans, with a contract size of 5000 bushels (shown in the model)

There are many factors influencing the supply side of the soybean market. Firstly, supply strongly depends on whether or not the harvest was successful. Crop diseases or potential delays could be causes of lower supply. Moreover, there exists variety in the growing time of soybeans, which lies between 100 – 150 days (BarChart, 2023).

3.2.2 A Discussion of Fundamentals and Speculation

A simple model of supply, demand and inventories can be used to show how changes in fundamentals are different from speculative changes. Moreover, the model can be adapted to include price expectations and speculative activity.

3.2.2.1 A Supply and Demand Model

Knittel and Pindyck (2016) emphasize the fact that the effect of speculation is not a shift in fundamentals, meaning a shift in consumption demand or supply. These shifts can cause price changes but are not caused by investors or speculators. A shift of fundamentals in the soybeans market could for example occur because of a failed harvest (which results in a downward shift in supply) or increased use of soybeans for different types of products (which results in an upward shift in demand). Price changes caused by speculators can occur in different forms, of which the following two are most common (Knittel & Pindyck, 2016):

- Holding soybean inventories: a producer of soybeans in principal holds inventories to avoid stock-outs in cases of higher demand. However, if the storage capacity is available, producers could also hold inventories to speculate. These ‘excess’ inventories are used to speculate on a higher prices in the future.
- Holding futures: an investor either holds a long futures position when he or she expects soybean prices to go up or holds a short futures position when he or she expects soybean

prices to go down. In other words, speculators 'bet' on prices by buying futures. This way of speculating is directly affected by the accumulation of inventories, which will change the value of storage and thereby change price expectations.

Knittel & Pindyck (2016) have provided a simple model of supply and demand in order to determine the role of speculation in the market for crude oil. They state that the model can be applied to different types of commodities. They distinguish three markets which interact through price-setting mechanisms. These three markets will be used as a starting point for the system dynamics model for soybeans.

3.2.2.2 The Cash Market and Market for Storage

The cash market as shown in Figure 3.1 involves the production and sales occurring at the spot price of the commodity. The difference between production and consumption concerns the inventory levels (for every commodity that is not sold, has to be stored somewhere), and depends on both the spot price and the price elasticities of supply and demand. These latter variables show how sensitive the level of supply and demand are to changes in price (Knittel & Pindyck, 2016). For soybeans, the price elasticity of supply is assumed to be 0.1 (Babcock, 2021) and the price elasticity of demand is assumed to be -0.4 (Huang, 1979). Changes in price do not directly result in changes in production or demand: perspectives of producers and consumers are delayed by the production adjustment time and demand adjustment time.

The second market involves the market for storage. The supply of storage is equal to the total quantity of inventories and, in equilibrium, is equal to the demand for storage. Knittel & Pindyck (2016) argue that the value of holding inventory depends on the demand for storage: when the total stock of inventories is very large, holding extra inventory will be of little value. This is consistent with the Theory of Storage by Working (1949), which states that the return on storing products between time intervals depends on the level of inventory during that interval. The value of storage can be measured through the marginal convenience yield: *"the value of the flow of services accruing from holding the marginal unit of inventory."* (Knittel & Pindyck, 2016, p. 93). The convenience yield reflects the value of holding the physical commodity as an asset instead of the underlying futures contract. In normal conditions of supply and demand, the convenience yield is likely to be small (near zero percent), for there are adequate inventories over the near term (Gulley & Tilton, 2014).

How are cash and storage markets connected? According to Knittel & Pindyck (2016), the spot price in the cash market depends not only on the futures price, but also on the per unit costs of physical storage and the convenience yield coming from the storage market. These factors have one thing in common: they relate to the cost of carry, which includes all costs that come from holding inventories (Chen, 2020). Storage costs (or the per unit cost of physical storage) are the most obvious cost item. A change in the per unit cost of physical storage mostly reflects a change in fundamentals: the prospect of a failed harvest leads to a temporary increase in the storage costs. Moreover, the higher the marginal convenience yield (which reflects the value of storage), the lower the actual cost of carry. High cost of carry implies that holding commodities is expensive, and this will be reflected in a lower spot price.

The risk-free interest rate is a theoretical concept which refers to an investment with zero risk: while in reality, no investment is without risk, the interest rate on the most secure investment opportunity of Treasury Bills is often noted as the risk-free interest rate (Van Binsbergen et al., 2022). The calculation of the present value of spot prices should account for this risk-free rate: this will be discussed in more detail in the model equations in section 5.2.

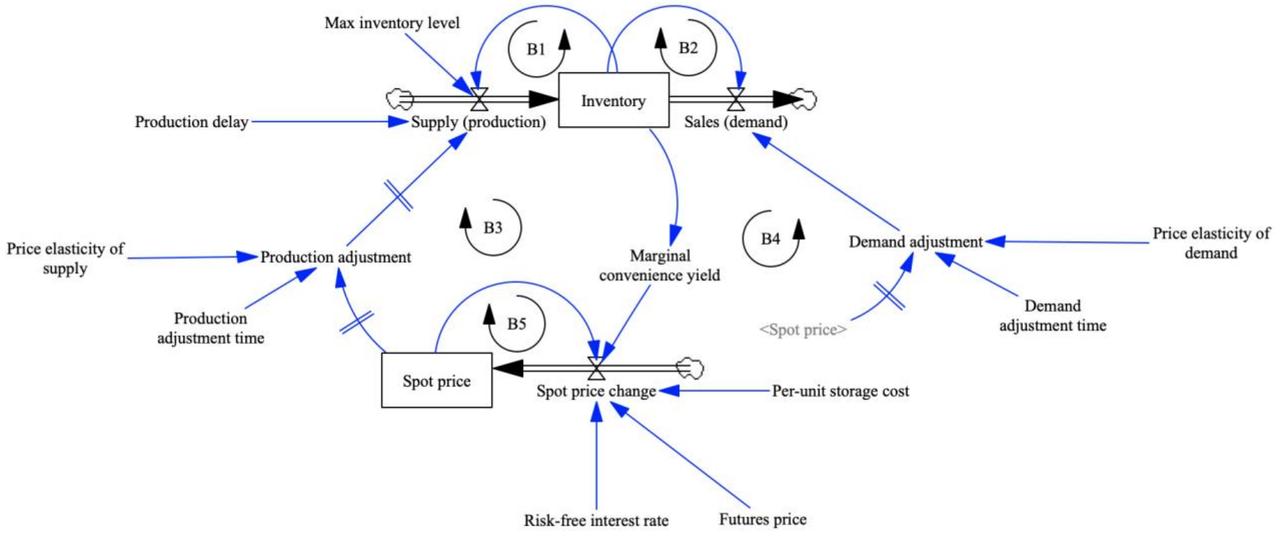

Figure 3.1: Conceptualization of the Cash and Storage Market

3.2.2.3 Expected Rate of Return and Price Expectations

Next to the cash and storage market, there exists a futures market (Figure 3.2) which is used by speculators to bet on spot prices. De Jong et al. (2022) define a risk premium that is associated with the expected profit of a speculator. This risk premium is calculated through the use of to the rate of return that is required for an investor to invest in the futures contract and yield a profit (Dupoyet, n.d).The expected rate of return compensates the speculator for the risk that is transferred from the hedger (Van Huellen, 2017). Differences between spot and futures prices can be explained through for example storage costs, but also through this risk premium, as confirmed by expert C.

If the expected rate of return is higher than the risk-free interest rate, a speculator experiences a positive systematic risk when holding a long position in the soybeans futures market. In this situation, the futures price lies below the expectations for the future spot price, which means investing in the futures market would most likely yield positive results for an investor who holds a long position (meaning the investor actually owns the futures contract and sells the soybeans at the higher expected spot price when the contract matures). When expectations for the future spot price are higher than the futures price, a market is in normal backwardation (Miffre, 2000).

The opposite situation occurs when the market is in normal contango, meaning the futures price exceeds the expectations of the future spot price (Miffre, 2000). In this case, the risk-free interest rate is higher than the expected rate of return, and investors will experience a negative systematic risk (Dupoyet, n.d). Speculators are betting short by selling the futures contract at the current futures price and are planning to buy back the soybeans once the lower expected spot price occurs.

How do speculators actually determine their expectations for prices in the next period? Many theories around price expectations have been formulated and compared. While traditional rational expectations theory has been employed often, Chow (2011) finds strong statistical evidence of support of the adaptive expectations theory. Moreover, the adaptive expectations theory matches most literature on speculative expectations (De Jong et al, 2021). In the simplest version, the spot price expectation of the current period is dependent on last period's expectations and the actual current spot price. More recent prices are expected to play a bigger part in current price expectations, and the importance of expectations from a very early period is limited.

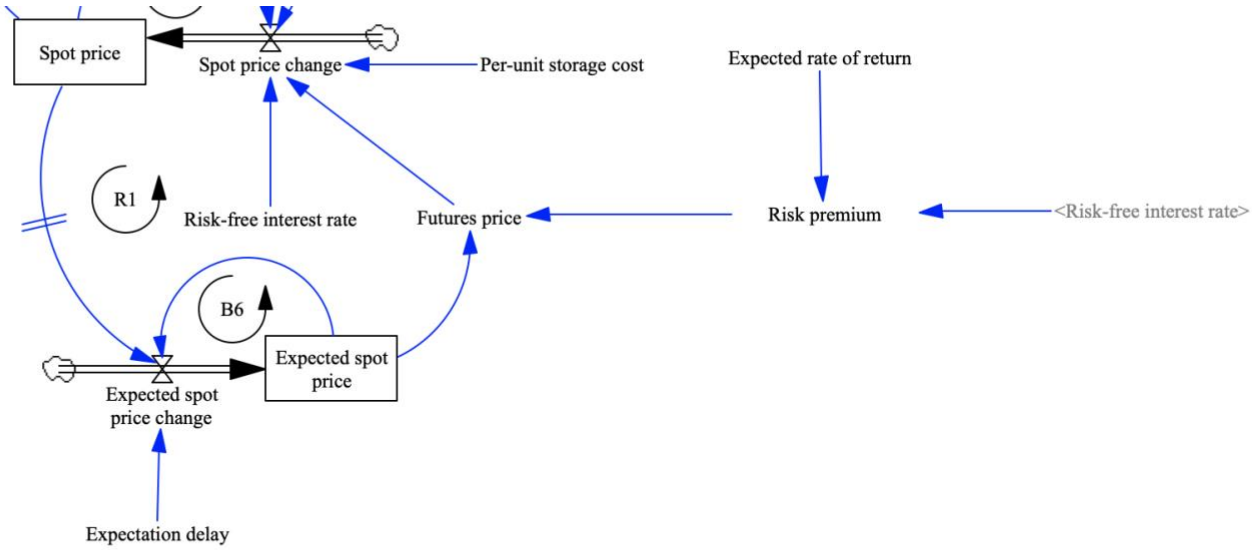

Figure 3.2: Conceptualization of the Futures Market

3.2.2.4 The Role of Speculation in the Expected Rate of Return

While the level of speculation that occurs in the commodity futures market as described by Knittel & Pindyck (2016) relates to the demand for futures, speculation itself cannot directly be measured through the volume of futures contracts. An increase in the demand for futures does not necessarily mean that an increased level of speculation has occurred. Therefore, other indicators should be used: previous research on speculative activity often uses the following indicators for speculation (Robles et al., 2009):

- One potential indicator is the open interest of futures contracts (Robles et al., 2009). Open interest in futures contracts includes the *"total number of contracts that have not yet been offset by an opposite futures position or fulfilled by delivery of the commodity"* (p. 4). This open interest is often used as an indication of risk hedging activities. Once a trader takes a long or short position in the market, this generates an open position until the contract either expires or until the trader chooses the opposite position. On average, open interest in the soybeans market has been increasing, as can be seen in Figure 3.3 (Van Arkel, 2023). A higher open interest could reflect an increase in the number of medium- and long-term speculators.

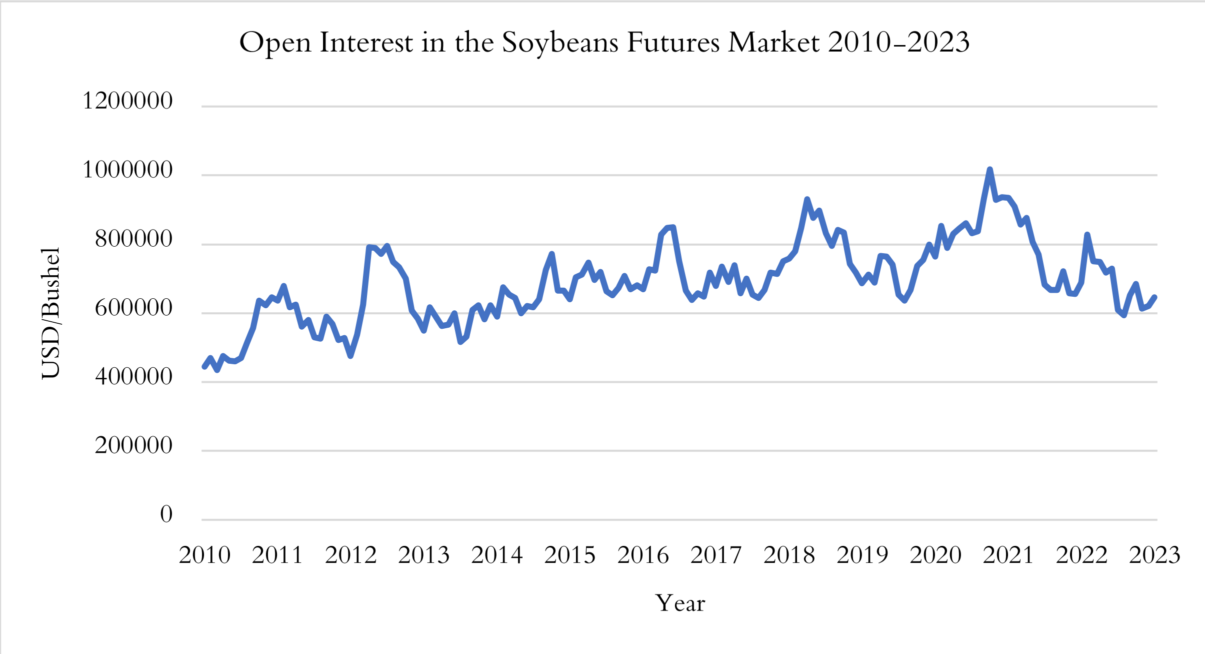

Figure 3.3: Growth in the Level of Open Interest (Van Arkel, 2023)

- Another potential indicator is the monthly ratio of the volume of futures contracts to the open interest of futures contracts (Robles et al., 2009). The ratio of volume of contracts to the open interest of contracts tries to capture speculation while assuming that speculators try to get in and out of the market very fast: short term speculators would generate a higher monthly volume of futures contracts, but would barely change the open interest, for their contracts are already offset or fulfilled.
- Another indicator that is often used, is the monthly ratio of noncommercial positions to total positions in futures contracts (Robles et al., 2009). A commercial trader uses futures contracts to hedge risks, whereas a noncommercial trader represents speculative activity to make a profit. The ratio therefore indicates the relative number of investors who engage in speculation.

The conceptual model will focus on the first indicator, the open interest level, to further formulate the quantitative model. The reason why the open interest is preferred over the other two indicators, is that accurate open interest data can be found through the CFTC (2023), whereas data on the volume of futures contracts if often less accurate or missing. Moreover, the distinction between noncommercial positions and commercial positions is often found to be unambiguous: commercial traders can have speculative purposes, and non-commercial traders can be motivated through other purposes than speculation (Alquist & Gervais, 2013).

Hong & Yogo (2010) argue that the level of market activity, measured through the level of open interest (as an indication of the number of contracts that is traded in the market), is a very powerful predictor of commodity returns. They find that *"a standard deviation increase in open-interest growth increases expected commodity returns by 0.64% per month"* (p.3). As stated earlier, commodity returns are closely related to the risk premium. The relation between risk premia in de futures market and the level of market activity has also been investigated by Kocagil & Topyan (1997). They find a positive correlation between the risk premium (which they define as the spread between the expected spot price and the futures price) and the open interest: an increase of the open interest leads to an increase in the spread between expected spot prices and futures prices. This can be explained through the fact that a higher intensity of trading indicates a higher level of market uncertainty. The market risk that is perceived by traders has to be compensated through the expected rate of return, which is why the spread between the expected spot price and the futures price grows with the open interest level. This corresponds to the findings of Hong & Yogo (2010).

As mentioned above, a higher expected rate of return results in futures prices that lie below the expected spot prices (an outcome known as normal backwardation). Therefore, the level of open interest moderates the effect of expectations on futures prices, and eventually on spot prices. Research not only shows how open interest levels can be used to predict futures prices in de long run: Gulati (2012) even finds a bi-directional effect between futures prices and open interest in the Indian futures market. A higher futures price attracts traders and is reflected in a higher level of open interest. In the model, this effect will follow from the influence of price expectations on the level of open interest, as can be seen in Figure 3.4. Higher price expectations result in a higher open interest level after the open interest adjustment delay.

3.2.2.5 Open Interest and Market Indications

Next to the use of open interest as a predictor of prices, open interest is also used as an indicator of market strength. Futures traders use the level of open interest as a sign of market conditions. Depending on whether or not market prices and open interest are rising/declining simultaneously, markets can be classified as *bearish* or *bullish* (Hall, 2022). The market is assumed to be strong and *bullish* when both prices and open interest are rising: participants and new money are entering the market because of attractive prices. A downward trend in both prices and open interest is also a *bullish* sign: speculators are forced to sell their positions out of fear of further decline in prices. However, there are also situations where prices are actually rising (declining) while open interest is declining (rising) (Hall, 2022). This happens either when speculators are selling short to cover their positions, and money is leaving, or when speculators believe new money is coming and start buying long. The conditions are therefore classified as *bearish* market trends.

As previously discussed, it is assumed that an increase in the expected spot price results in an increase in open interest. This would indicate *bullish* market signs because a higher price gives a higher open interest. However, due to potential delays in changes of price expectations (Lagi et al., 2011) and open interest, *bearish* market signals might also occur.

3.2.2.6 Speculation in Weakly and Strongly Coupled Markets

De Jong et al. (2021) argue that speculation has a stabilizing effect on prices when the coupling of the spot and futures market is weak. When the futures and spot market are weakly coupled, higher price expectations will lead to an increase in production and decrease in demand. Higher inventory levels result in a lower convenience yield, and therefore in lower spot prices. The balancing effect of the convenience yield makes for stable price dynamics: only external demand or supply shocks will temporarily disrupt the system.

The opposite happens in strongly coupled markets, where the number of speculators is high and storage costs are low. Financialization is one of the causes of stronger coupling between markets (De Jong et al., 2021). Expectations of speculators in the futures market become more important when the coupling strength between the spot and futures market increases: higher expectations raise both the futures and the spot price, and because of trend-following behavior, a higher spot price will lead to higher expectations. According to Ghosh (2010), speculation cannot create extreme price fluctuations in conditions of plenitude in supply: only if there is an expectation of higher prices due to for example an expected supply shortage (stimulated by an already existing indication of potential shortages), speculation will have significant influence on price changes. Let's say speculators predict a significant lower supply in the future (due to crop diseases), which leads to an increase in expected spot prices. Speculators will act by increasing their demand for futures and create a *self-fulfilling prophesy*: increased demand leads to higher prices (Gale, 1955), and expectations are confirmed. Other speculators will act again based on their new heightened expectations. The reinforcing effect of expectations makes for strongly fluctuating prices. The model will show this reinforcing effect through the expectation delay (Figure 3.4). Looking back at one of the indicators of speculation, the ratio of volume of contracts to the open interest of contracts, it was argued that this indicator captures speculation because most speculators try to get in and out of the market relatively fast. Speculators use a more technical analysis of the spot price, rather than an extensive fundamental analysis (CFI, 2023). They are more active traders: profit making through price fluctuations is only possible if speculators are able to react fast on price fluctuations, and therefore are able to adapt their price expectations without a long delay. In the model, it is therefore assumed that the expectation delay is lower when an increased number of speculators has entered the market.

An important side note to make here, is that in reality, the level of open interest will indicate a higher level of speculation and therefore influence the expectation delay. However, it is also argued that short-term speculators who lower the expectation delay change the total volume of future contracts, but not the open interest itself, since their contracts are already offset or fulfilled (Robles et al., 2009). Due to uncertainty regarding the quantitative effect of open interest on price expectations and delays, this link won't be shown in the model.

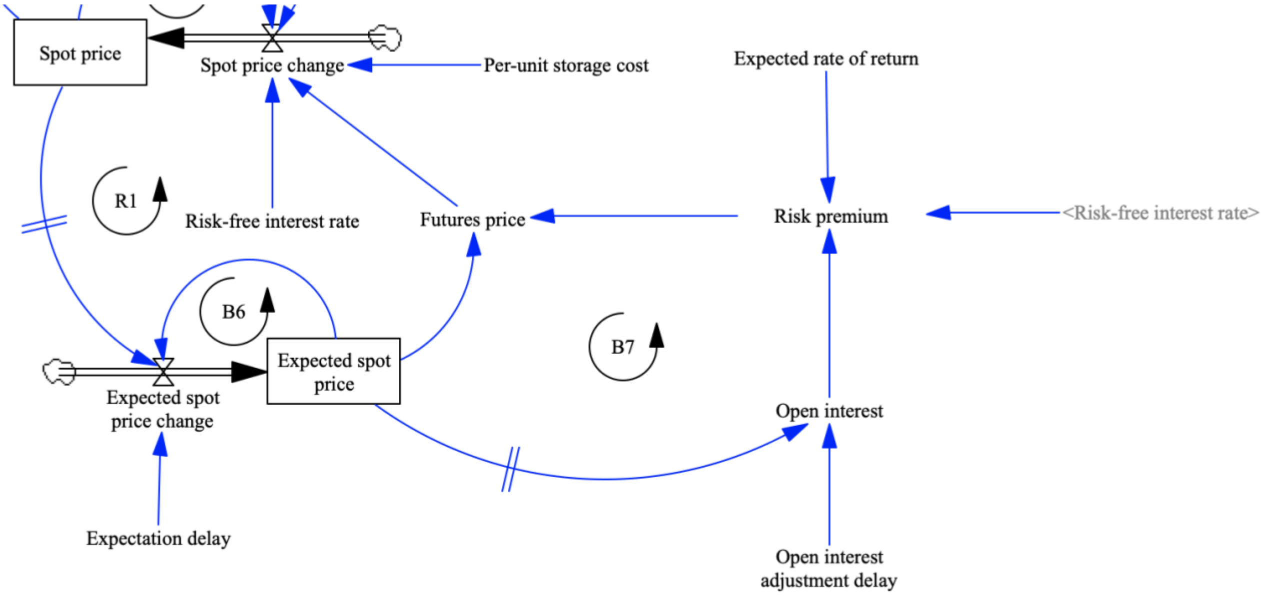

Figure 3.4: Conceptualization of the Futures Market and Speculation

3.3 Conceptual Model and Dynamic Hypothesis

Putting together the different parts of the conceptual model, Figure 3.5 shows a complete stock flow diagram of the system. Appendix A shows the sign of the relationship between each variable in the diagram. The following loops can be identified:

- **Inventory – supply loop** (**B1**): this balancing loop shows how the potential increase in supply change depends on the current inventory level. However, this loop is delayed by the production delay, which shows the time before soybeans can be harvested.
- **Inventory – sales loop** (**B2**): this balancing loop shows how sales depends on the current inventory level. If inventories are higher, sales can be higher. However, if the sales are higher, inventories are lowered.
- **Production – spot price loop** (**B3**) and **demand – spot price loop** (**B4**): these relationships form two balancing feedback loops, relating to one of the oldest concepts in economics: the law of supply and demand (Gale, 1955). Rising spot prices make an increase in production more attractive to suppliers (after a production adjustment delay), which results in an increase in supply after a production delay. However, higher prices make buying less attractive to customers, which results in a decrease in demand and sales

after the demand adjustment delay. Increased supply and decreased demand make for a higher supply/demand ratio: supply exceeds demand, which leads to a decrease in prices. This makes production less attractive, but consumption more attractive, and stabilizes the system towards a price equilibrium.

