Development of Tools for Planning and Coordinating the Production of Small Farmers as a Response to Market Opportunities

by

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ABSTRACT

For multiple reasons, the consumption of fresh fruits and vegetables in the United States has progressively increased. This has resulted in increased domestic production and importation of these products. The associated logistics is complex due to the perishability of these products, and most current logistics systems rely on marketing and supply chains practices that result in high levels of food waste and limited offer diversity. For instance, given the lack of critical mass, small growers are conspicuously absent from mainstream distribution channels. One way to obtain these critical masses is using associative schemes such as co-ops. However, the success level of traditional associate schemes has been mixed at best. This dissertation develops decision support tools to facilitate the formation of coalitions of small growers in complementary production regions to act as a single-like supplier. Thus, this dissertation demonstrates the benefits and efficiency that could be achieved by these coalitions, presents a methodology to efficiently distribute the value of a new identified market opportunity among the growers participating in the coalition, and develops a negotiation framework between a buyer(s) and the agent representing the coalition that results in a prototype contract.

There are four main areas of research contributions in this dissertation. The first is the development of optimization tools to allocate a market opportunity to potential production regions while considering consumer preferences for special denomination labels such as “local”, “organic”, etc. The second contribution is in the development of a stochastic optimization and revenue-distribution framework for the formation of coalitions of growers to maximize the captured value of a market opportunity. The framework considers the growers’ individual preferences and production characteristics (yields, resources, etc.) to

develop supply contracts that entice their participation in the coalition. The third area is the development of a negotiation mechanism to design contracts between buyers and groups of growers considering the profit expectations and the variability of the future demand. The final contribution is the integration of these models and tools into a framework capable of transforming new market opportunities into implementable production plans and contractual agreement between the different supply chain participants.

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INTRODUCTION

The current growth in population comes with an increment in overall goods consumption, including food. It is estimated that food demand will continue increasing for at least the next 40 years (Godfray, 2010), which will require to increase the food production by 70% (FAO, 2009). Besides the overall increment in the need for food, there is also a change in the type of food that is being demanded by the consumers. Due to an increment in consumers' income and healthier habits, there is a growing trend in people's diet to replace some staple products with healthier options, such as fresh produce. The increased consumption of fresh produce has resulted in a marked increment of the prices of some of these products (USDA, 2019). The increase demand of fresh produce and the need to minimize the food-waste call for better supply chain (SC) management strategies to best match the supply to the demand of these products. According to FAO (2009) 28% of food waste comes from fruits and vegetables, which encourages the consideration of perishability when making planning decisions regarding planting, harvesting, and distribution of these products.

The increment in the demand of fresh food implies new challenges to increase the overall production and improve the post-harvesting operations in the fresh produce industry. This also results in new opportunities for current and potential growers, and for the economic development of geographical zones that can grow these products efficiently; regions in which very often a gap is observed between current and maximum production potential due to different factors like agricultural practices, resource availability, lack of market information, among others. Another cause of this gap is the existence of small growers who are not able to produce high-value products, even when the adequate agronomical conditions are present, because they lack the financial or infrastructure means to embark on the production of these products. These negative factors may include not meeting the minimum capital required to start growing these products, not knowing existing and future market opportunities, not meeting the critical masses to make the production feasible or profitable, or not having access to an appropriate supply chain to collect and distribute their products in markets offering attractive prices. In the context of the research presented in this dissertation a **market opportunity** is defined as an identified future demand of certain crops in terms of time windows, price, and volume. In addition to this, a market opportunity's value can potentially be captured if the appropriate planning and coordination actions are undertaken.

In the absence of the appropriate market information and the corresponding underlying supply chains, very often the growers produce low-risk, low profit products for which a well-established supply chains exist. Even if the growers are capable of producing high-value products, the volume of production may not be large enough to access the proper logistics services to reach distant and more profitable markets (Camanzi et. al., 2011; Jang & Klein, 2011). This results in a reduced market coverage consisting mainly of local food stores or local buyers, and the loss of opportunities to reach markets with better prices. Currently, it is estimated that the value captured by the farmer of the product's potential value is low given the limited access to resources or to the markets. Cook (2011) reports that for every dollar spent by the final fresh food and vegetable customers, less than $0.20 is captured by the grower, while the other $0.80 is divided among the rest of the SC participants. The purpose of this work is to explore innovative supply chain options to increase the portion of the value chain captured by small growers. This will be achieved by creating temporary flexible coalitions of growers capable of capturing new market opportunities in an efficient and coordinated manner. In particular, with the use of planning and coordination supply chain strategies to best respond to market signals to achieve better profitability for participant growers, while providing transparency of the planning and execution processes.

The main hypothesis of the research presented in this dissertation is that the production of a group of growers within a region can be coordinated to form a coalition capable of reaching the critical masses and associated timing and logistics required to participate in more profitable markets that otherwise are inaccessible to them without the participation of intermediaries. The approach used to achieve this is based on an integrated environment capable of identifying market opportunities and articulate responsive supply chains capable of capturing the opportunity value in a timely manner, as shown in Figure 1-1 below. The envisioned environment is composed of a set of modules whose objective is to increase the margin of the value chain captured by the growers for their products, achieving higher profits. The research presented in this document contributes to the design of this new integrated environment from a theoretical perspective, and to the development of specific tools that will allow the envisioned environment to be deployed. As explained in the following sections of this document, this research attempts to close the gap between data analysis and high-level planning tools (left side of Figure 1-1) and tactical and operational decisions (right side of Figure 1-1). The proposed activities are key for the development of the "Central Coordination Platform" (CCP), on which a new envisioned agent of the supply chain will play the role of a logistics coordination agent interacting *with both the buyers in each potential market, and the growers in each potential production region. This agent is called the Supply Chain Articulator (SCA), and his/her main role is to translate market signals (demand) into operational decisions required to articulate and monitor the emerging supply chains (A, B and C in Figure 1-1). In the envisioned environment, the SCA will be capable of identify market opportunities and oversee the strategic, tactical, and operational planning activities of the new SC, and of monitoring its operations as well (D in Figure 1-1). This role also includes the generation of external (demand) and internal (production) contracts, which enables the collaboration of the different participants in the emergent SC and allows to share the additional profit that can be captured from the market opportunity. The work presented in this document consists mainly of two aspects: a feasibility assessment tool to determine if a particular identified market opportunity can be captured, given the existing resources and consumers' preferences; and if it is, develop specific allocation and production scheduling plans to respond to the opportunity. The former tries to determine what regions are ready to participate in supply chains designed to respond to a promising market signal (demand). The latter deals with the identification and coordination of the specific growers who by forming a coalition are capable to supply the produce demanded by the market.*