- **Spot price (change) loop (B5)**: this balancing loop shows how the change in spot price depends on many different variables (futures price, storage cost, etc.) but also on the current spot price. A higher current spot price indicates less change in the spot price.
- **Spot price – price expectations loop (R1)**: this relationship results in a reinforcing feedback loop. A higher spot price makes for higher expectations regarding potential future increases, which results in higher expected spot prices. These higher expected spot prices lead to an increase in the futures price. The hypothesis following from the literature review is that the futures price is directly related to the spot price.
- **Expected spot price (change) loop (B6)**: this balancing loop shows how the change in expected spot price depends on the current spot price and the expected spot price. However, this loop is delayed by the expectation delay, which shows the time before a new spot price leads to a change in price expectations by investors.
- **Open interest – futures price loop (B7)**: this balancing loop exists because of the positive influence of expectations on open interest levels and the negative influence of open interest on the risk premium and futures price. Higher expectations result in a higher open interest level (after a delay), and the latter variable is negatively correlated with the risk premium. A lower risk premium lowers the futures price, and therefore expectations.

From the complete conceptualization in Figure 3.5, it can be concluded that the system consists mostly of balancing loops that are delayed, with the exception of one delayed reinforcing loop. In system dynamics, oscillating behavior often occurs because of different interacting delayed loops (Meadows, 2008). The dynamic hypothesis therefore includes oscillating behavior. Depending on the delayed reinforcing loop, this oscillation might have an upward direction. The hypothesis is that the length of the delays determines the amplitude and speed of the oscillation.

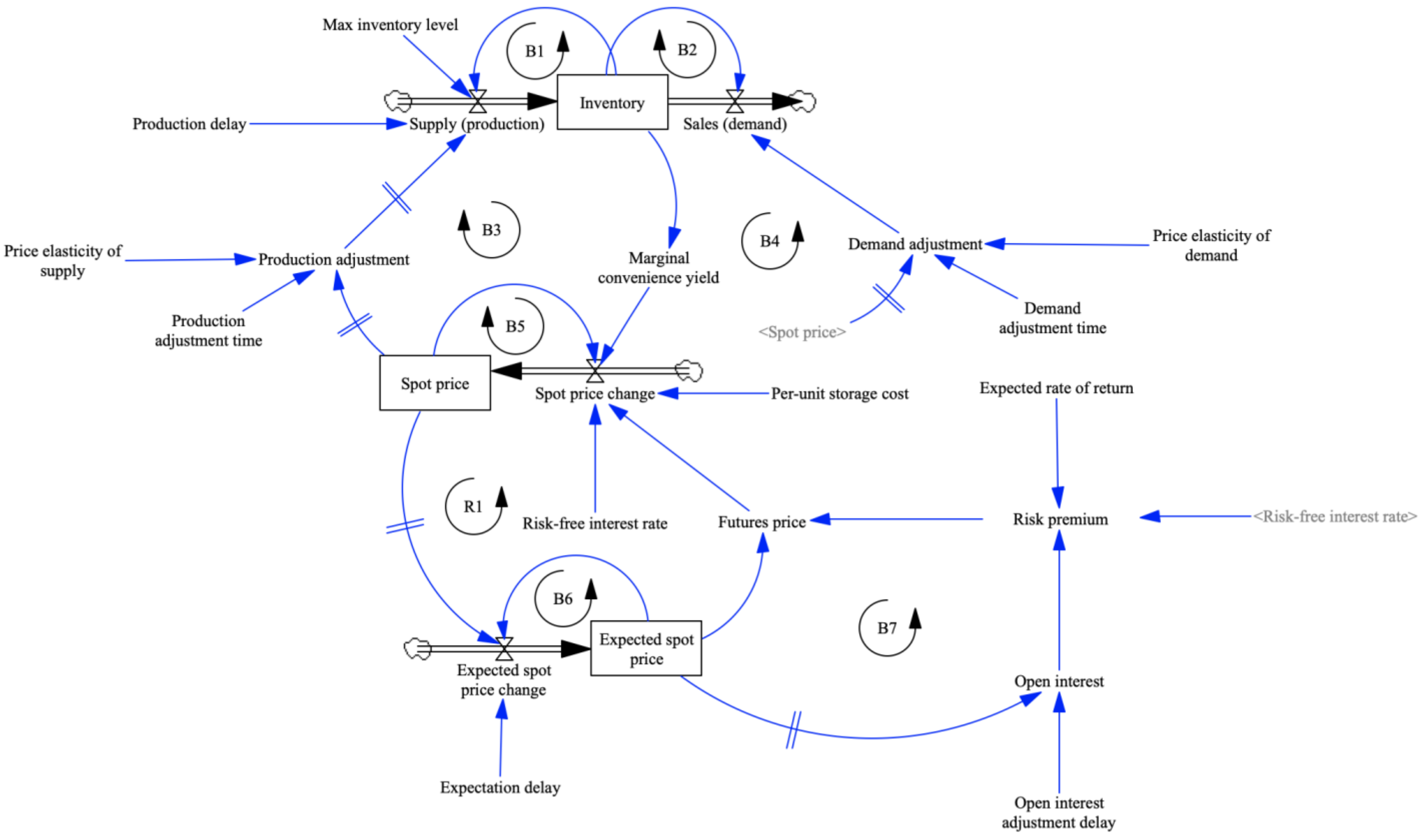

Figure 3.5: Complete Conceptualization

3.4 Conclusion on the Theoretical Role of Speculation

The literature review and following conceptual model provide an answer to the first sub-question S1: *'What is the theoretical role of speculation in commodity pricing?'* An investigation of the working of price discovery in the soybeans market indicates that spot prices are influenced by different factors. The storage market changes spot prices through the convenience yield (value of storage), showing a balancing effect of inventory levels on this yield and spot prices. Changes in spot prices lead to adjustments of production and demand levels. Another storage-related factor is the per unit storage cost, which holds a negative relationship with spot prices. The last factors that determine the spot price are the risk-free interest rate and the futures price. This latter variable shows the impact of price expectations on the spot price.

The impact of speculative activity through price expectations has been addressed by many authors, among which most acknowledge a strengthening of price expectations because of the trend-following behavior of speculators. Speculators are assumed to react faster to changes in spot prices, resulting in a shorter delay between current and expected spot prices. It is expected that model behavior is dependent on the interaction of this expectation delay, the material delay influencing supply, and information delays influencing production and demand levels. Lastly, empirical investigations in literature indicate a potential moderating effect of speculation in the form of open interest levels. Higher spot price expectations make for a more attractive market, which creates a higher level of open interest (after a delay). A rise in open interest is followed by a higher expected rate of return and a lower risk premium, which results in lower futures prices compared to spot price expectations.

Two theoretical effects of speculation are described in the conceptual model: speculators lower the expectation delay (within the reinforcing feedback loop), and while higher price expectations lead to an increase in the level of open interest, this lowers the risk premium and futures price (within the balancing feedback loop).

4. Regulations in Commodity Markets

Commodities are traded on commodity exchanges all around the world, such as the Chicago Mercantile Exchange (CME) and the Intercontinental Exchange (ICE). There are no global regulators formulating regulations on speculation and futures trading. The major regulatory systems in both the U.S. and Europe will be discussed, for markets in the U.S. and Europe are largely responsible for the determination of global commodity prices. Moreover, these areas are known for the implementation of active approaches to regulate commodity exchanges via for example position restrictions (Staugaitis & Vaznonis, 2022). This chapter answers the second sub-question: 'What policies are currently in place to deal with the effects of increased speculative activities?' The literature on this subject is extended through expert interviews. The general interview questions and expertise of the different experts can be found in Appendices G and H.

4.1 Commodity Trading before 2008: the Link between Food and Finance

Commodity trading is no new phenomenon: already in the 18th and 19th century, futures markets provided a way to bring merchants and farmers together (Clapp & Isakson, 2018a). The purchasing and selling of a commodity at a future date created a way to hedge risks that for example came from weather conditions. From this time onwards, speculators have always been suspected from manipulating markets instead of providing liquidity. Since 1974, the Commodity Futures Trading Commission (CFTC) is therefore responsible for the regulation of commodity exchanges in the U.S (IATP, 2008). It negotiates with legislative authorities all over the world by communicating bilateral memoranda of understanding, which are not legally binding, but are used to show a mutual willingness to take specific actions. The CFTC regulates commodity exchanges and futures through the Commodities Exchange Act (CEA), which passed in 1936 and has been amended several times (CFTC, n.d.). It states that all commodity futures should be traded on organized exchanges. The Act was used to impose limitations on speculation by for example restricting position sizes: the position limit was introduced, meaning a monthly or daily cap on the position that an investor is allowed to hold (IATP, 2008). However, in 2000, commodities futures trading was deregulated through the Commodities Modernization Act, which led to a massive increase in trading volume of different financial products linked to commodities (Gimet et al., 2019). According to Ghosh (2010), the US became an arena for speculators because of the enormous credit system and the deregulation mentioned above: investors were able to diversify even without purchasing futures contracts directly, for example through Commodity Index Funds. Expert B emphasizes that the relaxation of the rules in 2000 led to an inflow of new actors (including large-scale investors, such as pension funds) with an increased demand for new financial products, which coincided with price spikes.

4.2 The Financial Reforms after 2008

After the financial crisis of 2008, the U.S. again sought to regulate financial products through the Dodd-Frank financial reform act (IPES-Food, 2022). However, these legislations have been watered down following lobbies by the financial industry (as stated by expert B and expert D), which created many loopholes around speculative positions limits. In 2020, when the CFTC introduced a new position limits rule, commissioner Berkovitz concluded that this rule *"fails to achieve the most fundamental objective of position limits: to prevent the harms arising from excessive speculation."* (Ferrando, 2023, section *"If food is life"*). The definition of excessive speculation became a point of discussion, for the CFTC clearly had other boundaries in mind than the commissioner.

In Europe, the Markets in Financial Instruments Directive (MiFID) was adopted, which also introduced position limits (EC, 2016). Experts have concluded that these limits are too high to actually reduce the level of excessive speculation (Burns, 2016). In 2018, the European Security and Markets Authority (ESMA) set new spot month limits and open interest limits through consideration of European production, export, and market dynamics. However, recent years have shown that these guidelines did not prevent more intensified speculation: speculators' share in for example the Paris wheat market increased from 23% in 2018 to 72% in 2022 (Ferrando, 2023). Van Huellen (2017) concludes that limiting the potions of individual traders is not enough to curb speculation: instead, the total market weight of trend-following speculators should be monitored and curbed.

Both in Europe and the U.S., the reforms that were implemented to counter speculation were found to be insufficient (IPES-Food, 2022). Ferrando (2023) concludes: *"Rather than providing a guarantee against excessive fluctuations, the trading in future contracts by non-food actors left grain chains at the mercy of financial considerations and objectives, creating a domino effect that subverted the functioning of the supply chains and reverberated across the world."* (section *"evidence of excessive speculation"*).

4.3 The Crisis of 2008 Compared to the Current Food Crisis

The crisis of 2008 has been investigated extensively in literature. While commodity markets are currently experiencing similar price spikes as in 2008, the market behavior is different. Expert B mentions how prices have stayed high and volatile after the 2008 crisis, whereas we are currently looking at more temporary price spikes. This can be explained through different macro-economic conditions: while the interest rates on government bonds were very low in the years after the 2008 crisis, speculators can currently enter (safe) government bonds which pay a higher interest rate of 4% - 5% (Mercado, 2023). Commodity markets remained attractive after 2008 (because the returns on alternative investments such as government bonds remained low), whereas speculators now also move towards other options. In both crises, next to speculation, different factors were linked to the food commodity price spikes, such as biofuel conversion in 2008.

Expert B emphasizes that while the crises might seem similar on the surface, they are different in specific drivers.

4.4 Conclusion on Current Policies to Deal with Speculation

This chapter has provided an overview of the regulations that were implemented after the crisis in 2008. This was done to answer the second sub-question: *'What policies are currently in place to deal with the effects of increased speculative activities?'* Both in Europe and the US, the crisis of 2008 created some awareness with regard to speculation and its effects. The main regulatory measure that was implemented, involved position limits, which should have restricted the number of contracts that can be traded by one single investor. Lobbying by financial actors resulted in the fact that some measures were implemented ineffectively, to the point where most researchers acknowledge that these limits do not work with regard to limiting excessive speculation. Chapter 7 will expand our knowledge on these measures through the investigation of the specific deficiencies of position limits and the impact of identified policies on the structure of the conceptual model from Chapter 3.

5. Model Formulation

After the conceptual model discussion in Chapter 3, this chapter will describe the formalization of the model. First, a model overview shows which sub-models can be identified. Furthermore, the fundamental model assumptions will be discussed. Lastly, the model will be verified and validated using different validation tests that follow from Forrester & Senge (1980).

5.1 Model Overview

Figure 5.1 shows the three different sub-models that interact in the complete model. The following sections will discuss the model equations, delays, and lookups.

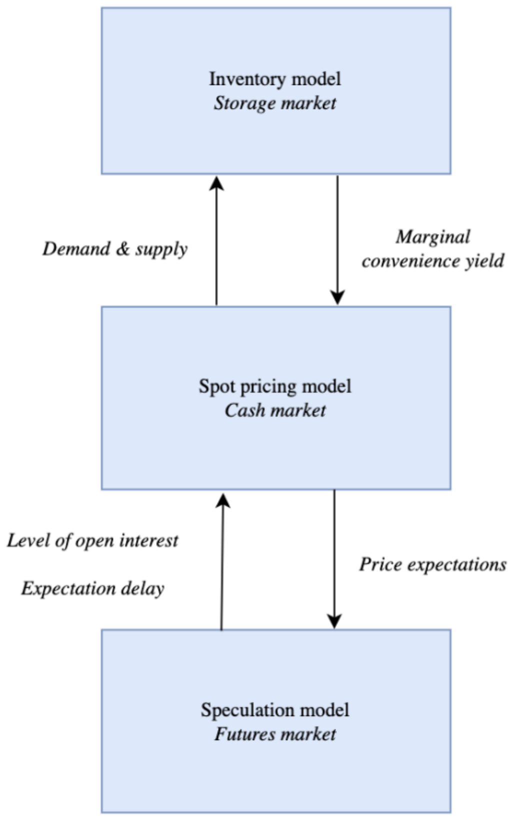

Figure 5.1: Sub-models and Interaction

5.1.1 Model Equations and Delays

A complete overview of the model equations and the visual model can be found in Appendix B. There are few equations that require specific attention. Firstly, equation (1) that is used in the spot price change is as follows (Gulley & Tilton, 2014; Dupoyet, n.d.):

$$\text{"Change in spot price"} = \frac{\text{"Futures price"}}{e^{(\text{"Risk-free interest"} - \text{"Marginal convenience yield"}) * \text{"Time until delivery"}}} - \text{"per unit storage cost"} - \text{"spot price"} \quad (1)$$

This equation shows how the futures price and the marginal convenience yield are positively correlated with the spot price, whereas the risk-free interest, time until delivery, and per unit storage cost are negatively correlated with the spot price. These correlations are the result of the process of discounting (Black, 1988): the futures price (at maturity of the contract) is converted to the present value of the spot price. Because the futures cash flow is certain once the contract is established, this futures price can be discounted to determine the present value of the underlying asset. Therefore, the spot price is equal to the discounted value of the futures price, minus the present value of the storage costs.

As previously discussed, speculators bet on differences between the current futures price and the coming spot price, but not without any risk. The discounting process explained above also serves to avoid the concept of *arbitraging*, which involves the process of buying and selling securities in different markets to profit from price differences (De Jong et al., 2022). An example: suppose an investor buys and stores bushels of soybeans by borrowing money at the risk-free interest rate. Simultaneously, the investor enters a futures contract which states that he or she should deliver the stock of soybeans against the discussed futures price in a few months' time. If the repayment of the loan (calculated over the whole time until delivery) and the present value of the storage costs are smaller than the yield of the sold soybeans (which consists of the marginal convenience yield over the whole time until delivery and the futures price), the investor owns the difference as a profit following from an investment with no risk (Dupoyet, n.d). Therefore, equation 1 holds to avoid arbitraging opportunities.

The use of the natural logarithm in equation 1 indicates a compounding interest, meaning that the marginal convenience yield is compared to the risk-free interest rate while the interest and yield are charged continuously over the new amount (Dupoyet, n.d.). Continuous compounding has an infinite number of compounding periods (no specific incremental time steps over which the interest rate and yield are calculated) during the whole duration of the futures contract. While in reality, continuous compounding is not possible, this way of calculating prices is used extensively in finance to price futures contracts (Harper, 2022).

The model shows no delays between the futures price and spot price because the calculation of the spot price already involves a discounted value of the futures price. In order to calculate the futures price, the following equation (2) is used (Knittel & Pindyck, 2016; Dupoyet, n.d.):

$$\text{"Futures price"} = \text{"Expected spot price"} * e^{(\text{"Risk premium"} * \text{"Time until delivery"})} \qquad (2)$$

The equation shows how the futures price depends on the expected spot price, the risk premium, and the time until delivery. This risk premium is calculated by subtracting the expected rate of return from the risk-free interest rate. A thorough inspection of equation (1) and (2) could raise questions regarding the role of the risk-free interest rate in spot price discovery: if the risk-free interest rate is removed from both equations, nothing will happen to the numerical results coming from running the model. However, for the purpose of clarity and transparency in the workings of price-setting mechanisms, the risk-free interest rate is not removed.

The third equation (3) shows how the expected spot price changes through changes in the current spot price:

$$\text{"Change in expected spot price"} = \frac{\text{"Spot price"} - \text{"Expected spot price"}}{\left(\frac{\text{"Expectation delay"}}{\text{"Delay order"}}\right)} \tag{3}$$

This equation shows one of the information delays that is incorporated in the model. It indicates the time it takes for expectations to change based on the information of changes in spot prices. This delay is currently modelled as a first order information delay. However, the model validation in Appendix F shows tests with different delay orders. Next to this expectation delay, four other delays were identified, which were already presented in the conceptual model in Figure 3.5:

- Production delay: it takes three to five months for soybeans to grow after planting (BarChart, 2023). This delay is modelled as a third order material delay due to different phases in the growing process.
- Production adjustment delay: it takes some time before changes in spot prices affect the beliefs and predictions of producers. Planned production is therefore only adjusted after a delay time. Lagi et al. (2011) found that the time over which producers choose to contract for delivery is about six months to one year. In the model, this delay is modelled as a first order information delay.
- Consumption adjustment delay: it takes some time before changes in spot prices affect the beliefs and predictions of consumers. Consumption is therefore only adjusted after a delay time. Lagi et al. (2011) found that the time over which consumers choose to contract for delivery is about six months to one year. In the model, this delay is modelled as a first order information delay.
- Open interest adjustment delay: once price expectations start to rise, it is expected that open interest levels also start to rise (as found in the literature review in Chapter 3). However, this does not happen overnight: speculative bubbles can have a duration of over a year (Lagi et al., 2023). This delay is modelled as a first order information delay.

In short, there are different types of delays in the model. The sub-model of the storage market shows both material and information flows, whereas the futures market shows only information flows. However, the length of these different delays is uncertain: therefore, Appendix B shows the range of values that was tested in the model. Moreover, interaction between these delays (with different potential lengths) is an important point of investigation and will be reflected on in the experiments of Chapter 6.

The model might not contain all delays present in the economic system. For example, it is unknown if the changes in open interest directly affect risk premia in futures prices. This is potentially a missing delay. This research is mostly focused on delays in the physical spot market: further research into delays in the futures market is required.

For verification and validation, the spot price and inventory variable will be used as key performance indicators. These variables are most effective in showing problematic system behavior, which arises from both an increase of the spot price to unaffordable levels and an unrealistic accumulation of inventories. Accumulation of inventories indicates that while higher demand could be satisfied (since there is enough inventory in stock), the level of demand stays low (because of too high prices).

5.1.2 Assumptions in Model Lookups

Some relationships between variables in the model have to follow from substantiated assumptions, since limited quantitative knowledge is available. This is the case for two lookups used in the model. The first lookup defines the relation between the expected spot price and open interest levels. While the exact relationship is unknown, an assumption can be made based on the possible ranges of both variables. Data show how open interest rates in the period 2010-2023 differ between 400.000 contracts referencing bushels of soybeans and 1.000.000 contracts referencing bushels of soybeans[1] (CFTC, 2023). In the same period, spot prices range from about 8 USD/Bushel to about 18 USD/Bushel (IMF, 2023). Using these ranges and the averages of both variables, a dimensionless graph of the relation was made to construct the lookup, which can be seen in Figure 5.2. The reference point (1,1) refers to 700.000 contracts and a spot price of 12 USD/Bushel, which are the average values of these variables in 2010-2023 (CFTC, 2023; IMF, 2023). It is assumed that open interest levels are capped: once prices more than double, no more speculators will enter the market out of fear of an extreme collapse of the price bubble. At lower price levels, it is assumed that there will always be some speculation, because prices are bound to increase at a certain point in time, and speculators will realize this.

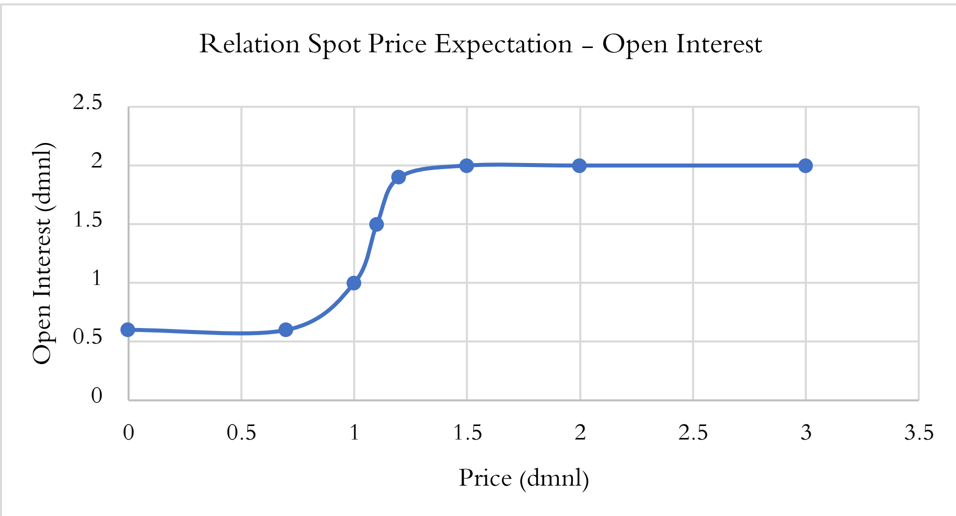

Figure 5.2: Assumption Relationship between Spot Price Expectation and Open Interest

[1] These contracts each reference 5000 bushels of soybeans (see Chapter 3).

Another relationship on which quantitative knowledge is limited, is the relation between the inventory levels and convenience yield. Most research indicates that the range of convenience yield lies within 0% – 10% (Gulley & Tilton, 2014). Furthermore, the curve is known as the downward sloping yield curve (Peterson and Tomek, 2003). An estimated guess of the potential inventory levels and convenience yield is presented in Figure 5.3. The reference point (1,1) refers to a 5% yield and an inventory of 1200 million bushels. A doubled level of the normal inventory level leads to a halved convenience yield. At very high inventory levels, the convenience yield will reach zero (Gulley & Tilton, 2014).

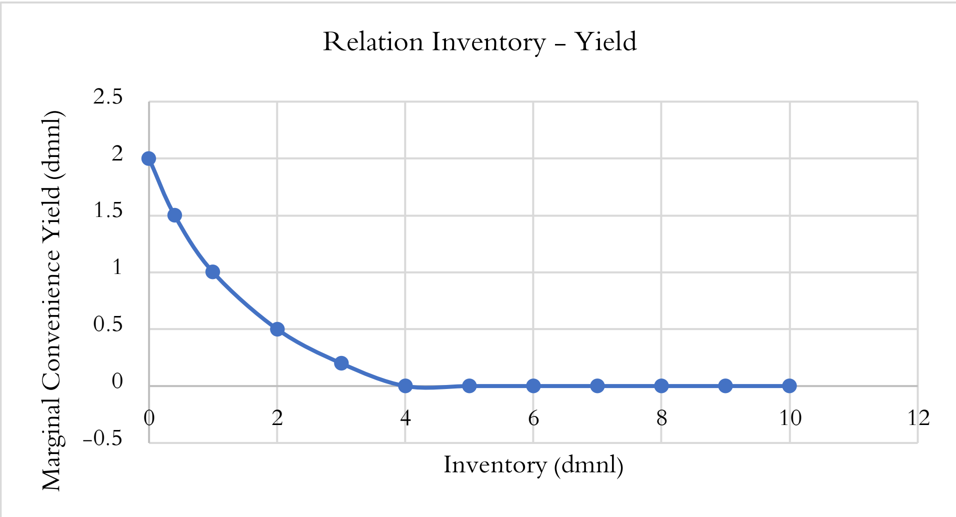

Figure 5.3: Assumption Relationship between Inventory and Convenience Yield

By varying the function of these lookups and looking at the behavior in the model, these lookups and assumptions will be validated (see Appendix F).

5.2 Model Assumptions and Limitations

Since models are (by definition) simplifications of reality, the development of a model requires making assumptions. In economics, discussions on assumptions are always present, specifically regarding causation mechanisms (Heckman, 2000). This section will discuss and substantiate the assumptions and following limitations that were most important for each sub-model.

5.2.1 Inventory Sub-model

The inventory model currently assumes a constant monthly supply and demand. In reality, seasonality might also play a role: since the harvest season of soybeans lies in autumn, this season is marked by increasing soybeans supply (BarChart, 2023). As in other agricultural commodity markets, seasonality could result in volatile prices over the year. However, this seasonality aspect of the soybeans market is not incorporated in the model. The model represents the system on a higher aggregational level, using smoothed data, such as the monthly averages of soybean production and demand. Moreover, it is argued that seasonality effects on prices are limited, since different global weather conditions result in varying harvesting times on different continents (Ghosh, 2010).[2]

To prevent the stocks of demand and planned production from reaching a value below zero, it is assumed that before changes in these stocks can occur, it is checked whether the potential change in demand or planned production would result in a negative stock. If this is the case, demand adjustment and production adjustment automatically become zero. This results in relatively high production levels when rapid negative price changes occur (because planned production is not further adjusted), and relatively high demand levels when rapid positive price changes occur (because demand is not further adjusted). While this might not be the case in reality, these extreme price changes (within one time step) also do not occur in the real world. This model limitation is therefore not considered problematic for the analysis.

Thirdly, no maximum storage time is defined. This is because the maximum duration of storing soybeans depends on specific characteristics of soybeans. The moisture content of the beans as well as the storing temperature heavily influence the allowable storage time (NDSU, n.d.). Low temperatures and moisture content allow soybeans to be stored for almost a year. However, the characteristics of soybeans are not considered to be relevant for the scope of this research.

Furthermore, the price elasticities of demand and supply are assumed to be constant and time-independent. In mathematical economics, this is called an isoelastic function (Knittel & Pindyck, 2016). Even though this clearly is a simplification of reality (different current price levels will result in different magnitude of changes in demand and supply), economic research very often assumes constant elasticities. Change of elasticities lies outside the scope of this research as well. However, it must be noted that because of this non-changing elasticity, planned production and therefore inventories will still be relatively high when prices are near zero, which forms a limitation in the model.

Another assumption is made regarding the per unit storage cost. The inventory model includes the convenience yield and storage costs as two separate independent variables that influence the spot price. In reality, inventory levels influence the per unit storage cost as well (Knittel & Pindyck, 2016). However, these changes in the per unit storage cost will be small (specifically compared to changes in the convenience yield), since storage costs for soybeans are relatively low (USB, 2022). Inventory levels already work through on the spot price through the convenience yield, making an investigation of inventory levels and storage costs less relevant for this research. However, a range values for the per unit storage cost is tested during the model development.

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[2] However, a trend impacting seasonality is identified as an important determinant of the supply and demand of soybeans: the global trend of climate change (De Ridder et al., 2014). The exact impact of climate change is of course uncertain, but longer dry seasons might for example result in different amounts of soy that can be harvested. While the model is able to simulate a temporary production shock, limited time and resources make that inclusion of climate change in the quantitative model is not possible.

The last discussion point for the inventory model concerns the assumption that inventories can grow almost endlessly: a maximum of 5000 million bushels is assumed, which is four times the production in 2010 (FAO, 2023). The exact limit to inventories is unknown, for these extreme conditions have never occurred. The value of 5000 million bushels does not significantly influence model behavior for most parameter values, and therefore provides room for exploring how supply, demand and speculation determine price discovery. Section 5.4.2 and Appendix E will further assess the sensitivity of the model behavior to the max inventory level. From the extreme conditions test in Appendix D, it can already be concluded that extreme values for the inventory capacity (meaning almost no limit or a very low limit) influence model behavior, which shows why the current limit of 5000 million bushels produces more realistic model behavior. Moreover, because of the delays in production, it is possible that the inventory level is slightly higher than the maximum inventory level allows. Since the exact limit is unknown anyway, this is not considered to be problematic for the model and results.

5.2.2 Spot Pricing Sub-model

The relation between spot and futures prices is a much-debated subject. Lagi et al. (2021) stated that *"the futures market serves as the starting point for spot market prices"* (p. 12). However, empirical evidence shows that the effect of investor demand and futures prices on spot prices is dependent on the market type as well as the market condition (Gulley & Tilton, 2014). Most empirical investigations use Granger causality tests to determine which price causes the other price to change (Robles et al., 2009; Irwin & Sanders, 2010; Mayer et al., 2017). The empirical evidence of Van Arkel (2023), which shows how futures prices changes 'Granger cause' spot price changes, is used in the model. However, this is one of many investigations, and the direction of the causation is often debated. Since the approach of system dynamics assumes causality (Sterman, 2000), this assumption is very important in the model formulation. Future research could show how the model behaves in case of reversed causality (meaning spot prices influence futures prices).

Another assumption relates to the theoretical equations for the spot and futures prices. While these equations form the basis of the spot pricing sub-model, this does not mean that prices have behaved this way in reality. This part of the research shows how the traditional economic theory can be translated into a system dynamics model. Whether these equations actually hold true for the soybeans market specifically has to be investigated through empirical approaches using historical pricing data. An investigation of the data might show different, non-traditional behavior of both spot and futures prices.

5.2.3 Speculation Sub-model

One assumption in the speculation model concerns the risk premium and maturity of the futures contract. Bisso (2017) estimates the risk premium in the soybeans market for future contracts with different maturities. The expected rate of return depends on the time until delivery: the longer the maturity of the futures contract, the higher the risk for the investor, and the higher the expected rate of return should be to compensate for the increased market risk. However, the relation between maturities and risk premia is very complex and can only be estimated through a large econometric study. Therefore, assumptions had to be made on the reference expected rate of return which determines the risk premium of a futures contract. Since it is considered to be normal for markets to vary between states of normal backwardation and contango, the focus of this part of the model is to create insight into factors that can change these market conditions. By setting the reference expected rate of return equal to the risk-free interest rate (0.04%), these conditions can be explored. Since experimenting with different types of futures contracts is outside of the research scope, and futures contracts with duration of six months are commonly traded, both the expected rate of return and time until delivery are fixed values of 0.04% and six months. With these values, the risk premium varies from positive to negative values, which was also found by Bisso (2017). The model therefore provides insight into the behavior of spot prices that follows the behavior of a six-month futures contract. The model also shows how a smaller time until delivery leads to futures and spot prices that converge more than with a higher time until delivery.

Another important assumption involves the length of the expectation delay. While there is limited information available on the behavior of speculators, the expectation loop in the model required a specific delay time. As previously argued, speculators are known to reduce the average expectation delay, but exact values are unknown. Chapter 6 therefore shows how changes in the expectation delay influence model behavior.

Lastly, as expert A argues in the interview, there is never *"a perfect indicator"* to measure speculative activity, which is why we should look at a broad range of indicators. The model uses the level of open interest and the delay time as variables that indicate speculation. However, expert C explains that the open interest level does not capture the different trader types in the market (hedgers vs speculators), which is why it could be considered to be an imperfect indicator[3]. Further research can be used to look at the effects of using different indicators in the system dynamics model. Moreover, investigations of the actual trading behavior of speculators are required to be able to assess specific actions that follow from for example anticipation on a shortage in supply or demand.

5.3 Model Verification

To assess whether the model has been coded in a correct way, and whether the formalized model is consistent with the conceptual model (computerized model verification), different verification tests can be performed (Sargent, 2013). First of all, a correctness of coding test will be performed. No stock in the model should be able to reach values below zero, since the stocks represent prices,

[3] However, since the data provided by the CFTC does not make a more accurate distinction between hedgers and speculators, this indicator is considered most suitable given existing data limitations.

inventories, planned production, demand, and open interest levels. However, during the first model tests, it was found that prices could indeed descend below zero for certain input values. To solve this error, IF THEN ELSE functions were implemented, to check whether a negative change in stock would cause the stock to reach a value lower than zero.

Next, a dimensional consistency test has been conducted for the model. Failure of this dimensional consistency test often indicates a faulty model structure (Forrester & Senge, 1980). The model does not produce unit errors: the Units Check function in Vensim states that *"all units are OK"*. Furthermore, numerical errors due to the incorrect choice of time step are checked in Appendix C. A time step of 0.06125 is chosen (with a unit of months), and the Euler method is used to run the model. This method is suitable for discontinuous models, whereas the Runge-Kutta methods are mostly applied in continuous models. Since the model includes MAX/MIN and lookup functions, the Euler method is used. The time period of simulation runs from 2010 – 2025. The approach of system dynamics is not suitable to predict future values (see Chapter 2) and is therefore only used to assess whether or not speculative activity would have been able to cause the behavior of spot prices in recent years (2010-2023). However, since this time interval is relatively short, the simulation time is extended to 15 years.

5.4 Model Validation

To validate the quantitative model, different tests can be performed. The first section will discuss the relation between the structure of the model and the parameters. The second section will investigate the relation between the structure of the model and the observed behavior.

5.4.1 Structural Validity

The structure verification test is used to compare the structure of the system to elements in the real world (Forrester & Senge, 1980). It shows whether the model corresponds to knowledge about the real world. It often goes hand in hand with the parameter verification, which has been conducted to check whether the parameters in the model match conceptually and numerically to the real world (Forrester & Senge, 1980). The objective of both tests is to ensure that the model describes the real-world processes. Ranges of parameters are derived from the literature review as much as possible. For the uncertain parameters of which limited knowledge is available, the uncertainty range is empirically tested using the model (see Appendix B). These uncertainties make the model unsuitable to show accurate price predictions in spot, futures, and storage markets. However, the purpose of the model is not to predict, but to investigate to what extent financial speculation results in behavior that fits the real-world development of prices.

The extreme conditions test is an effective test to identify flaws in the model structure (Forrester & Senge, 1980). It shows how proposed formulations look plausible at first but fail under extreme conditions. Imaginary maximum and minimum values are considered for different constants in the model and can be found in Appendix D. The extreme conditions test show that the model indeed shows the expected behavior under extreme conditions.

5.4.2 Behavioral Validity

The first behavior test to assess validity of the model is the behavior sensitivity test. This test is used to assess whether shifts in parameters result in shifts in model behavior (Forrester & Senge, 1980). While every model is numerically sensitive to changes in parameters, behavioral sensitivity can indicate that specific parameters are important to keep an eye on when assessing policies and interventions. Sensitivity does not necessarily invalidate the model. Sensitivity tests are performed by differentiating values of constant parameters with -/+ 10%. The results of the sensitivity analysis can be found in Appendix E. The model KPI's appear to show some behavioral sensitivity to reference variables in the model, as well as to the max inventory level which indicates the stock capacity. Therefore, further investigation of the reference expected rate of return, reference yield and max inventory level is recommended. This will be discussed in more detail in Chapter 9.

The second behavior test includes the behavior anomaly test. This test is mainly used to defend model assumptions by showing how behavior changes through alteration of assumptions (Forrester & Senge, 1980). It can, for example, be used to defend ranges of certain parameters and lookups. Appendix F shows how anomaly tests either validate the assumption on lookups in the model or show limited effect of changes in the assumption on model behavior.

Lastly, the behavioral validity is assessed through the expert interviews. The temporary price peaks that occur in the model are confirmed by expert B and expert D. Expert A and expert C also acknowledge that speculation contributes to increased price volatility as shown in the model. The oscillatory model behavior therefore matches the collection of knowledge or the mental model (Schumacher & Czerwinski, 1992) that these experts have regarding the behavior of speculation through futures markets.

5.4.3 Conclusion Validation

As discussed in Chapter 2, the purpose of the model is to create a better understanding of the effects of financial speculation on commodity prices and to explain whether or not speculative activity would have been able to cause the behavior of spot prices in recent years. The model validation is done in order to check whether the model is fit for this purpose. The validation tests as described in sections 5.3 and 5.4 show that the model produces the expected behavior. Moreover, the model behavior corresponds to the observations by experts. However, the sensitivity tests in Appendix E showed some behavioral sensitivity of spot prices and inventory levels to changes in the reference convenience yield and reference expected return. Since both variables are difficult to measure, and the limited number of articles on the issue exhibits a variety of assumptions, this sensitivity is no surprise.

While the model is not fit to quantitatively evaluate policy interventions, it does create an understanding of how the system structure of different economic variables (including an increased level of speculative activity) affects spot price discovery and therefore spot price behavior. The model creates an understanding of the holistic system structure of price-setting. It can therefore be concluded that the model is fit for purpose. Moreover, the model enables the exploration of the different delays in the system, which are important factors in the behavior of spot prices, and which will be further discussed in Chapter 6.

6. Experimental Design and Results

This chapter elaborates on the model results and discusses the experiments that were done to answer the third sub-question: 'To what extent does speculation influence the behavior of commodity prices in the soybeans market?'

6.1 Model Analysis of Base Case

The results of the base case are shown in Figure 6.1. The base case assumes an expectation delay of three months, which means it takes three months for investors to change their expectations of the future spot price according to the current spot price. The model shows oscillating behavior, with price peaks reaching 17 USD/Bushel. Most peaks reach their highest point after 30 months (about two and a half years). The oscillating behavior can be explained through the interaction between the different sub-models. At first, the futures market reacts faster than the market for storage, resulting in an upward trend in prices and inventory levels. However, the reinforcing effect of price expectations does not take over the model behavior, because the balancing feedback loops of the market for storage produce moderated behavior after the production and demand delays. The combination of these markets creates price bubbles, but also makes the bubbles burst. Moreover, it can be concluded that inventories start to accumulate after a spot price peak because of high production and low sales.

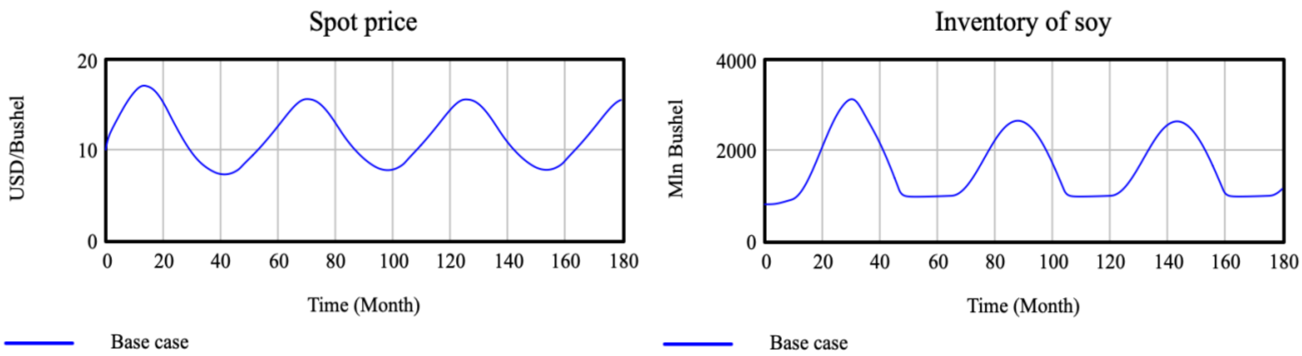

Figure 6.1: Base Case Results for KPI's

As discussed in the literature review, most markets vary between a state of normal backwardation and normal contango, in which futures prices are either below or above the expectations of spot prices. Figure 6.2 shows that while the expected spot price and the futures price move closely together, the market indeed varies between these two states. This happens when the reference expected rate of return is equal to the risk-free interest rate, as in the base case.

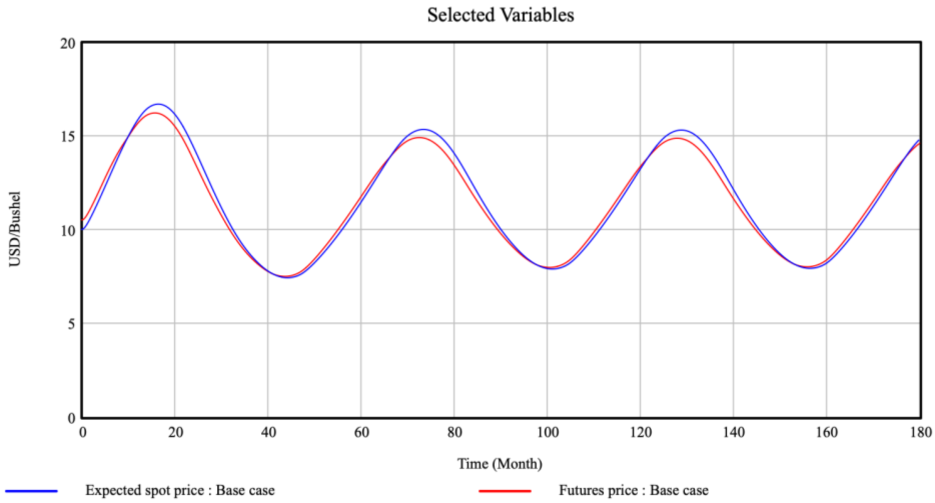

Figure 6.2: Base Case Results for Expected Spot Price and Futures Price

6.2 Model Analysis of Speculative Activity

Following the assumption derived from the literature review that speculators are fast-reacting market participants, the expectation delay is lowered to assess the impact of an increased number of speculators. Figure 6.3 shows the results from lowering the expectation delay from three months to one or half a month. The oscillating behavior changes: spot prices show higher peaks, which occur after a shorter time (about two years in the case of a delay of one month), and deeper lows. The model shows how an increased level of speculation strengthens the creation and crashing of price bubbles, meaning speculation adds to price volatility[4].

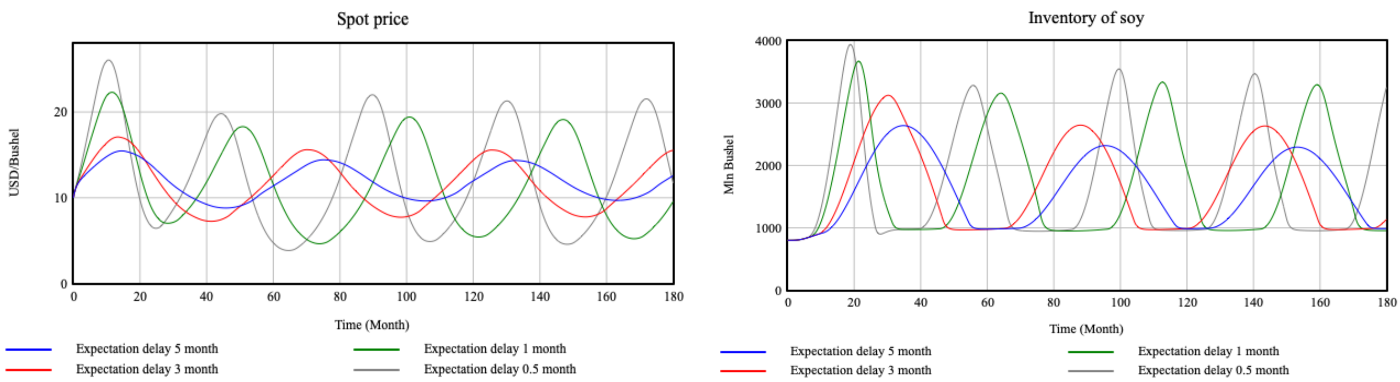

Figure 6.3: Effect of Changes in Expectation Delay on KPI's

[4] It must be noted that the same changes in behavior occur when experimenting with the time until delivery (a higher time until delivery also creates more frequent oscillation with a higher amplitude). This relation shows how futures contracts with higher times until delivery could experience more changes in prices. However, this would in reality mean that the reference expected rate of return also rises (to compensate for the increased risk level). The model does not show this effect (see section 5.2), which means the effect of changes in the time until delivery cannot be estimated.

To assess the impact of other delays in the model, changes in speculative activity (expectation delay) are compared to changes in the production and demand delays. These delays show how fast producers and consumers adapt their planned production and demand to changes in the spot price of soybeans. The production and demand delays are halved to three months and doubled to twelve months (from the base case value of six months). This is compared to halve and double the expectation delay (from the base case value of three months). The result of spot price behavior can be seen in Figure 6.4. The ratio between the expectation delay and the production and demand delays is important in model behavior. When comparing changes in the production and demand delays to the expectation delay, it can be concluded that the latter has a higher impact on the amplitude of the oscillation, or the height of the price peaks. However, both delays have a significant impact on the timing of the oscillation: with a lower expectation delay or higher production and demand delays, the futures market responds more quickly to changes in price than the market for storage, which enables prices to grow or shrink more strongly through the reinforcing feedback loop of price expectations. The opposite happens when either the expectation delay increases or the production and demand delays decrease: the balancing feedback loop of the market for storage reacts faster than the reinforcing expectations loop, making for more moderated oscillation.

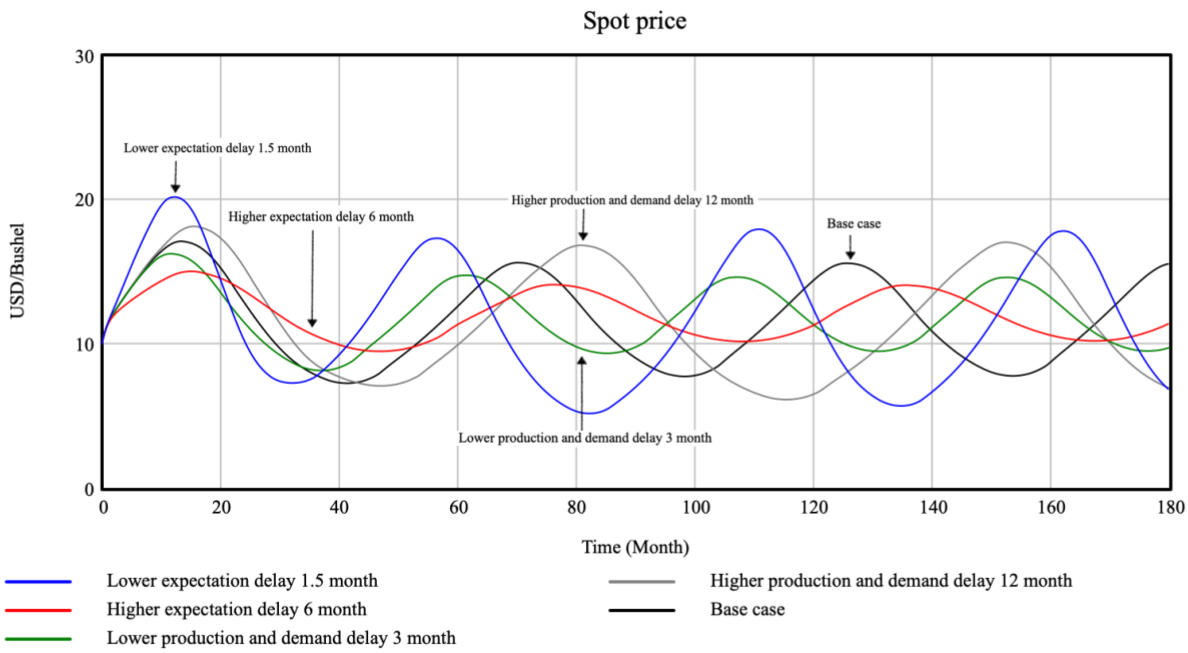

Figure 6.4: Effect of Changes in Different Delays on the Spot Price

6.3 Model Analysis of Change in Fundamentals

To compare a change in speculative activity to a change in fundamentals (as also discussed by Knittel & Pindyck, 2016), an experiment with a production shock will be performed. A production shock can occur through a temporary change in the amount harvested: for example, due to a drought, the soybean harvest is lowered by 200 million bushels (which is 20% of the average annual production during 2010-2023). When a production shock occurs after four years and lasts as long as the time it takes to grow soybeans (as shown in Figure 6.5), the model behaves as shown in Figure 6.6. It can be seen that right after the shock occurs, the price level reaches a peak of about 19 USD/Bushel. However, some months later, the price level starts to oscillate around the same value as in the base case with a slightly smaller amplitude. Whereas speculative activity resulted in strengthening of peaks and lows, a change in fundamentals only led to a temporary price increase. To check whether this behavior occurs when a longer time period is considered, the simulation time is extended from 180 months to 360 months (30 years). While a production shock has significant effect on prices and inventories in the first five years after the shock, prices and inventories will eventually stabilize again.

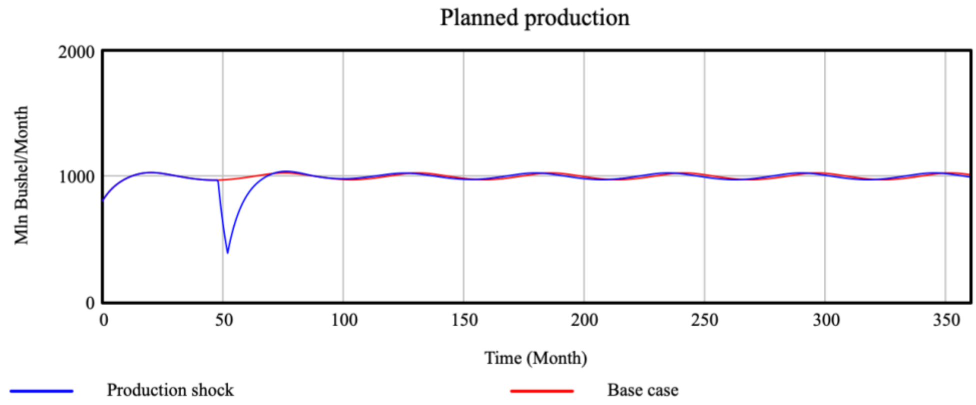

Figure 6.5: Production Shock

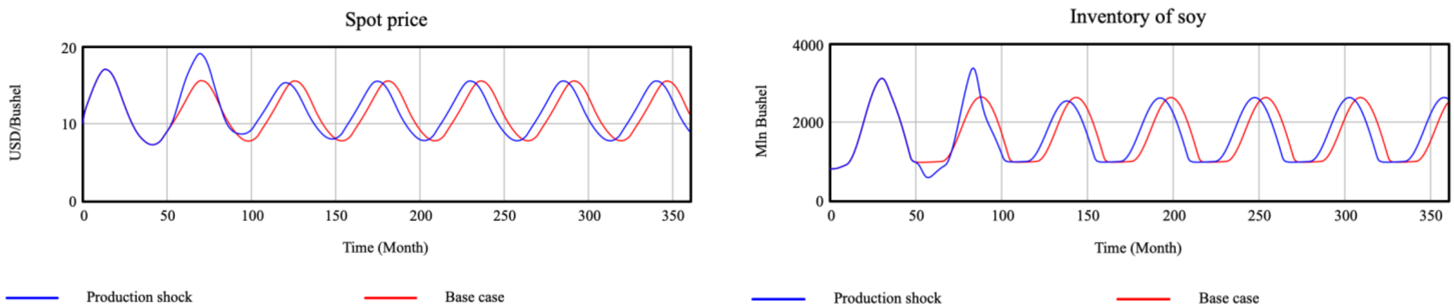

Figure 6.6: Effect of Production Shock on KPI's

6.4 Conclusion on the Influence of Speculation on Behavior of Prices

After the experiments, the third sub-question (S3) can be answered: '*To what extent does speculation influence the behavior of commodity prices in the soybeans market?'* The dynamic hypothesis included oscillatory, upward behavior due to different interacting delays in the conceptual model. The model indeed shows oscillation: however, in the base case, no upward trend is identified. This can be explained through the market of storage, which plays a significant stabilizing role in model behavior. Furthermore, it can be concluded that the interaction between the delays in the market of storage and the futures market determine the oscillation that the model behavior exhibits.

With the assumption that speculators react more quickly to changes in spot prices, they are indeed able to strengthen the oscillation of spot prices. The effect of increased open interest levels on futures prices is limited, and this loop does not significantly affect model behavior in the base case (while the model behavior is sensitive to initial values and reference values incorporated in this loop). Based on the simulation experiments discussed in Chapter 6, it can be concluded that speculation directly changes model behavior over a longer time period, whereas a shock in fundamentals (for example through a bad harvest) changes behavior significantly only on over a shorter term. While the model behavior is still relatively simplistic, it does show how speculators can contribute to the creation of price bubbles through their ability to react relatively fast to changes in prices.

7. Policy Reflection

Price spikes in recent years have brought back the discussion on commodity prices and derivatives to the political debate. In Chapter 4, the current regulatory measures in commodity markets were identified. The model created in Chapters 5 and 6 has provided insight into the process of spot price discovery. The next step involves an outlook to the future: how have discussions on financial regulations been evolving, and how do parties involved view potential subsequent steps? References to expert interviews will extend the knowledge on opinions of different actors regarding the need for policy intervention. Policy interventions will also be linked to the qualitative conceptual model. The general interview questions and expertise of the different experts can be found in Appendices G and H.

7.1 Opinions on the Need for Policy

As argued before, speculation and its effects have been discussed for many years by different parties, among which researchers and policy makers. The first section will discuss the reasons for this debate and the opposing views within the debate. The second section shifts the focus towards developing countries.

7.1.1 Reasons for Debate

Expert A identifies the two different opposing views in the literature and expresses his views as a mix of extremes. He acknowledges that speculation through the storage of commodities is indeed good for price stability, liquidity in the market, and protecting the farmers. However, expert A also admits that, even though some level of speculation is required, at some point it can contribute to heightened uncertainty. The expert points at the war in Ukraine to stress this point: *"Something strange happened in the markets: there was no real shortage, but something crazy happened."* When prices are not driven by market fundamentals, but by the rational expectations of investors, or even by the algorithm that is betting on price returns, problems in the functioning of markets can arise. Expert B acknowledges the fact that in March 2022, there was no shortage of grain (which would be a change in fundamentals), but there was indeed a price spike. Furthermore, it is also a fact that financial actors switched to buying more commodities. The same happened in 2008, according to expert D: there was no change in supply, and (still) the destabilizing effect of speculation on prices occurred. Only when changes in fundamentals occur, speculation will eventually have a stabilizing effect which makes prices return to equilibrium. According to both expert D and expert B, we need speculation, but not in the form of big financial firms owning a disproportionally large share of the market while having no interest in the actual commodity. Or as expert D states: *"Why do you need to allow players in the futures market who have zero interest in the actual commodity?"* Expert B also argues that regulation should be implemented in a way that it ends *"abuse of consumers"*, but also does not harm the producer.

Expert C shares one of the reasons that the effect of speculation (specifically index trading) is difficult to quantify. To be able to quantify a positive or negative effect on prices, one needs a *"counterfactual"*: a hypothetical scenario in which commodity prices evolve in the absence of index investors, which shows the fundamental value of commodities. Within the stock market, there is some idea on this fundamental value, because the prices of stocks included in a particular index can be compared to the prices of stocks that are not included in that index. In commodity markets, it is unsure what the true value of soybeans would be if only supply and demand factors were to play a role (without the presence of index investors): index trading happened, and we cannot know a scenario in which it did not. Expert C also mentions that the reason for many opposing views is also the different questions that are discussed within research: whether or not you find an effect of speculative activity depends on the question you want to answer. Authors could for example be looking at the effect of speculation on prices, or price volatility, or returns. Expert C also argues that the literature from earlier years often employs relatively simplistic methods that make for too drastic conclusions. Furthermore, research by specific parties who definitely have an interest in the following policy recommendations (such as the Chicago Board of Trade) is very often biased; or, at least, there might be a conflict of interest (that is often not reported). Moreover, regulators often do not provide access to the data that are required to prove a certain hypothesis (S. Storm, personal communication, May 11, 2023). The CFTC, under political pressure, allowed the meaning of the two categories of hedgers and speculators to become blurred by reclassifying swap dealers, whose positions are mostly speculative, as hedgers or commercials. This blurring of categories happened, not coincidentally, exactly when purely financial investments in commodity markets began to increase (S. Storm, personal communication, May 21, 2023).

The literature has often been an instrument to prove a 'preferred' hypothesis. Expert D acknowledges that with statistics, you can make pretty much any argument by using different data, different time periods, or different (control) variables. Expert E therefore argues that we should also focus on the political nature of the debate on speculation in commodity markets: the conversation of pros and cons is *"politically interwoven."* While the focus is often on the question of *"what is excessive speculation?"*, the actual impact of speculation on especially poor consumers, but also small farmers, is forgotten, according to expert E. Drawing a line between speculation and excessive speculation is impossible through statistical measures if you also want to include a political perspective: *"If every food supplier/buyer is talking about the role of speculators, why do we need statistics?"*

7.1.2 Implications for Developing Countries

Expert D discusses the impact of (speculation-driven) commodity price peaks in developing countries specifically. Price peaks following from speculation are often seen as temporary (as the model analysis of Chapter 6 also has shown). This is mostly the case for global markets. However, when zooming in on markets in specific countries, the impact of food commodity speculation can last for a long time. In developed countries, speculation indeed leads to a temporary price spike. However, for developing (and mostly food-importing) countries, an increase in global prices is immediately translated into higher domestic prices. On average, consumers in poorer nations spend 25-30% of their incomes on food, compared to consumers in rich nations who spend only 7-10% of their incomes on food. Higher food prices therefore have a much larger (negative) impact on consumers in developing countries. Expert D also noted that higher food commodity prices raise the import bill for food-importing developing countries, often increasing the trade deficit and triggering a depreciation of their currencies. The currency depreciation raises the domestic prices of all imported commodities, not just food. When the global food commodity price eventually goes down, the domestic price level in these developing countries stays higher compared to before the price peak, mostly because of the devalued exchange rate. This happens because developing countries cannot implement fiscal stimulus as a means to recover from the collapse in demand. When discussing policies, one should therefore always consider different perspectives – and be aware of the fact that higher food commodity prices have a larger and longer-lasting impact on (poor) consumers and producers in developing countries. Expert D also argues that the open capital accounts play a very important role in the fiscal situation of developing countries. If the trade deficit of a country increases because of higher food commodity prices in world markets, and if its exchange rate depreciates, then this may lead to a financial outflow out of the poor country. This will result in further depreciation of the currency and a destabilization of its economy. More in general, liberalized financial flows between rich and poor countries make for a very fast transmission of for example a crisis in the US to destabilization of the economy of a developing country. Interest rate differences create a disadvantage that results in long-term losses in developing countries.

In short, the interviewed experts agree on the fact that some kind of policy intervention is required to limit the negative impact of speculation, specifically in developing countries. They also acknowledge that the literature is still divided on this topic (as was shown in Chapter 1), which, according to the experts, can be attributed to the choice of research method, indicators, and research questions, but also to the difficulties in quantifying the exact effect. The next important question to ask: if policy intervention is required, which policies would be most effective in limiting speculation?

7.2 Dealing with Speculative Activity: A Debate among Policy Makers

Ferrando (2023) identifies two options for policy makers to deal with the current problems in food markets. The first option involves defining and curbing 'excessive' speculation, while tolerating 'normal' levels of speculation. This would allow betting on food prices, without *"reaching a level that could provide confusing or unsupported signals to the food actors and the underlying price."* (Ferrando, 2023, section *"If food is life"*). This option implies that a certain 'excessive' level can be found through extensive research, and that calculations could provide the right level for position limits.

The second option according to Ferrando (2023) is to reconsider the *"legal, economic and ethical acceptability of speculation over food commodities."* This would involve discussions on whether or not food can be considered as a financial instrument when also taking fundamental human rights into account. Should commodity markets be de-financialized? If so, which short-term steps can be taken to reach the long-term goal of de-financialization of food commodity markets?

The first option has gained traction by members of the European Parliament and academics, whereas the second option is only considered by a minority of experts (Ferrando, 2023). The next sections will investigate the effective measures of the first option, after which a normative view on speculation will provide clarity on the second option.

7.2.1 Curbing Speculation through Limits and Taxes

Setting position limits is no easy task: if position limits are set too low, this might result in distorted markets that function less smoothly (Verrastro & Harney, 2009), whereas if limits are set too high, these will not be effective against excessive speculation. Moreover, the frequency at which limits are reviewed is under discussion (Kornher et al., 2022). Exemption rules around hedged positions also potentially reduce the effect of setting position limits. Kornher et al. (2022) emphasize the importance of market diagnostics and transparency to monitor speculation and the overall performance of commodity markets. Moreover, expert A discusses the fact that there is no transparency regarding the exact limits from financial authorities. How are positions measured? What is meant by a single trader[5]? And do we need daily, or weekly limits? This transparency is required to be able to understand whether position limits are effective at all, according to expert A. Expert B adds to this the fact that more clarity is needed on who is a speculator, and who is a hedger of risks. As expert C states, the general definition of speculation is any activity that is forward looking with an aim for profit. Since hedging is also forward looking, there is rarely any trader that can be classified as non-speculating. We should distinguish between the traders who are in the market to cover the assets risks and the traders who are just in the market to diversify their investments. Expert C considers position limits to be an inappropriate measure, because capturing how traders actually take position is impossible.

Coordinated trade between countries is necessary, for imposing regulations in the U.S. alone will not be enough to completely cover the negative global effects of excessive financial speculation. M. Cooper (2009), the director of research of the Consumer Federation of America,

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[5] The increased level of financialization in recent years has resulted in a network of financial actors, which are interwoven with each other (S. Storm & C.W.M. Naastepad, personal communication, 2021): often, different actors are related (or even the same), and these inter-linked financial firms make the definition of a single trader more difficult.

has recommended other potential regulations, among which the taxation of short-term capital gains by 33% to 50%. By imposing taxes on these gains, long-term investments become more attractive, and short-term speculation will be reduced. This idea of taxation has previously been suggested by Stiglitz (1989), who stated: *"The heart of the argument is simple: the turnover tax is likely to discourage short-term speculative trading."* Taxes in the futures market are currently organized according to the 60/40 rule: 60% of the profits is categorized as long-term gains, whereas 40% is classified under short-term gains. This happens regardless of how long a position is held. By changing the taxation system of futures, short-term trading could be discouraged (Tun, 2022). Expert C has no doubt that income from finance should indeed be taxed more. However, expert A emphasizes that taxation in one place encourages the problem to move elsewhere. It can therefore be concluded that taxing short-term gains can only help when implemented globally.

7.2.2 Normative View of Speculation in Commodity Markets

A more precautionary approach of dealing with speculation is related to ethical considerations: world hunger is increasing as a result of rising global food prices, and something should be done to stop this trend. The complexity of speculation and its (dis)advantages make that some researchers do not believe in creating consensus on the effects of speculation, let alone agreeing on regulatory measures. Waiting for conclusive proof is not the right response, according to Sutton (2012). A more precautionary response is required: as the World Commission on the Ethics of Scientific Knowledge and Technology states, *"when human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm."* (COMEST, 2005, p. 14). When data are insufficient, imprecise, or inconclusive, but the dangerous situation has been identified, the precautionary principle can be evoked by policy makers (EC, 2000). Sutton (2012) argues that this is applicable to the situation of speculative activity in food commodity markets. Expert A also acknowledges that even 15 years after the crisis of 2008, *"we still do not know what happened…"* Therefore, it can be argued that we should not focus on trying to prove that speculation is a cause of the price spikes, but that we should focus on trying to prove it is not. Expert A agrees that something has to be done beforehand, particularly since there is more information on the subject of speculation than fifteen years ago.

The main question is: what is the value and danger of regulating speculation in these markets? As mentioned in the literature review, speculation helps in the efficient functioning of markets. The risk of food producers is hedged by transferring the risk to the speculators: speculation aids in the interaction between buyers and sellers. The presence of speculators makes (in principle) for a more liquid and stable market, which, in a sense, is a form of social good. Imposing limits to speculation could reduce these benefits. However, increased liquidity if not always beneficial, according to Turner (2010). Once markets become more liquid, the benefits of further liquidity decrease (a form of diminishing marginal returns). Moreover, more market activity creates uncertainty on how the market is going to behave, and therefore instability. The social value of speculation is therefore questionable. Furthermore, some people argue that while assessing the value of speculation, the type of market should be considered. As Olivier De Schutter, co-chair of IPES-Food, states on the rise of wheat prices in Ukraine: *"This is not gold or silver we're talking about, its people's daily bread – driving up food prices affects millions and millions of people. It's a scandal and it shouldn't be allowed to happen."* (Harvey, 2023). According to Cindy McCain, the former US ambassador to the UN agency for Food and Agriculture (FAO), the current food security situation should even be considered a national security problem (Harvey, 2023). Food security can be found in the Universal Declaration of Human Rights, in which a reference is made to an adequate standard of living: *"Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, ..."* (article 25(1)). Even though the exact effects of speculation have proven to be difficult to assess, this should not matter, according to the precautionary approach: it is a fact that prices are rising, causing people to starve. This violates the human right of food security, with speculation being one of the potential causes of the increases in prices. Acting on excessive speculation by implementing regulatory measures is desirable and necessary when taking the precautionary approach and ethical aspects of commodity speculation into account. As expert B states: *"The social good needs to be prioritized over the private right to earn money."*

Expert E brings another point of view to the table. He argues that within the discussion of the financialization of commodity markets, we should focus on the kind of food system we want, and on the exceptional role of agricultural commodities. If we accept that the freedom of making money is more important than the right to food, then maybe the effects of speculation can be accepted as well. However, if we want a food system that is based on human rights, we should indeed worry about the effects of financialization.

7.3 Further Action Plans

Expert A states that it is impossible to go back to a market situation with no financial speculation because markets have changed and have become more interlinked. Financialization cannot be removed from commodity markets, according to expert C and expert E. Expert B also mentions that there is indeed a long-standing relation between financial markets and commodities. Moreover, big investors do not see their investing as "*betting on hunger*", but as diversifying their portfolios, according to expert B. Expert D discusses three practical steps to be taken to tighten rules in commodity futures markets.

1. Only market participants with a clear and real interest in the commodity should have access to the market. For example, a pension fund should not be able to trade soybeans futures because of the lack of actual interest in ownership of the soybeans.
2. The position limits for those participants should depend on their extent of interest or their degree of requirement.

3. If the first two steps are implemented correctly, reserve requirements to enter the market can be lowered as to involve smaller players such as small farmers.

There are also other parties arguing for steps towards de-financialization of food commodity markets. Ferrando (2023) proposes an action plan on the de-financialization of food commodity markets in seven steps. His proposal matches an opinion report of the European Economic and Social Committee (EESC, 2022), which urges member states and institutions to pay attention to the current food crisis.

1. Food derivative trading by financial operators (asset managers, pension funds) should be prohibited, for they are in no way connected to the actual physical goods.
2. Agri-food indexes should be banned.
3. Parties that are indeed allowed to invest in derivative products should be obliged to report in a transparent way (to the Agricultural Market Information System as stated by the EESC (2022)).
4. The use of high-frequency trading algorithms should be curbed.
5. Returns on food speculation should be taxed.
6. No public funds should be provided to companies active in the food derivative market.
7. Public support should be given to other forms of risk management (such as climate change related insurance).

The EESC (2022) adds to this specific instructions about position limits. When commodity futures markets start to show abnormal behavior, strict price movement curbs and daily limits (that reflect the active interest of the trader in the specific commodity) should be implemented. Moreover, financial actors should be disincentivized to invest in commodities through the introduction of capital requirements.

The fourth point of this action plan by Ferrando (2023) has been discussed in the interviews as well. Innovations in the financial sector, such as high-frequency trading platforms, have opened up different markets (including the commodity markets) to new investors. These markets becoming more easily accessible is a clear sign of the financialization discussed in the literature review. Expert C states that this also enables the substitution of wage with financial income: everyone can become a financial trader. This not only enables the formation of price bubbles as discussed earlier, but this also limits the profits from the real economy. It can therefore be argued that no societal benefit is obtained through these financial innovations. Expert D is not convinced that we should even call these developments 'innovations': *"New ways of making money by taking money from someone else is not innovation in my eyes."* Or, as the EESC (2022) argues, the food sector should be addressed as *"massive money-making off the backs of people"* (key point 7) and the introduction of a food speculation tax to limit high-frequency trading could counter this.

Expert E adds to this the fact that these financial innovations seem to lift the burden of responsibility for an effective and sustainable food system from the shoulders of public actors. We should therefore pay attention to this development as well.

7.4 Policies and Model Behavior

While there exists uncertainty about the exact quantitative effects of policy interventions on the model, a qualitative exploration of the effects of these policies using the conceptual model is possible. Most discussed policies affect the number of speculators that is present in the market (and therefore also affect the expectation delay). For example, by only allowing parties with a clear market interest to participate, the number of speculators will be reduced. The same goes for the taxation of short-term capital gains. With a smaller number of speculators in the market, the average expectation delay will go up, as it is argued that speculators react faster to spot price changes. These policies will therefore mainly impact the reinforcing loop of price expectations: the higher expectation delay will moderate the peaks and lows in the model behavior, creating oscillatory behavior with smaller amplitude.

By setting strict position limits, the average level of open interest likely goes down. Position limits are reflected in the open interest level: when the number of contracts an investors can hold is restricted, this will most likely be translated into less outstanding futures contracts, thus a lower open interest level. This policy will therefore impact the quantitative relation between price expectations and the open interest, and will therefore also impact the difference between the expected spot price and the futures price.

If the focus of policy interventions would be on specifying the distinction between speculators and hedgers, the impact on the model behavior is more difficult to assess. The model currently does not differentiate specifically between speculators and hedgers. This would require the addition of an indicator like the share of non-commercial to commercial investors. This indicator could replace / complement the open interest level, and therefore change the feedback loops of price expectations and risk premia.

7.5 Conclusion on Effective Policies in Commodity Markets

This chapter has identified potential policies that could limit speculative effects through expert interviews. The fourth sub-question (S4) can therefore be answered: *'Which policies could be effective in addressing the effects of speculation in commodity markets?'* While there is no consensus within the literature on the effects of speculation in commodity markets, the interviews show how all experts agree that speculation should be limited to some extent. Since commodity markets have become interwoven with futures markets, a complete ban of the futures market is impossible. However, a more precautionary approach could be implemented in order to protect developing countries from higher price levels. The main difficulties of setting position limits or taxing short-term speculative gains have been discussed. With an increased level of transparency, including a clearer classification of traders into speculators/hedgers, position limits or taxation could be effective in curbing speculation and high-frequency trading. However, the question is whether this distinction between a speculative trader and a hedger can actually be made. Apart from these measures, it can be argued that only parties with a clear and active interest in the market should be able to participate. We should assess the design and values on which our current food system is based.

8. Discussion

The purpose of this chapter is to discuss the model results that were presented in Chapter 6. The dynamic hypothesis is reflected upon, and the results are compared to reality. Lastly, the most significant research limitations are discussed.

8.1 Reflection on Dynamic Hypothesis

As follows from the results in Chapter 6, the model shows a potential way in which speculative activity creates temporary price bubbles in the soybeans market. The dynamic hypothesis was partly confirmed because the model shows oscillatory behavior, as could logically follow from the conceptualization in Chapter 3. This cyclical spot behavior was also found in the system dynamics model created by Abaunza & Aramburo (2009). No upward trend was identified, partly because of the balancing effect of the market for storage. Moreover, this lack of growth is the result of the assumption of several constant parameters which, in reality, have changed over time (such as the per unit storage cost, risk-free interest rate, or price elasticities, see section 5.2). Chapter 9 will reflect on the uncertainties created by these variables and link these uncertainties to Exploratory Modelling and Analysis (EMA).

The model shows how price peaks are followed by an accumulation of inventories of soybeans, as was found in the literature review. In contrast to a change in fundamentals, a change in the expectation delay through increased speculation results in a different pattern of model oscillation. A short shock that results from a temporary bad harvest is not able to produce significantly higher price peaks and falls on the long term. After a change in fundamentals, the market will return to the equilibrium through the balancing effect of the market for storage on production and demand.

The effect of the balancing loop between open interest levels and futures prices is not able to fully counter the reinforcing effect of lower expectation delays. This means that, even though the literature indicates that higher open interest levels result in more market uncertainty and therefore higher expected rate of returns, this effect of speculation is less significant than the effect on the lower expectation delay that is caused by speculators.

8.2 Comparison to Reality

As Figure 1.1 already showed, the spot price of soybeans in reality produces irregular oscillatory behavior. In system dynamics models, oscillations arise through any significant delay in one of the negative feedback loops in the system (in this case, through the market for storage or through the open interest) (Sterman, 2000). However, oscillations are almost never perfectly regular in the real world. While the graphs from the experiments in this study (Chapter 6) do not show perfect oscillation, the model also does not produce quite similar irregular oscillation as the oscillation shown in Figure 1.1. The real behavior of prices of soybeans includes high peaks and deep lows but is not as cyclical as the model suggests. While this does not mean the model is invalid, it does show how complex the system of financial and economic markets is, and therefore how difficult it is to intervene through regulation. The model does not fully capture all the different interactions between variables that create irregular oscillations: small interacting production or demand shocks could potentially create this irregular behavior, but also changes in the risk-free interest rate or price elasticities. Moreover, the influence of seasonality as discussed in section 5.2 could also result in more irregular oscillatory behavior.

It must be noted that while the model indeed shows how a quicker reaction of expectations could increase price volatility, this does not mean that any other variable inside or outside the model could produce the same behavior. The model therefore cannot produce a definite answer on whether speculation is the cause of price spikes. Moreover, the type and length of the delays in the model are uncertain, but also play a significant role in the problematic model behavior. It is important to acknowledge the impact of these delays since different delays might produce different model behavior.

However, the model behavior currently matches the problematic behavior that was identified through the expert interviews and literature review. Moreover, the model is able to explain this behavior through the model interactions and delays. It therefore holds a high communicative value, which can contribute to a more thorough understanding of the price-setting process in financial markets.

8.3 Limitations of the Research

As discussed in section 5.2, developing a model includes making assumptions. These assumptions often result in limitations of the research, which were already partly discussed in section 5.2. However, some of the model limitations require a more detailed discussion.

The first significant limitation relates to the theoretical equations that were used to define the relation between spot prices, futures prices, and spot price expectations (see section 5.1). These equations are widely used in the financial literature (Gulley & Tilton, 2014) to calculate prices: however, these equations remain theoretical, even though they are applied to a quantitative system dynamics model (and are important in model behavior and results). The model results are therefore not completely based on empirical proof coming from the soybeans market, but also on theoretical ideas on price discovery. While the literature argues that general price discovery is based on these equations, these equations might not reflect what happens in reality in the soybeans market. Even though the model results show the expected behavior, empirical investigations of relations between spot and futures prices could possibly show different model behavior.

The interview with expert D shows how the model and its results are partly context specific, as is often the case in economic models (Dow & Dow, 2005). The model shows the behavior of spot prices of soybeans on a global level. On this global level, peaks and lows in prices occur, but only temporary. A higher temporary spot price is not translated into a much structurally higher spot price on the long term. However, as expert D states, this behavior is not the same when the focus is on different national markets. For wealthy countries, the behavior as shown in the global market of the model would occur, whereas developing countries would experience different behavior: a temporary increase in the global price leads to a structurally higher domestic price. The model structure and behavior can therefore not be generalized to the smaller aggregational level of national markets[6].

Another limitation follows from the fact that the model assumes no direct connection of the time until delivery and expected rate of return. This is because the research focusses on one type of futures contract (with one single maturity), and the value for the expected rate of return is difficult to locate in literature. However, in reality, the expected rate of return depends on the time until delivery: the longer the maturity of the futures contract, the higher the risk for the investor, and the higher the expected rate of return should be to compensate for the increased market risk. While the research accounts for the impact of increased risk at higher open interest levels on the expected rate of return, the research does not provide insight into the impact of increased risk at longer times until delivery.

The last limitation of the research follows from the approach of system dynamics itself. In system dynamics, one assumes causal relations between variables to formulate the model. However, previous research shows uncertainty in the causal direction between spot and futures prices. The results are therefore dependent on this uncertain assumption. In Chapter 9, suggestions to deal with this uncertainty (and others) are proposed. Chapter 10 will go further into limitations of the research approach specifically.

[6] However, the model can be generalized to different commodity types using different values for the model parameters.

9. Conclusion and Future Research

With the model results and policy reflection in mind, an answer to the research questions can be formulated. In this chapter, the main research question is answered using the answers to the individual sub-questions. Moreover, relevant recommendations for policy makers and future research are suggested.

9.1 Answers to Research Questions

To answer the main research question, the answers to the individual sub-questions will first be discussed.

S1: 'What is the theoretical role of speculation in commodity pricing?'

An investigation of the literature on speculation and its effects identified different factors that affect the process of spot price discovery in the cash market. First, the market for storage shows balancing effects of inventory levels on spot prices. The value of storage (convenience yield) was found to be an important factor influencing changes in the spot price. This was linked to the law of supply and demand, which shows how planned production and demand are adapted through changes in prices. Other identified factors from the market of storage that influence the spot price are the per unit storage cost and the risk-free interest rate. Higher storage costs imply that holding soybeans is more expensive, thus reducing the spot price compared to the futures price. The risk-free interest rate is used to calculate the present value of buying a commodity while also entering a futures contract to sell the commodity at a specific moment in the future. A higher risk-free rate implies higher investment costs, thus lowering the current value of the spot price compared to futures price.

Through the futures price, the link between the cash market and the futures market can be identified. To determine futures prices, spot price expectations proved to be relevant: historical values of spot prices determine the future spot price expectations, which in their turn affect the futures price via a reinforcing loop. It was found that speculators are fast-reacting, trend-following entities, which is why price expectations are adapted faster when an increased level of speculators is present in the market.

Another important concept that was found in literature relates to the expected rate of return to compensate the speculator for the transfer of risk from the hedger. The risk premium resulting from this return shows the difference between the expectations of the spot price and the futures price. Empirical investigations in literature indicate a balancing effect of open interest levels on the futures price through this risk premium. A higher expected spot price attracts traders, creating an inflow of investors, which is reflected in higher level of open interest. This higher open interest indicates a higher level of market uncertainty, which has to be compensated through the expected rate of return for the investor. A higher expected rate of return reduces the risk premium and ultimately the futures price. The conceptual model that was created involved two theoretical effects of speculation: one through the lower expectation delay (within the reinforcing feedback loop), and the other through the increased level of open interest (within the balancing feedback loop).

S2: 'What policies are currently in place to deal with the effects of increased speculative activities?'
Both in Europe and the US, new policies to regulate financial markets were adopted after the crisis of 2008. The most important measure involved position limits to restrict the number of contracts that can be traded by one single investor in order to limit market power of big financial investors. However, the lobby of financial actors proved to be effective, as most measures were implemented in ways that did not hurt them, according to the interviewed experts. Position limits were set too high, or specific exemption rules resulted in a limited reduction of excessive speculation.

S3: 'To what extent does speculation influence the behavior of commodity prices in the soybeans market?'
The theoretical role of speculation was tested through a quantitative system dynamics model. The model shows how oscillation of spot prices and inventories occurs through the interaction between the futures market and the market for storage. Higher prices indeed result in the temporary accumulation of inventories because of limited demand and higher supply. This accumulation is temporary, because higher inventory levels reduce the value of storage and the spot price, making production less attractive and inducing higher demand. With the assumption that speculators react more quickly to changes in spot prices, speculators are able to strengthen the oscillation of spot prices in the model. They contribute to higher peaks and deeper lows. In contrast, the other theoretical effect of speculation through the open interest level and risk premium shows a limited effect on the oscillation. A higher open interest level (increased speculative activity) only affects model behavior through the initial and reference values. Since these values are uncertain, the effect of speculation on the futures price through the open interest should not be removed from the model.

Through the comparison of the impact of a shock in production and the impact of increased speculative activity on model behavior, it can be concluded that the latter changes behavior significantly both in the long and short term, whereas a production shock is only felt in the first few years after the shock. A shock in fundamentals does not produce the same results as a speculative shock, as was also discussed in the expert interviews.

S4: 'Which policies could be effective in addressing the effects of speculation in commodity markets?'
With commodity markets becoming interwoven with futures markets and other financial markets, a complete halt to financialization of food commodity markets is not possible. Commodity markets have proven to be an additional investment option to investors. Financial

speculators are always after diversification of their portfolios in order to spread investment risks and are therefore searching for investment opportunities in different financial markets, including commodity markets. However, the interviews showed how experts agree that speculation should be limited at least to some extent, specifically to protect developing countries from the structural effects of higher global prices. The effective implementation of position limits requires, first and foremost, a higher level of transparency from regulators with regard to calculations and the intended purpose of the position limits. Global taxation of short-term capital gains could also be an effective measure to limit high-frequency trading and speculation in commodity markets. Lastly, the requirement of an active interest in the commodity that is traded, is mentioned as a measure that could drastically reduce the number of market speculators. While a producer of meat substitutes should be able to enter the soybeans' futures market because of the material interest in soybeans, a pension fund should not.

RQ: 'What are the likely effects of the increase in financial speculation on the behavior of commodity prices in the current soybeans market, and which policies can be used to regulate these effects?'

This research has investigated the theoretical effects of financial speculation in commodity markets through a literature review, from which it can be concluded that there is still no consensus on the magnitude of the effects of increased speculation. Within the conceptual system dynamics model for the soybeans market, four important feedback loops were identified: two balancing loops that connect the market for storage to the cash market through the law of supply and demand, one reinforcing loop that describes the effects of price expectations on the spot price, and one other balancing loop that shows how the open interest could moderate the futures price compared to the expected spot price. The balancing loops in the market for storage and the reinforcing loop of price expectations determine the model behavior, which in the base case shows oscillation of prices and inventory levels. Speculators are able to increase the amplification of the oscillation through lowering of the expectation delay: they are able to cause a higher amplitude of the oscillation, which can be compared to a soybean price bubble forming and crashing. This change in behavior is modelled to be permanent, compared to the temporary effects of a change in fundamentals. A temporary change in fundamentals will only disrupt the behavior in the market temporarily, for the market will restore the original behavior through the balancing effect of the storage market on production and demand. However, increased speculative activity permanently influences the process of expectation forming, since speculators are trend-following and fast-reacting. While the experts agree on the fact that some kind of policy intervention is required to limit the negative effects of speculation, there is still a lot of uncertainty regarding potential policies and whether they are effective against financial speculation. Attention should be paid to the level of transparency in setting position limits and the evaluation of actual interest of market participants, so that the number of speculators in the futures market could be reduced, and developing countries are protected from structurally higher food prices.

9.2 Recommendations

In the following section, recommendations for future research will be given. This is followed by recommendations for policy makers to deal with financial speculation.

9.2.1 Recommendations for Future Research

The first recommendation to further improve the model relates to the causal direction between futures and spot prices that is assumed. Since previous statistical causality tests have shown different directions between these variables, and the system dynamics approach assumes causality, model tests could be done in order to determine model behavior when the opposite assumption is used (meaning spot prices directly influence futures prices). This could further extent the knowledge on the behavior of cash markets and futures markets.

The next assumption that can be improved involves the choice for indicators of speculation. The model currently uses the open interest level and expectation delay as variables influenced by the number of speculators. By incorporating other speculative indicators into the model, it can be seen whether the different indicators for speculation also produce differences in model behavior. Different indicators could for example include distinctions between non-commercial and commercial investors, where the ratio between these investor types would determine the time between a change in the spot price and a change in price expectations.

Moreover, the model does not include index investors. Index investment is one of the most popular speculative strategies (as described in Chapter 1). Next to direct investment in commodities through the futures market, the role of these index investors might also be significant in price discovery. Index investment involves a more passive investment strategy than investment via the futures market (CFI, 2023). This 'buy and hold' strategy implies slower reactions to changes in prices. Because of the massive inflow of index investors in recent years, the expectation delay could potentially have been raised instead of reduced (as was assumed in the model), since index investors update their expectations less frequently than futures investors. However, these index investors are also trend-following, which would suggest they add to the reinforcing effect of price expectations (with high prices causing even higher prices). The exact effect of increased index investment is difficult to assess using the current model. A more explicit role for this type of investment can be investigated in future research.

Another recommendation relates to the actual trading behavior of speculators. To extend the price expectations model, more knowledge on the determination of expected spot prices is required. How do investors form their expectations? How would speculators react to the expectation of a failed harvest? This can be done either through interviews with active market traders, or a more thorough investigation of literature on investing strategies.

While the model already allows for different types of delays, further investigations of delays and length of delays in the futures market are also required. The model for example assumes a direct translation of changes in open interest on the expected rate of return and risk premium.

Whether this is truly the case can be assessed by experimenting with different types and lengths of delays within the futures market. Moreover, further research is required into the range of values for the expected rate of return and reference yield in de soybeans market.

As mentioned in Chapter 8, the modelled system includes many uncertain variables. In the field of economics, the system under investigation highly depends on human behavior, which results in variables with a relatively big uncertainty range (e.g., the price elasticities of demand and supply, but also the delays of production and demand adjustment). For modelling under uncertainty, Exploratory Modelling and Analysis (EMA) can be used (Kwakkel & Pruyt, 2013). This approach is used to vary modelling assumptions in experiments. It shows the dynamics that a system can exhibit and enables the modeler to test the outcomes and robustness for different policy interventions. The combination of EMA and system dynamics can provide insight into the dynamics of the system given a range of uncertainties. Since the model behavior showed behavioral sensitivity to changes in different parameters (see Chapter 5), the assessment of the impact of uncertainties is required. With unlimited time and resources, EMA could prove to be a helpful tool in identifying the exact role of speculation in price-setting behavior, despite the presence of uncertainties in for example price elasticities, the risk-free interest rate, and the expected rate of return. Moreover, the orders and length of time delays can be varied (to test the impact of different uncertain information delays in the cash market) as well as the uncertain non-linear lookups. For example, the uncertainty in the slope of the convenience yield curve at different levels of inventories can be varied and assessed in a more systematic way. Lastly, since the max level of inventory is currently unknown, the impact of different values for this parameter on model behavior can be assessed by using the EMA workbench.

The research approach that was followed in this research could be further improved by adding another purpose to the expert interviews, which were currently used to assess model behavior and policy options. However, the structure of system dynamics models can also be validated through expert interviews (Forrester & Senge, 1980). Since the knowledge of experts on the structure of dynamic models and following behavior was limited, as well as the time to complete the research, the focus was on behavior validation (through comparison of the model behavior and their mental models) and policy reflection. In future research, the model validation could be improved through interviews with experts on both economics and dynamic models.[7]

Lastly, the expertise of the academic experts that were interviewed mostly lies in the field of development economics. Future research could investigate the views of other actors, such as traders in the futures market, or regulators. This would add knowledge on the perceptions of these actors regarding the (dis)advantages of speculation, regulations, and their effectivity.

[7] One author, who has used the system dynamics approach to investigate the causes of the price spikes in commodity markets (including speculation), was approached for an interview: however, this author did not have time to validate the model behavior or structure.

9.2.2 Recommendations for Policy Makers

The research findings from the model experimentation and expert interviews show that some policy interventions are desired, especially when looking from the perspective of developing countries that experience negative effects from the financialization of the food sector. Even if the literature provides no consensus on the exact effect of speculation, a precautionary approach could be employed in order to protect developing countries from the price peaks that result in structurally higher prices and increased world hunger. While the discussion on effective regulations continues, several recommendations for policy makers were already identified.

- To be able to quantify the effect of speculation, clarity has to be created on whether it is even possible to make a distinction between speculators and hedgers. It could be that the two activities are too interwoven.
- If this first distinction is difficult to make, it is argued that traders in the futures market should show a clear and active interest that proves why they require ownership of the specific commodity.
- Position limits could further help in limiting the market power of actors. However, transparency from policy makers is key: how are limits calculated, what kind of limits are required? Financial regulators should be transparent with regard to data publication and calculation of limits.
- Global taxation of short-term capital gains coming from food commodity markets could reduce high-frequency trading.

The first recommendation will change the model structure in case the distinction between speculators and hedgers can indeed be specified. The model currently does not differentiate specifically between speculators and hedgers. In case a 'fair' distinction can be made, the model would require additional indicators like the share of non-commercial to commercial investors, which might result in an expectation delay that is dependent on this ratio. This indicator could also replace or complement the open interest level, and therefore change the feedback loop of price expectations and risk premia. Most of the other proposed policies lower the number of speculators that is present in the market, and therefore moderate the peaks and lows in behavior of prices. The reinforcing effect of prices on price expectations will occur less strongly because of the higher expectation delay that follows from less speculation in the market. Moreover, position limits influence the quantitative relation between price expectations and open interest levels: by setting more strict limits, the average level of open interest most likely goes down.

The proposed regulations were not tested in the quantitative model because of limited quantitative knowledge of the consequences of these regulations. Evaluation of the impact of position limits and taxation on the number of speculators is required as to substantiate the policies that were recommended. An increased level of transparency on the line of thought and calculations behind these policies would enable future researchers to qualitatively evaluate the proposed policies.

10. Reflection

This chapter describes how the discussed results are relevant to the research field. Moreover, the research approach and methods are reflected upon.

10.1 Scientific Relevance of the Study

As stated in Chapter 1, the application of system dynamics in economic systems has gained attraction in recent years (Lane & Rouwette, 2023). However, this study is the first known attempt to incorporate the quantitative effects of speculation into a price-setting model of a commodity market. The system dynamics approach has been used to formulate conceptual models on supply and demand, but no conceptual models which include the market for storage or price expectations were found. This research therefore adds to knowledge on a more complete picture of the structure of economic systems with interacting factors and loops that determine the behavior of spot and futures prices.

Secondly, the literature review has shown how statistical methods (often Granger causality tests) have been employed extensively without resulting in consensus on the effects of speculation or required policies. The system dynamics approach offers a new perspective on the problem at hand and can be used to deepen our understanding of the mechanisms involved in spot price discovery. The model visually shows the different relations between economic variables and the consequences of the interaction between these variables. While previous research mostly focused on the cause-and-effect of separate variables (e.g., the futures and spot price), this research uses a more holistic approach to provide a more complete picture of the system structure. The system dynamics approach does not solve the debate, but it can help in moving it forward: if statistical methods show different results depending on the used indicators, research questions, and time period, system dynamics can help in explaining how these different results occur through comparison of different models. For example, by incorporating a different indicator to measure speculation, the system might show different behavior. The model provides a more understandable, transparent way to explain this behavior than available statistical methods, which are mostly used to test traditional economic theories. The approach of system dynamics will be further reflected on in section 10.2.

To improve the working of the model, a quantitative way to incorporate policies is required. However, this would also require a higher level of transparency from regulators regarding the calculation of position limits and specification of types of traders. The need for this transparency can also be seen in the criticized European position limits as mentioned in Chapter 4. The MiFID introduced limits that were too high to actually reduce the level of excessive speculation: how much of the 'excessive' speculation were these limits actually meant to curb? With a more complete picture of the working of financial markets, combined with transparency on calculations, the overall effect of implementing specific position limits on spot prices and inventories could have been assessed beforehand (at least partly). By extending the model in such a way that the number of speculators can be influenced through different policies, policy makers gain more knowledge on the 'complete' picture, which could enhance the decision-making process.

10.2 Reflection on the Research Method

In Chapter 2, the arguments in favor of the system dynamics approach have been discussed. It was concluded that the system dynamics approach is useful to show non-linear behavior, to account for feedback loops and different types of delays, and to investigate the economic system without a data intensive approach. After the modelling phase and interviews, the system approach can be re-evaluated and compared to statistical approaches. The interviews showed how most experts acknowledged the fact that statistical approaches (that have mostly been employed within the topic of speculation and financial markets) often lead to results that are taken out of context. Statistical approaches offer a more quantitative answer to questions on the effects of speculation than the system dynamics model, while the latter approach is more suitable to provide insight into the behavior of the system (and the behavioral mechanisms involved) but cannot elaborate on the exact magnitude of the effects. However, when statistical methods are used, one has to be careful not to exaggerate the extent to which the results can be generalized: the fact that a significant effect of one specific indicator has been found, does not mean that the same conclusion can be drawn with different data, a different period under investigation, or a different indicator. Within a system dynamics model, the structure of the model remains the same regardless of the data, the period under investigation, or the type of external indicator. At the same time, the results of a system dynamics model should also be handled with care, since the modelling approach requires a large number of assumptions, which cannot always be substantiated with literature. Both approaches therefore require clear communication about their limitations, as was done in section 5.2.

While the model is relatively simplistic, it is also a first step in combining the fields of system dynamics and financial speculation. The research can therefore serve as a reference for future modelers in the field of commodity market speculation. It can be considered 'proof of principle' (Azeem, 2020): it shows the feasibility of using the approach of system dynamics to investigate the effects of speculative activity. The 'hybrid' approach of translating existing economic theories into a system dynamics model (Radzicki, 2009) has shown how traditional (and mostly static) economic theories can be adapted to produce realistic behavior using the approach of system dynamics. Not only does the model produce realistic behavior, but its communicative value also shows how the approach of system dynamics can be combined with (non)traditional economic theory in an effective way. If the assumptions of the model are clearly communicated, and the resulting limitations are acknowledged, the system dynamics approach can be a powerful tool within the field of economics and financial markets.

10.3 The Role of Financial Speculation in Commodity Markets: Harmful or Helpful?

While the model behavior shows how speculation potentially creates peaks and lows in spot prices, the results from different previous studies should not be overlooked. Both the literature review and expert interviews have shown how speculation also holds positive effects: to a certain extent, speculation can provide liquidity in the market, which enables the hedging of risks of market participants (e.g., protecting the farmers). Speculators fill the imbalances that occur through hedgers' demand and supply and could therefore stabilize the market. This research does not show that speculation in food commodity markets is solely harmful, nor does it show that it is completely helpful. Finding the right balance between speculation and hedging activities is required to reap the benefits of price risk mitigation, while also preventing a surge in prices.

While this chapter has shown that each research approach holds its limitations, and could therefore always be improved, the current approach has provided a fresh analysis of both the potential impacts of financial speculation on food commodity prices as well as policies that could influence the level of financial speculation. The need for policies to stop the increase in food insecurity and world hunger has become evident. The system dynamics model carries a highly communicative, holistic value, and the addition of the information gathered through expert interviews has allowed for a realistic view on policy implementation.

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Appendices

Appendix A. Overview of Literature on Speculation and Prices

Table A1 shows the literature that has been reviewed for the literature study. It states the author(s) of the article, the method, the market, and the time period, and answers the question whether or not speculation was found to influence commodity prices. Table A2 shows and explains the relations between variables in the stock flow diagram.

Table A1: Investigated Sources

Authors	**Method**	**Market**	**Time period**	**Does speculation influence the commodity price?**
Masters & White (2008)	Theoretical model on index investment	Multiple	2003 - 2008	Yes
Robles et al. (2009)	Granger causality test using monthly data	Agriculture	2002-2008	Yes
Irwin & Sanders (2010)	Granger causality test using weekly data	Agriculture & energy	2006-2009	No
Lagi et al. (2011)	Dynamic, quantitative model using monthly data	Agriculture	2004 - 2011	Yes
Falkowski (2011)	Theoretical model on price formation	Multiple	-	Depends on the market
Dwyer et al. (2012)	Principal Component Analysis (PCA)	Multiple	1990-2011	No
Tang & Xiong (2012)	Regression analysis	Multiple	1998 - 2011	Yes
Algieri (2013)	Johansen cointegration test	Wheat	1980-2012	Yes
Fattouh et al. (2013)	Theoretical model through comparison of literature	Oil	2003-2008	No
Bos & Van Der Molen (2013)	Non-parametric, highly flexible empirical model	Coffee	1989 - 2008	Partly, spiky behavior
Kilian & Murphy (2014)	Vector-autoregressive (VAR) model	Crude oil	2003 – 2008	No
Kim (2015)	Cross-sectional analysis	Multiple	1992 – 2012	No

Knittel & Pindyck (2016)	Simple model of supply and demand	Crude oil	1989 – 2008	No
Basak & Pavlova (2016)	Theoretical, dynamic model of commodity futures markets	Multiple	–	Yes
Mayer et al. (2017)	Granger-causality tests and EGARCH volatility analysis	Metal	1993 – 2013	No
Clapp & Isakson (2018b)	Theoretical model on the agri-food sector	Agriculture	–	Yes
Natoli (2021)	Theoretical model on financialization	Multiple	–	Yes
Zloty (2021)	Pearson's linear correlation	Multiple	2000 – 2018	Yes
Kornher et al. (2022)	Theoretical model on speculative indicators	Agriculture	2000-2022	Yes
Ready & Ready (2022)	An empirical model using intraday data (regression)	Multiple	2008 - 2020	Yes
IPES-Food (2022)	Theoretical model on global food security	Agriculture	–	Yes

Table A2: Relations Variables in Stock Flow Diagram

From	To	Relation	Explanation
Supply	Inventory	+	More supply results in a higher inventory level.
Demand (sales)	Inventory	–	More demand (sales) results in a lower inventory level.
Inventory	Supply (production)	–	The inventory level determines how much supply can still be stored: with a higher inventory, there is less room for new supply.
Inventory	Sales (demand)	+	The inventory level determines how much demand can be satisfied: with a higher inventory, more demand can be satisfied.
Inventory	Marginal convenience yield	–	The higher the inventory level, the lower the marginal convenience yield or the value of storage (Knittel & Pindyck, 2016).
Production delay	Supply (production)	–	With a higher production delay, it takes a longer time before a new level of supply can enter the inventory. A higher delay will therefore lower the amount of supply (production) in one timestep.
Max inventory level	Supply (production)	+	With a higher maximum inventory level, the inventory holds more room for additional supply.
Production adjustment	Supply (production)	+	The higher the production adjustment, the higher the new level of supply (production).
Price elasticity of supply	Production adjustment	+	The price elasticity of supply is zero or higher than zero. Therefore, the higher the price elasticity of supply, the bigger the change in production once changes in spot price occur (Knittel & Pindyck, 2016).
Production adjustment time	Production adjustment	–/+	With a higher production adjustment time, it takes a longer time before a new level of production occurs. It depends on the sign of the production adjustment whether or not the delay has a positive or negative relationship with the production adjustment.

Demand adjustment time	Sales (demand)	–/+	With a higher demand adjustment time, it takes a longer time before a new level of demand occurs. It depends on the sign of the demand adjustment whether or not the delay has a positive or negative relationship with the demand adjustment
Demand adjustment	Sales (demand)	+	The higher the demand adjustment, the higher the new level of sales (demand).
Price elasticity of demand	Demand adjustment	–	The price elasticity of demand is zero or smaller than zero. Therefore, the higher the price elasticity of demand, the smaller the change in demand once changes in spot price occur (Knittel & Pindyck, 2016).
Spot price	Demand adjustment	–	The higher the spot price, the lower the demand adjustment, because the price elasticity of demand is negative (Knittel & Pindyck, 2016).
Spot price	Production adjustment	+	The higher the spot price, the higher the demand adjustment, because the price elasticity of supply is positive (Knittel & Pindyck, 2016).
Marginal convenience yield	Spot price change	+	A higher marginal convenience yield results in a higher spot price (Gulley & Tilton, 2014).
Per unit storage cost	Spot price change	–	A higher per unit storage cost results in a lower spot price (Gulley & Tilton, 2014).
Risk-free interest rate	Spot price change	–	A higher risk-free interest rate results in a lower spot price (Gulley & Tilton, 2014).
Futures price	Spot price change	+	A higher futures price results in a higher spot price (Gulley & Tilton, 2014).
Spot price	Spot price change	–	The higher the spot price, the lower the change in spot price.
Spot price change	Spot price	+	The higher the change in spot price, the higher the spot price.
Spot price	Expected spot price change	+	A higher spot price makes for higher expectations of the spot price because of trend-following behavior by speculators (De Jong et al., 2021)

Expectation delay	Expected spot price change	–/+	With a higher expectation delay, it takes a longer time before expectations are adapted to the current spot price. The sign of this relation depends on whether the difference between the current spot price and the expected spot price is positive or negative.
Change in expected spot price	Expected spot price	+	The higher the change in expected spot price, the higher the expected spot price.
Expected spot price	Expected spot price change	–	The higher the expected spot price, the lower the change in expected spot price.
Expected spot price	Futures price	+	A higher expected spot price results in a higher futures price (Knittel & Pindyck, 2016).
Expected spot price	Open interest	+	A higher expected spot price makes for a more attractive market, with a higher inflow of speculators and thus a higher open interest level.
Open interest adjustment delay	Open interest	–/+	With a higher open interest adjustment delay, it takes a longer time before the open interest is adapted to the expected spot price. The sign of this relation depends on whether the difference between the current open interest and the next is positive or negative.
Open interest	Risk premium	–	A higher level of open interest indicates more market uncertainty, meaning the expected rate of return of the investor should be higher. Since the risk premium shows the difference between the risk-free interest rate and the expected rate of return, it will therefore be lower (Kocagil & Topyan, 1997; Hong & Yogo, 2010).
Risk premium	Futures price	+	A higher risk premium results in a higher futures price (Knittel & Pindyck, 2016).
Risk-free interest rate	Risk premium	+	Since the risk premium shows the difference between the risk-free interest rate and the expected rate of return, it will be higher once the risk-free rate is higher (Kocagil & Topyan, 1997; Hong & Yogo, 2010).

Appendix B. Model Variables

Table B1 explains the variables and equations that are used in the quantitative system dynamics model. Moreover, it presents both the base case value as well as the range of values that was tested using the model. Figure B1 shows a visualization of the model in Vensim.

Table B1: Model Variables and Equations

Variable name	Type of variable	Unit	Formula	Description	Base case	Range	Source
Inventory of soy	Level	Mln Bushel	INTEG(Supply of soybeans - Sales of soybeans)	The total global stock of soybeans	xx	xx	xx
Initial inventory	Initial	Mln Bushel		Initial value for the global inventory of soybeans in 2010	800	100 - 1600	(FAOSTAT, 2023)
Supply of soybeans	Auxiliary	Mln Bushel /Month	DELAY3((MIN(Planned production, Available room to store)), Production delay)	The total inflow of soybean supply	xx	xx	xx
Sales of soybeans	Auxiliary	Mln Bushel /Month	MIN(Inventory of soy/ Minimal storage time, Demand)	The total outflow of soybean sales	xx	xx	xx
Available Room to Store	Auxiliary	Mln Bushel /Month	MAX((Max inventory level/Minimal storage time-Inventory of soy/Minimal storage time -Planned production),0)	The room left in the stock to store soybeans	xx	xx	xx
Max inventory level	Constant	Mln Bushel		Maximum total inventory	5000	1000-10000	Assumption: 'endless' inventory capacity
Minimal storage time	Constant	Month		The minimal storage time of soybeans	1	xx	Assumption
Planned production	Level	Mln Bushel /Month	INTEG(Production adjustment)	The total planned production of soybeans	xx	xx	xx
Production adjustment	Auxiliary	Mln Bushel /(Month*Month)	IF THEN ELSE(Planned production + (Reference production*(1+Percentage change in production/100)) > 0, ((Reference production*(1+Percentage change in production/100)) – Planned production)/Production adjustment time + Production shock, 0)	The change in planned production occurring through changes in price	xx	xx	xx
Production adjustment time	Constant	Month		Time between a change in price and a change in planned production	6	1 - 12	Time over which producers and consumers choose to contract for delivery (Lagi et al., 2011)
Initial production	Initial	Mln Bushel /Month		The initial production in 2010	800	100 - 1600	(FAOSTAT, 2023)
Production delay	Constant	Month		Time between planting and harvesting soybeans	4	3 - 5	(BarChart, 2023)
Reference production	Constant	Mln Bushel /Month		The average of monthly production levels 2010-2023	1000	xx	(FAOSTAT, 2023)
Reference spot price	Constant	USD/Bushel		The average spot price 2010-2023	12	xx	(IMF, 2023)
Price elasticity of supply	Constant	Dmnl		Responsiveness of supply of soybeans to changes in price	0.1	0 - 1	(Babcock et al., 2021)

Percentage change in production	Auxiliary	Dmnl	Price elasticity of supply*((Spot price-Reference spot price)/Reference spot price*100)	Percentage change in production through changes in price	xx	xx	xx
Initial demand	Initial	Mln Bushel /Month		The initial demand for soybeans in 2010	800	100 - 1600	Assumption: no ending stocks remaining, so initial demand is equal to initial supply
Demand	Level	Mln Bushel /Month	INTEG(Demand adjustment)	The total demand for soybeans	xx	xx	xx
Demand adjustment	Auxiliary	Mln Bushel /(Month*Month)	IF THEN ELSE(Demand + (Reference demand*(1+Percentage change in demand/100)) > 0, (((Reference demand*(1+Percentage change in demand/100)) - Demand)/Demand adjustment time), 0)	The change in demand occurring through changes in price	xx	xx	xx
Demand adjustment time	Constant	Month		Time between a change in price and a change in demand	6	1 - 12	Time over which producers and consumers choose to contract for delivery (Lagi et al., 2011)
Reference demand	Constant	Mln Bushel /Month		The average of monthly demand levels 2010-2023	1000	xx	Assumption: no ending stocks remaining, so reference demand is equal to reference supply
Percentage change in demand	Auxiliary	Dmnl	Price elasticity of demand*((Spot price-Reference spot price)/Reference spot price*100)	Percentage change in demand through changes in price	xx	xx	xx
Price elasticity of demand	Constant	Dmnl		Responsiveness of demand for soybeans to changes in price	-0.4	0 - -1	(Huang, 1979)
Spot price	Level	USD/Bushel	INTEG(Change in spot price)	The spot price of soybeans	xx	xx	xx
Initial spot price	Initial	USD/Bushel		Initial value for the spot price in 2010	10	1-20	(IMF, 2023)
Change in spot price	Auxiliary	USD/Bushel /Month	IF THEN ELSE(Spot price + ((Futures price/(EXP(("Risk-free interest"-Marginal convenience yield)*Time until delivery))-Per unit storage cost)) > 0, (((Futures price/(EXP(("Risk-free interest"-Marginal convenience yield)*Time until delivery))-Per unit storage cost)-Spot price)/Minimal storage time), 0)	The difference between the current and next spot price	xx	xx	(Dupoyet, n.d).
Risk-free interest rate	Constant	Dmnl		The interest received on a risk-free investment opportunity	0.04	0.01 – 0.10	(YCharts, 2023)
Per unit storage cost	Constant	USD/Bushel		Cost to store one bushel of soybeans	0.08	0.06 - 0.15	(USB, 2022)
Marginal convenience yield	Auxiliary	1/Month	(Reference yield*Effect inventory on marginal convenience yield)/100	The value of storing one bushel of soybeans extra	xx	xx	xx
Reference inventory	Constant	Mln Bushel		Variable to install lookup	1200	800 - 1600	Assumption: potential range follows from anomaly test

Reference yield	Constant	1/Month		Variable to install lookup	5	0 - 10	(Knittel & Pindyck, 2016; Gulley & Tilton, 2014)
Effect inventory on marginal convenience yield	Auxiliary with Lookup	Dmnl	WITH LOOKUP(Inventory of soy/ Reference inventory, ((0,2),(0.2,2),(0.4,1.5),(1,1), (2,0.5),(3,0.2),(4,0),(5,0),(6,0), (7,0),(8,0),(9,0),(10,0)))	Variable that connects the marginal convenience yield to levels of inventory	xx	xx	Assumption: exponentially decreasing curve (Considine et al., 2020)
Futures price	Auxiliary	USD/Bushel	MAX((Expected spot price*EXP(Risk premium*Time until delivery)), 0)	Value of the futures price in the futures market	xx	xx	(Dupoyet, n.d).
Risk premium	Auxiliary	Dmnl	Risk-free interest-Reference expected rate of return*Effect speculation on expected rate of return	Variable that determines the spread between expected spot prices and futures price	xx	xx	(Dupoyet, n.d; De Jong, 2021; Kocagil & Topyan, 1997)
Expected spot price	Level	USD/Bushel	INTEG(Change in expected spot price)	Expected spot price of soybeans	xx	xx	xx
Change in expected spot price	Auxiliary	USD/Bushel /Month	(Spot price-Expected spot price)/(Expectation delay/Delay order)	The change in expected spot price	xx	xx	(De Jong et al., 2021)
Expectation delay	Constant	Month		Time before price expectations are adapted	3	1 - 12	Assumption: the more speculators, the lower the expectation delay (CFI, 2023)
Initial expected spot price	Initial	USD/Bushel		Initial value for the expected spot price in 2010	10	1 - 20	Assumption: expectations in beginning of the model are equal to current spot price
Time until delivery	Constant	Month		Time until delivery date (maturity of the futures contract)	6	1 - 12	Assumption: value depends on the focus on specific type of contract (Bisso, 2017)
Reference open interest	Constant	Contracts		Variable to install lookup	700000	xx	The average of open interest levels 2010-2023 (CFTC, 2023)
Effect speculation on expected rate of return	Auxiliary with Lookup	Dmnl	WITH LOOKUP(Open interest/Reference open interest, ((0.25,0.58),(0.5,0.76),(1,1),(2,1.31)))	Variable that connects the levels of open interest to risk premium	xx	xx	100% increase of open interest results in 31% increase of the expected rate of return (Hong & Yogo, 2010)
Reference expected rate of return	Constant	1/Month		Variable to install lookup	0.04	0.01-0.10	Average expected return on a futures contract with 6 months maturity (Knittel & Pindyck, 2016; Bisso, 2017)
Initial open interest	Initial	Contracts		The initial open interest in 2010	400000	300000 - 1400000	(CFTC, 2023)
Open interest	Level	Contracts	INTEG(Change in open interest)	The level of open interest	xx	xx	xx
Effect expectations on open interest	Auxiliary with Lookup	Dmnl	WITH LOOKUP(Expected spot price/Reference spot price, ((0, 0.6), (0.7, 0.6), (1,1), (1.1, 1.5), (1.2, 1.9), (1.5, 2), (2,2), (5,2)))	Variable that connects price expectations to levels of open interest	xx	xx	Assumption: S-shaped curve

Change in open interest	Auxiliary	Contracts /Month	((Reference open interest*Effect expectations on open interest)–Open interest)/Open interest adjustment delay	The change in open interest	xx	xx	xx
Delay order	Constant	Dmnl		Variable that specifies the order of the delay	1	1 – 3	Assumption: expectations are delayed by either a first or third order delay
Open interest adjustment delay	Constant	Month		Time it takes before updated expectations lead to different open interest levels	12	12 – 24	Speculatively driven bubbles can be expected to have a natural duration of a year or longer (Lagi et al., 2011)
Switch failed harvest	Constant	Dmnl		Switch to simulate a shock in production	0	0 or 1	xx
Production shock	Auxiliary	Mln Bushel /(Month*Month)	IF THEN ELSE(Switch failed harvest = 1, (PULSE(48, Production delay)*Decrease in harvest), 0)	Variable that is used to experiment with temporarily lower planned production levels	xx	xx	Assumption: a production shock occurs after four years and lasts as long as the production delay
Decrease in harvest	Constant	Mln Bushel /(Month*Month)		The amount by which production is lowered due to a bad harvest	–200	xx	Assumption: a production shock implies that production adjustment is lowered by 200 million bushels

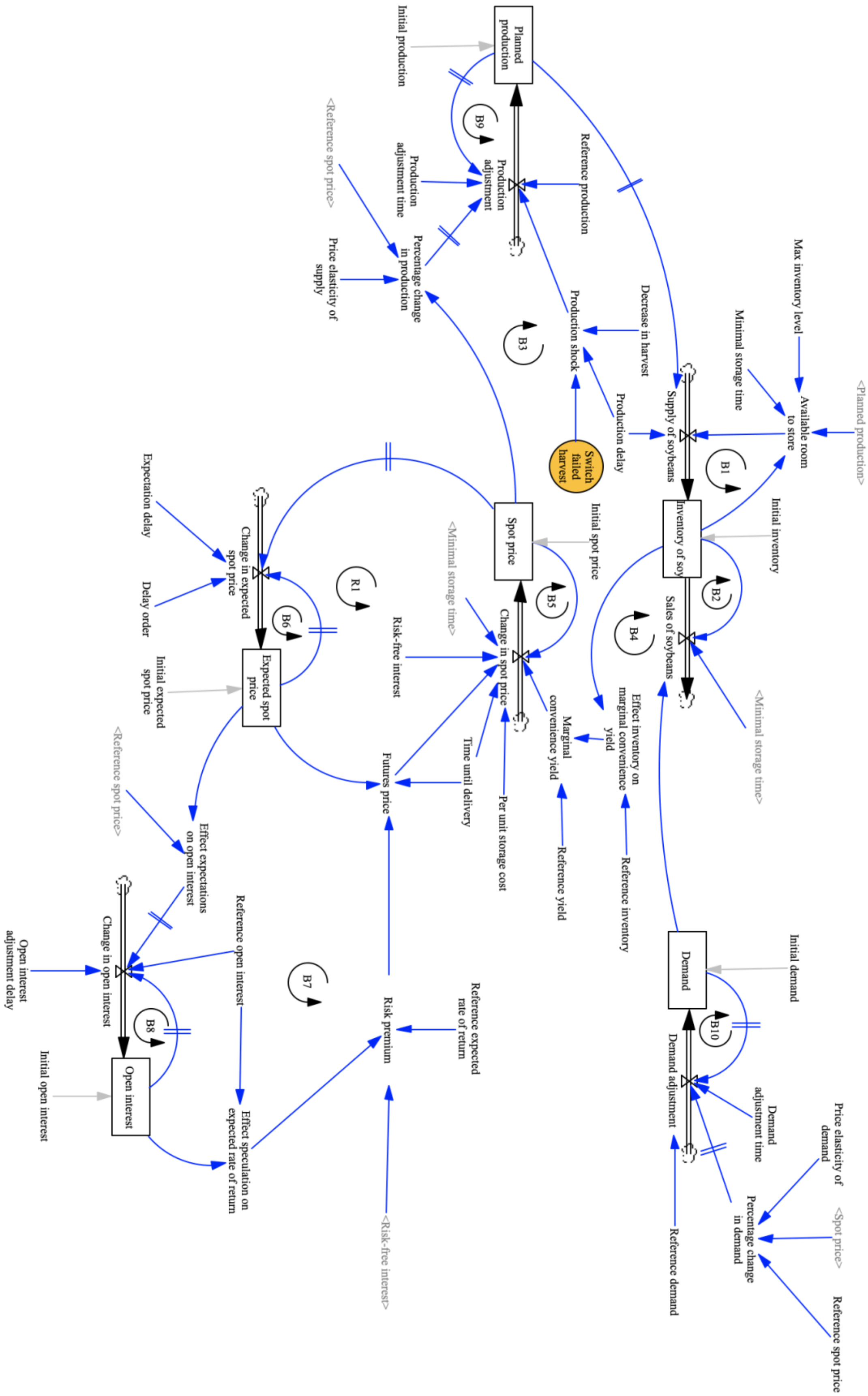

Figure B1: Model Overview

Appendix C. Choice of Model Time Step

To check the correct choice of time step, runs with different time step sizes are performed. A significant change in model behavior indicates a wrong step size. Therefore, the step size is halved until almost no changes in behavior are visible. From Figure C1 and C2, it can be seen that in the first few years, a reduction of the time step does not result in different behavior, whereas later periods show that a time step size of 0.0625 produces different behavior than a time step of 0.125. However, the difference between 0.0625 and 0.03125 is barely visible, which is why a time step of 0.0625 is chosen for running the model.

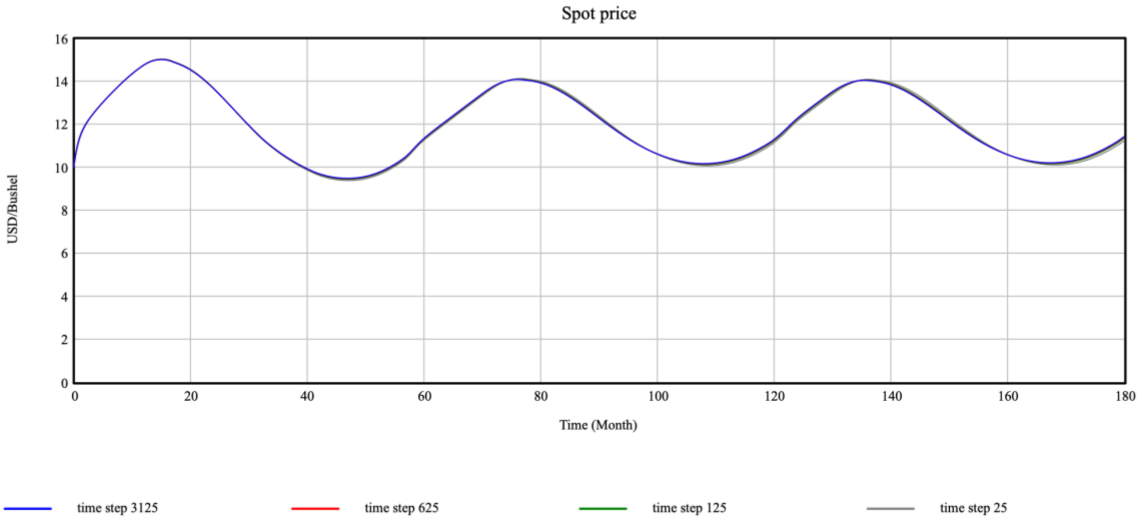

Figure C1: Time Step Test

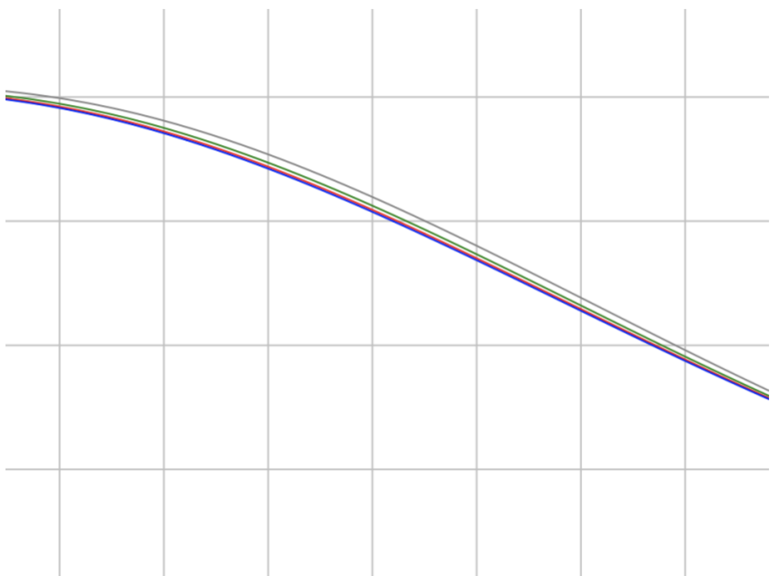

Figure C2: Close-up of Time Step Test

Appendix D. Extreme Conditions Test

Table D1 shows the different extreme conditions tests that are performed. Each extreme value test will be compared to the base case. Changes in behavior will be discussed and explained.

Table D1: Values for Extreme Conditions Tests

Input parameter	Base case value	Min value	Max value
Reference expected rate of return	0.04	0.0004	4
Reference yield	5	0.05	15
Expectation delay	3	0.07	300
Max inventory level	5000	500	50000

D.1 Extreme Values for Reference Expected Rate of Return and Reference Yield

The first extreme conditions test is performed for the reference expected rate of return. This reference expected rate of return determines futures prices and therefore also spot prices. When an extremely low value for the reference expected rate of return (0.0004) is used in the model, the initial increase in the spot price is much higher compared to the base case. This was expected since a lower expected rate of return results in higher futures and spot prices. After this increase, the spot price starts to oscillate around this higher value (which is not so clearly visible in Figure D1), because the balancing convenience yield loop starts to play a role: inventories also show oscillation in Figure D1. The balancing open interest loop is not able to play any role because of the extremely low expected rate of return. It was expected that after a while, because of the fast-reacting futures market (compared to the slow-reacting storage market), the reinforcing price expectations loop starts to dominate. The results in Figure D1 show this expected behavior: the price starts to increase. Even though in reality, one would expect that inventories start to accumulate, this does not happen according to the results. This can be explained through the fact that the maximum inventory level is reached, and supply cannot increase any longer. Even though the planned production is extremely high, inventories cannot increase any further. Both supply and demand are near zero: since demand stays slightly higher (it cannot be further adjusted because this would lead to demand below zero), inventories will eventually be emptied. This was checked through extension of the simulation period, showing an empty inventory after 200 months.

When an extremely high value for the reference expected rate of return is used (4), the expectation is that prices will start to drop immediately through the expectation loop. It can be seen from the results in Figure D2 that no oscillation takes place: prices start to decrease instead. This is because with a too high expected rate of return, the balancing loops of the inventory model and open interest model will not start to play a significant role in model behavior. With prices going towards zero, it is expected that inventories will stabilize around a lower value. The model again shows the expected behavior. Because the adjustment cannot result in a planned production below zero, the planned production level stays relatively high.

Figures D3 and D4 show what happens with extreme conditions for the reference yield: an extremely low reference yield (0.05) makes the spot price go down without oscillation, just as a very high expected rate of return did. With a too low reference yield, the balancing loops of the inventory model and open interest model will not start to play a significant role in model behavior. An extremely high value of the reference yield (15) results in an initial increase of prices, after which oscillation occurs more frequently than in the base case, because bigger and more frequent changes in convenience yield occur.

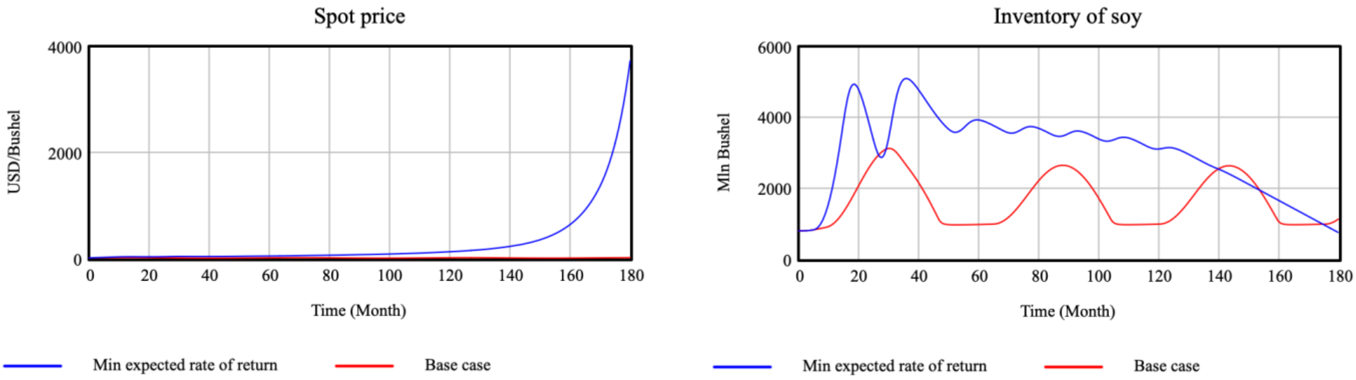

Figure D1: Min Reference Expected Rate of Return

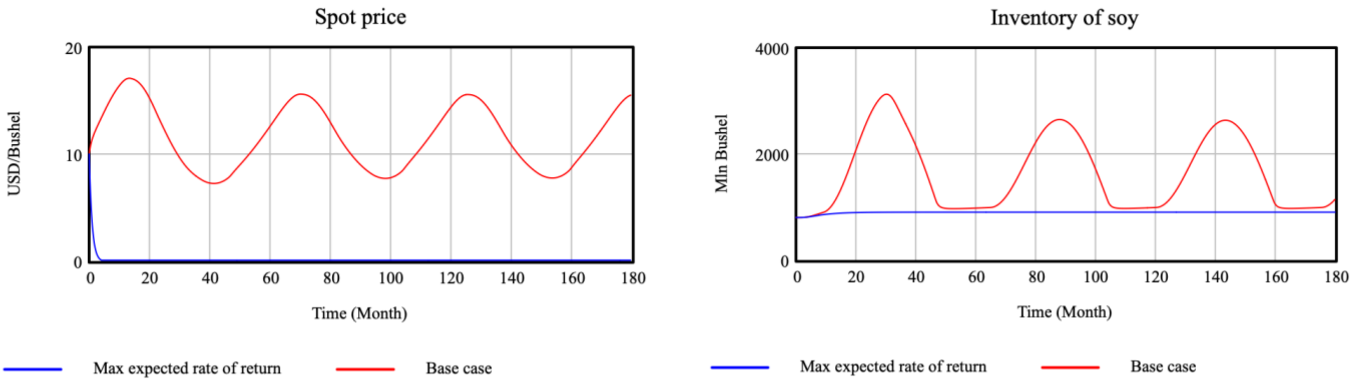

Figure D2: Max Reference Expected Rate of Return

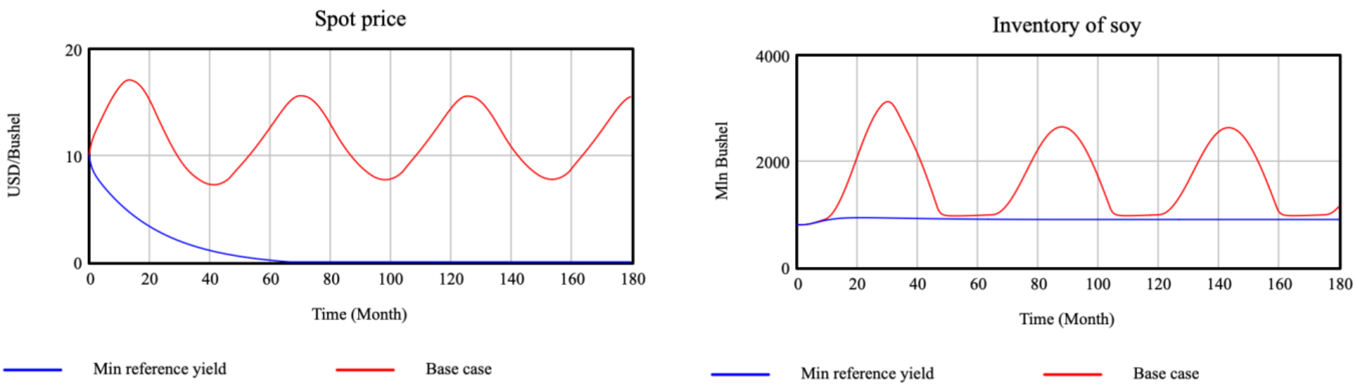

Figure D3: Min Reference Yield

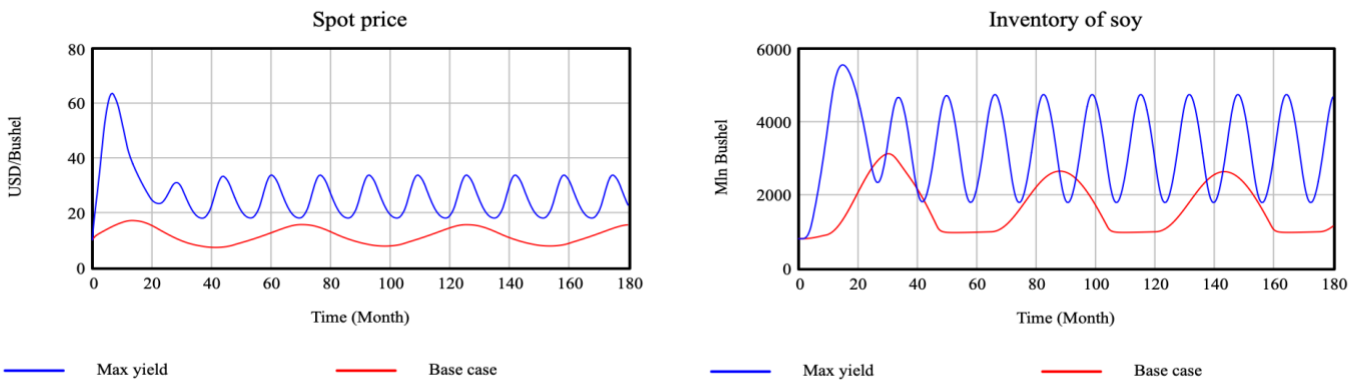

Figure D4: Max Reference Yield

D.2 Extreme Values for Expectation Delay

An extreme conditions test for the expectation delay is performed to test whether the expectations loop behaves as expected. When an extremely low delay is used (0.07 months, which is the smallest possible value that is still above the model time step), expectations are adapted almost instantly. It is expected that inventory levels and prices change more frequently (implying higher price volatility). The results in Figure D5 indeed show a more frequent oscillation in both price and inventory levels. When an extremely high value for the expectation delay is used (300 months), it is expected that almost no change in price or inventory levels will occur, because the running time of the model is only 180 months. The results in Figure D6 show how indeed almost no changes occur.

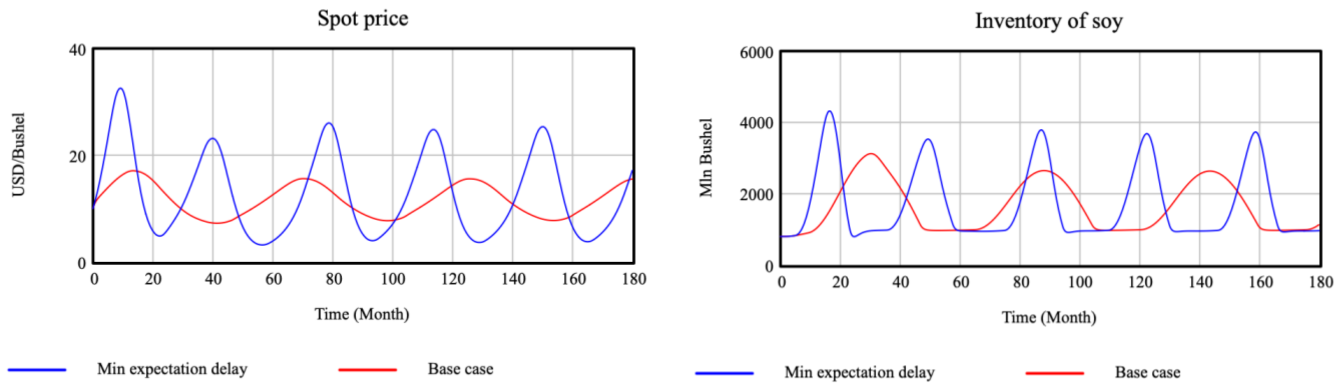

Figure D5: Min Expectation Delay

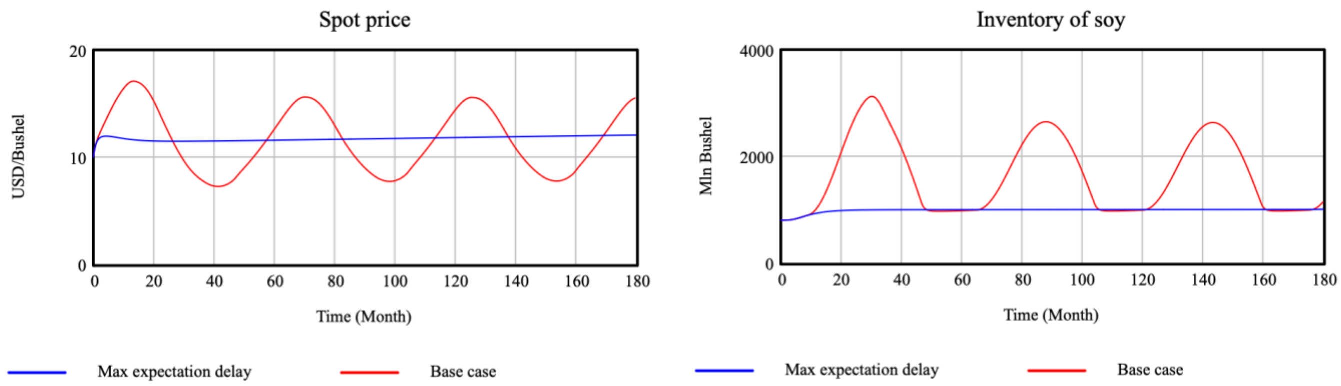

Figure D6: Max Expectation Delay

D.2 Extreme Values for Max Inventory Level

To further test whether the model behaves as expected under extreme conditions, the max inventory level is used. This variable determines the capacity of the inventory and can therefore cap or enable the supply of soybeans. It is expected that extremely low values for the max inventory level (500) will 'shutdown' the role of the inventory model and the balancing loop of the convenience yield. The results in Figure D7 indeed show how inventory levels stay low compared to the base case. Furthermore, after some years, prices start to rise exponentially. This can be explained through the role of the open interest: at first, the open interest keeps increasing due to small increases in prices. However, as mentioned in the model overview, open interest levels will not increase endlessly as prices do, because of fear of a 'burst of the price bubble'. Therefore, once the maximum open interest level is reached, the balancing effect of open interest levels on futures prices will stop. This enables prices to grow exponentially. While in reality, prices will never rise to levels as seen in the results, this could happen in theory. The model therefore shows the expected behavior.

At extremely high inventory levels (50000), it is expected that the model behavior will not change significantly. Inventory levels will not become extremely high, because of the Theory of Storage (Working, 1949: see literature review). The results in Figure D8 do show some change in model behavior: the initial inventory increase is higher compared to the base case, which produces a slightly lower price during the first oscillation. However, the model still shows the same oscillating behavior, as was expected.

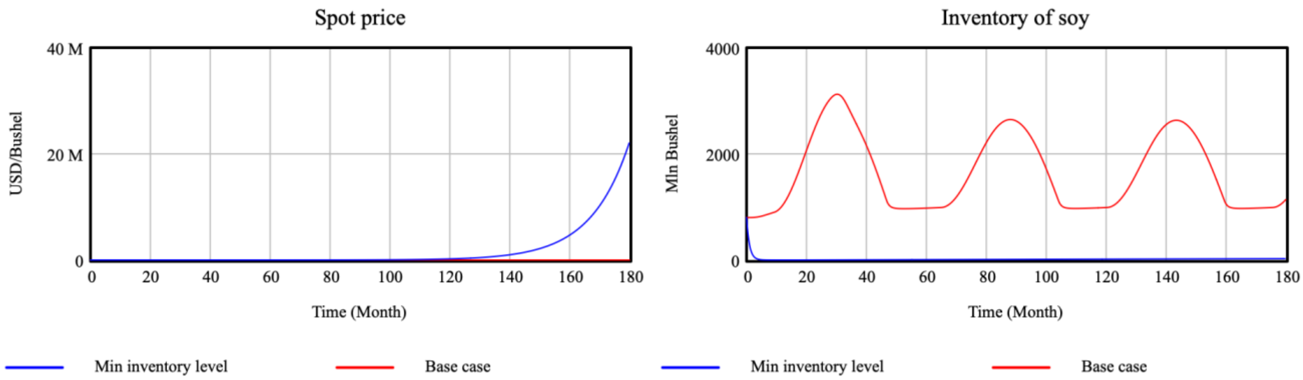

Figure D7: Min Inventory Level

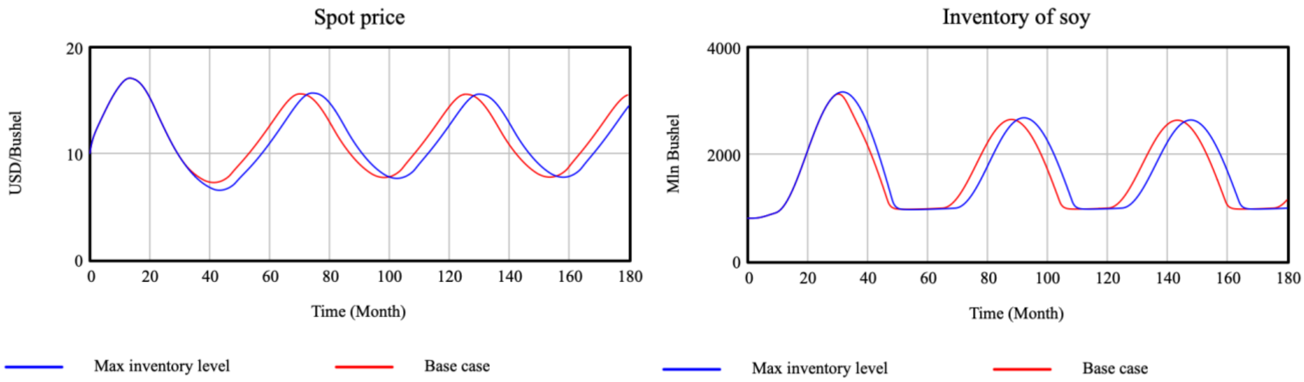

Figure D8: Max Inventory Level

Appendix E. Sensitivity Analysis

The sensitivity of the model to small changes in uncertain parameters will be measured through adding or subtracting 10% from the original value, as is done in Table E1. Two techniques are used to evaluate sensitivity. First, the multivariate sensitivity analysis gives an overview of the overall sensitivity of the model. Second, the univariate technique will indicate individual sensitivity of specific parameters. For both techniques, the sensitivity tool in Vensim is used. Moreover, Latin Hypercube Sampling is used to ensure equal sampling, with 200 different runs.

Table E1: Ranges of Multivariate Sensitivity Analysis

Variable name	Type of variable	Unit	Min value	Base case	Max value
Initial inventory	Initial	Mln Bushel	720	800	880
Max inventory level	Constant	Mln Bushel	4500	5000	5500
Production adjustment time	Constant	Month	5.4	6	6.6
Initial production	Initial	Mln Bushel	720	800	880
Production delay	Constant	Month	3.6	4	4.4
Reference production	Constant	Mln Bushel	900	1000	1100
Reference spot price	Constant	USD/Bushel	10.8	12	13.2
Price elasticity of supply	Constant	Dmnl	0.09	0.1	0.11
Initial demand	Initial	Mln Bushel	800	720	880
Demand adjustment time	Constant	Month	5.4	6	6.6
Reference demand	Constant	Mln Bushel	900	1000	1100
Price elasticity of demand	Constant	Dmnl	-0.44	-0.4	-0.36
Initial spot price	Initial	USD/Bushel	9	10	11
Risk-free interest rate	Constant	Dmnl	0.036	0.04	0.044
Per unit storage cost	Constant	USD/Bushel	0.072	0.08	0.088
Reference inventory	Constant	Mln Bushel	1080	1200	1320
Reference yield	Constant	1/Month	4.5	5	5.5
Expectation delay	Constant	Month	2.7	3	3.3
Initial expected spot price	Initial	USD/Bushel	9	10	11
Time until delivery	Constant	Month	5.4	6	6.6
Reference open interest	Constant	Contracts	630000	700000	770000
Reference expected rate of return	Constant	1/Month	0.036	0.04	0.044
Initial open interest	Initial	Contracts	360000	400000	440000
Open interest adjustment delay	Constant	Month	10.8	12	13.2

The results from the multivariate sensitivity analysis in Figure E1 show how the oscillating behavior of spot prices and inventory levels always occurs, but the amplitude and value around which oscillation takes place differs. This indicates numerical sensitivity. Moreover, it can be seen that the timing of the oscillation differs: different runs show different moments of peaks and lows. This indicates some behavioral sensitivity, which is also confirmed through the fact that over time, the oscillation of inventory levels fades away.

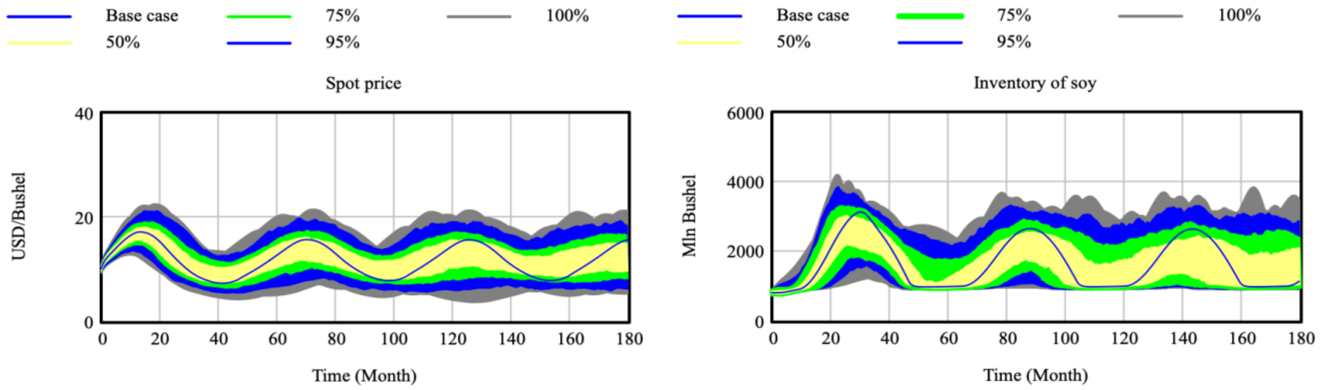

Figure E1: Multivariate Sensitivity Analysis

To further investigate individual parameter influences, the univariate results will be discussed in more detail. The main focus of these tests is the variation of uncertain variables, which are more difficult to find in the available literature. First, the sensitivity of the KPI's to changes in the reference yield is evaluated through a univariate analysis. From the results in Figure E2 it can be seen that sensitivity mainly occurs through the timing of the oscillation (different moments of peaks and lows).

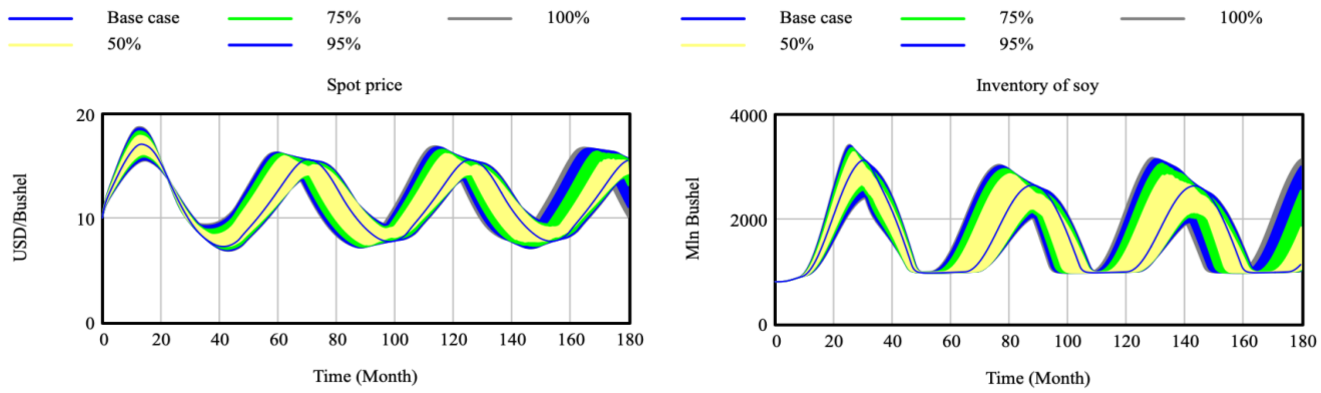

Figure E2: Univariate Sensitivity Analysis of Reference Yield

Furthermore, from the extreme condition tests, it was already concluded that the influence of the yield also depends on the max inventory level. With a very low value for the max inventory level, the yield will continue to be high. Therefore, another multivariate test is performed with both the reference yield and the max inventory level (both varied by -/+ 10%). The results in Figure E3 show that the KPI's are indeed highly more sensitive to a combination of these parameters. The same was tested for a combination of the reference yield and reference expected rate of return. Again, the model appeared sensitive to the combination of these values, as can be seen in Figure E4.

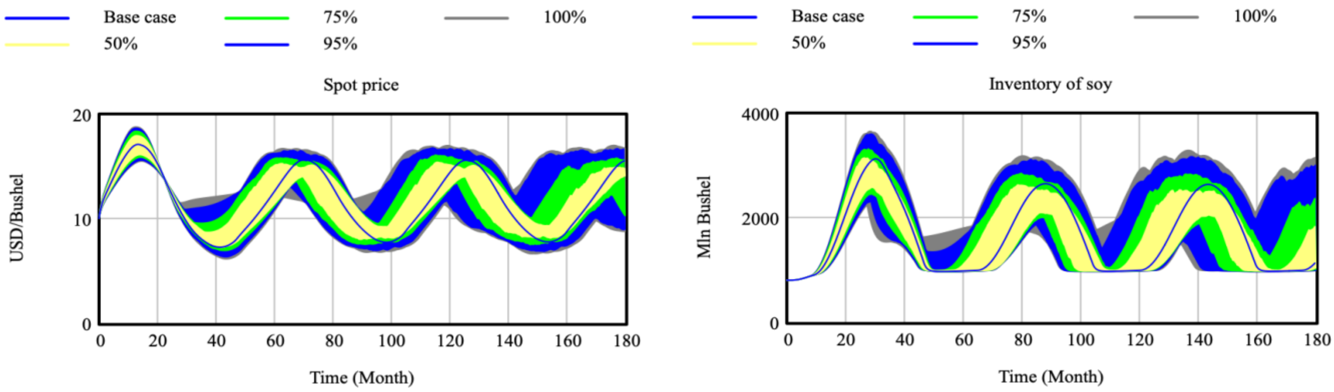

Figure E3: Sensitivity Analysis of Reference Yield and Max Inventory

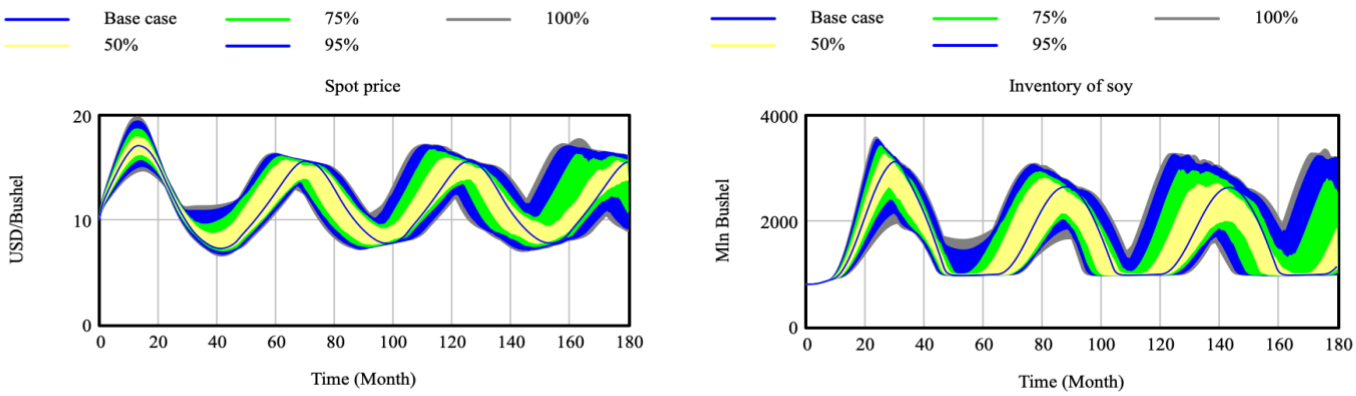

Figure E4: Sensitivity Analysis of Reference Yield and Reference Expected Rate of Return

Appendix F. Behavior Anomaly Test

For the first anomaly tests, lookup functions in the model will be varied. While extreme conditions tests show how extreme conditions for the reference values of these lookups result in different behavior, anomaly tests actually provide insight into the assumed relationship between two variables. When a different assumption on the relationship results in abnormal behavior, the normal model assumption is validated. The tests will be focused on uncertain lookup functions, which are more difficult to find in literature. Table F1 shows the two lookups that are varied in the anomaly tests.

Table F1: Values for Anomaly Tests

Input parameter	Base case value	New assumption
Effect inventory on marginal convenience yield	WITH LOOKUP("Inventory of soy"/ "reference inventory", ((0,2),(0.2,2),(0.4,1.5),(1,1),(2,0.5),(3,0.2),(4,0),(5,0),(6,0),(7,0),(8,0),(9,0),(10,0)))	WITH LOOKUP("Inventory of soy"/ "reference inventory", ((0,2),(10,0)))
Effect expectations on open interest	WITH LOOKUP("Expected spot price"/ "reference spot price", ((0, 0.6), (0.7, 0.6), (1,1), (1.1, 1.5), (1.2, 1.9), (1.5, 2), (2,2), (5,2)))	WITH LOOKUP("Expected spot price"/ "reference spot price", ((0,0), (5,5)))

F.1 Anomaly Test Effect Inventory on Marginal Convenience Yield

The first test involves the effect of inventory levels on the marginal convenience yield (value of storage). As mentioned in the literature review, the downward sloping yield curve indicates that for higher levels of inventory, the convenience yield will be lower. While evidence was found that the convenience yield decreases exponentially with inventory levels (Peterson and Tomek, 2003), a behavior anomaly test will be used to substantiate this assumption. Therefore, the lookup is changed so that the curve becomes a downward sloping linear curve: this means that for higher values of inventory, the convenience yield is higher compared to the previous lookup function.

The results in Figure F1 show very different behavior compared to the base case. First, inventories start to increase, and the convenience yield stays high compared to the base case. The max inventory level is reached quickly (after 20 months or so). While the inventory goes down after reaching this peak, the high spot price has stimulated planned production to such a high level that there is never enough room to store the soybeans. Inventories therefore start decreasing, whereas prices keep increasing. This should not be possible. Of course, by increasing the maximum inventory level in the model, this behavior can be avoided. However, the current base value for the maximum inventory level is already more than four times the production level in

2010 (FAO, 2023). A linear relation between the inventory level and convenience yield therefore produces abnormal behavior, whereas the firstly assumed exponential curve is actually producing expected behavior.

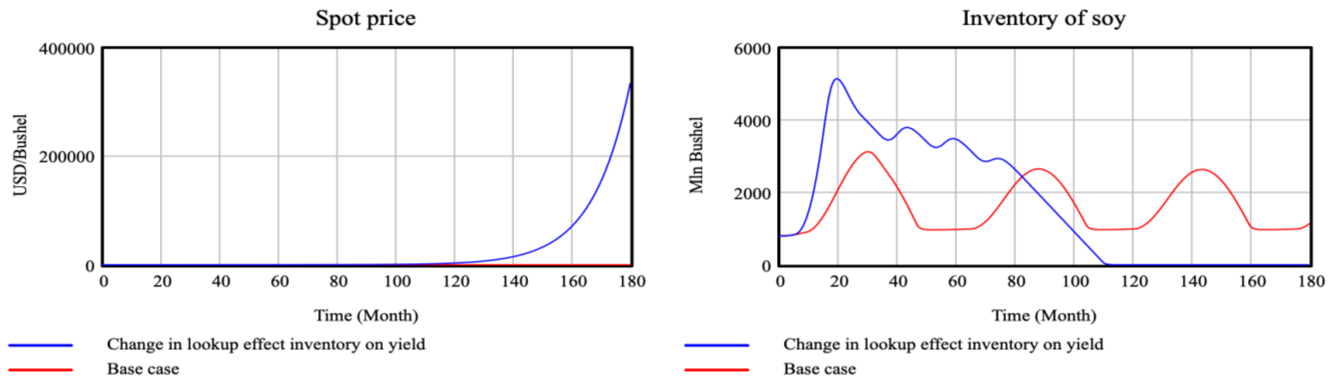

Figure F1: Anomaly Test Change in Lookup Effect Inventory

F.2 Anomaly Test Effect Expectations on Open Interest

The second anomaly test concerns the effect of spot price expectations on open interest levels. This relation cannot be found in literature. An S-shaped curve was assumed, because there is a specific range of values for prices that changes open interest levels: below this range, open interest will not decrease (for there will always be speculation), whereas above this range, open interest will not increase (because of fear of 'burst of the price bubble'). For this test, a linear curve was assumed, and the range of values was extended. The results in Figure F2 show that spot prices and inventory levels behave slightly different compared to the base case. The oscillation changes, and sometimes higher prices and inventory levels occur. Big changes in open interest occur less frequently (see Figure F3), because the S-shaped curve is flattened. However, no abnormal behavior actually occurs. This implies that both assumptions could be correct. It also shows how the model is not very sensitive to the balancing feedback loop of the open interest. While this test does not necessarily validate the assumption of the relation between expectations and prices, it shows that the assumption does not have a significant influence of model behavior.

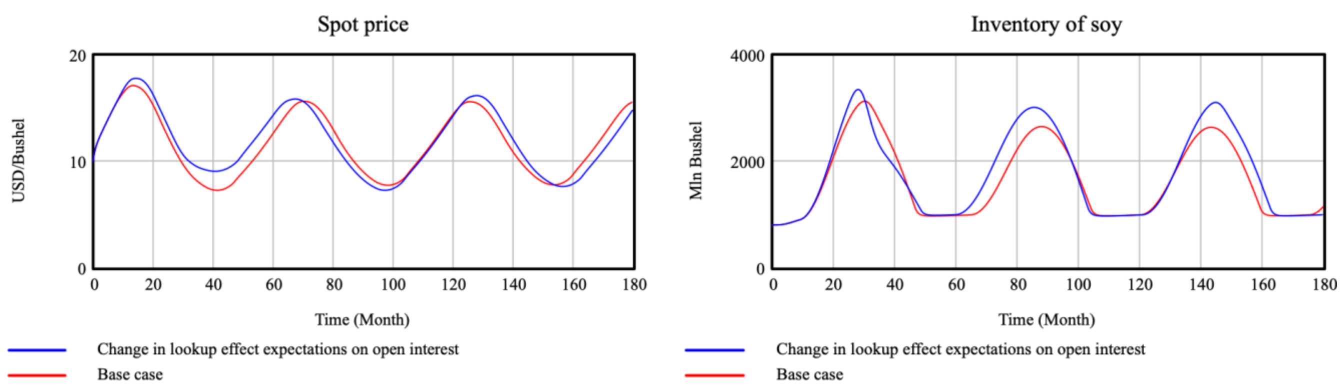

Figure F2: Anomaly Test Change in Lookup Effect Price Expectations

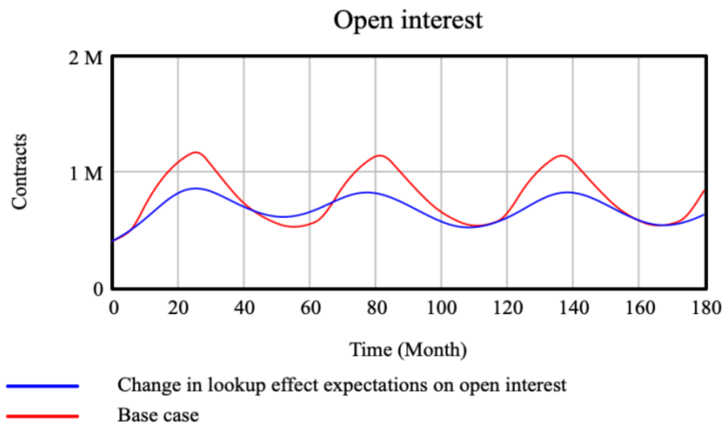

Figure F3: Anomaly Test Change in Lookup Effect Price Expectations (Open Interest)

F.3 Anomaly Test Expectation Delay

One other uncertain modelling assumption involves the delay type that is incorporated into the price expectations loop. The relationship between the spot price and expected spot price is currently delayed by the expectation delay, which is modelled as a first-order information delay. To show whether this assumption is valid, an anomaly test with a higher-order information delay is performed. The difference between the two delay types can be seen in Figure F4. A higher-order delay makes for a different kind of oscillation: the amplitude of the oscillation increases. This enables spot prices to come close or exceed a spot price of 20 USD/Bushel, whereas a first-order delay creates bubbles that only reach a price level of 17 USD/Bushel. The higher-order delay makes spot prices decrease till 5 USD/Bushel, whereas the first-order delay limits the decrease to about 8 USD/Bushel. The data of the IMF (2023) shows how prices range from about 8 USD/Bushel to about 17 USD/Bushel. The higher-order delay therefore shows abnormal behavior in the form of a price range that exceeds the limits in reality. The assumption of the first-order delay is therefore validated.

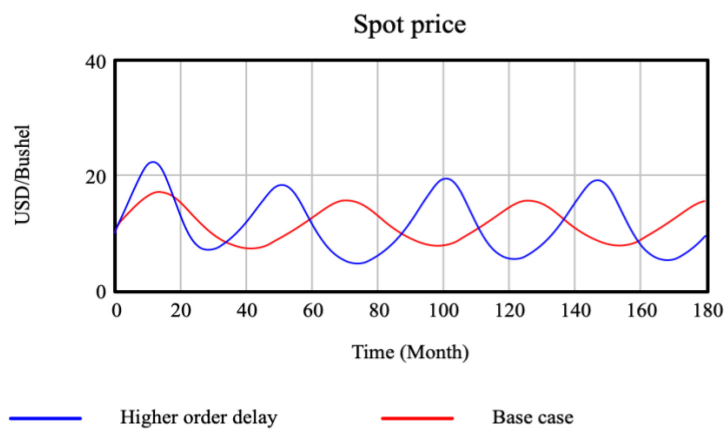

Figure F4: Anomaly Test Change in Delay Order

F.4 Anomaly Test Reference Inventory

The value that is currently assumed for the reference inventory level cannot be based on literature. Therefore, it is important to defend the assumption that substantiates the reference inventory level of 1200. To test this assumption, a lower (800) and higher (1600) value for the reference inventory level are incorporated in the model. With a lower value, it can be seen that the model shows limited peaks and lows for the spot price compared to the oscillation that is taking place in reality (see Figure F5). A higher value distorts the oscillation and results in more chaotic model behavior (see Figure F6). While this might actually be more realistic behavior when looking at the development of the spot price in the last few years, this behavior also produces a very high spot price at the beginning of the model run. It is therefore argued that a value in between the range 800-1600 results in the most realistic model behavior.

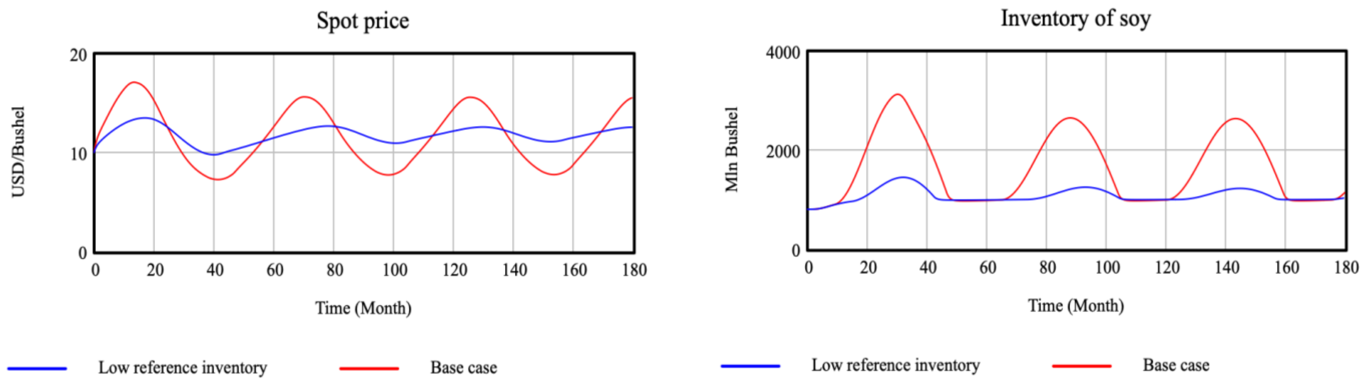

Figure F5: Anomaly Test Lower Reference Inventory

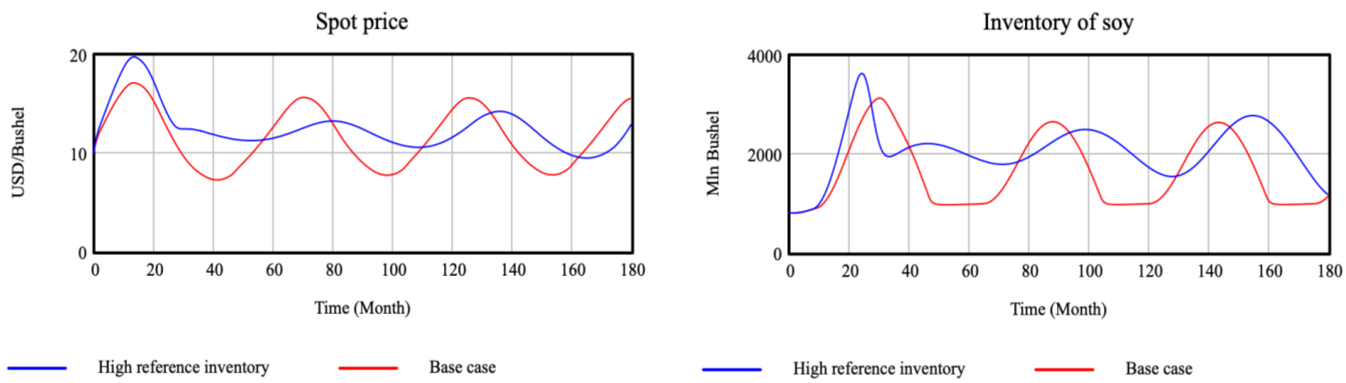

Figure F6: Anomaly Test Higher Reference Inventory

Appendix G. General Interview Questions

1. What is your opinion on the effects of speculation in food commodity markets?
2. Within this topic, several, controversial and opposing claims have been made concerning the role of speculation in commodity futures markets and the extent this is harmful. Focusing on the so-called 'opponents' of your thesis, what mistake do you think they are making? Is it because of a wrong observation of the phenomenon, a wrong (econometrical) approach, wrong assumptions…?
3. In general, how do you perceive the activity of speculating on basic food such as grains when taking into account ethical considerations ('betting on hunger')? Should it all be banned, or would you keep it just under a certain level? Besides, we know that a certain level of speculation is beneficial for the liquidity of the markets. Therefore, completely banning speculation would mean destroying the dynamics of futures markets. If that is the case, do you think that futures markets should not exist at all?
4. How is the current food crisis different from the 2008 one? Do you think that the policy recommendations given in light of the 2008's events are still applicable today? Are there any new recommendations you would give in addition?
5. What do you think about the development and growth of financialization from 2008 until today?
6. We know that speculation is hard to be defined and isolated within the whole framework. Within the statistical analyses, several indicators of speculative activity have been found, such as: open interest, commercial vs non-commercial rations, long-short positions, as well as indicators of excessive speculation such as the T index. Do you think these indicators properly represent and detect the phenomenon? What are the main flaws of such indicators? Do you think the data available is sufficient for detecting speculation? What indicator do you think is the most representative?
7. Do you think that statistical methods are useful when trying to identify the degree of speculation in a market? What limitations do these methods show?
8. To what extent do you think that innovation within the financial sector (such as high-frequency trading, financial markets easily accessible for everybody, open trading platforms) is beneficial for the society as a whole and the real economy? Do you think that the benefits of these innovations outweigh the drawbacks? Could market transparency be enhanced with all these new activities on play?
9. What do you think are potential effective regulatory measures to limit speculation? What are the (dis)advantages of setting (individual) position limits, and how should these limits be determined? How do you feel about the taxation of capital gains following from short-term speculative trading?

Appendix H. Description of Experts

Table H1 describes the expertise of the experts that were interviewed for this research.

Table H1: Expert Description

Expert	Expertise
A	Global Development, Trade, Markets & Services
B	Environment, Resources & Sustainability, Political Economics
C	Development Economics
D	Development Economics
E	Law & Food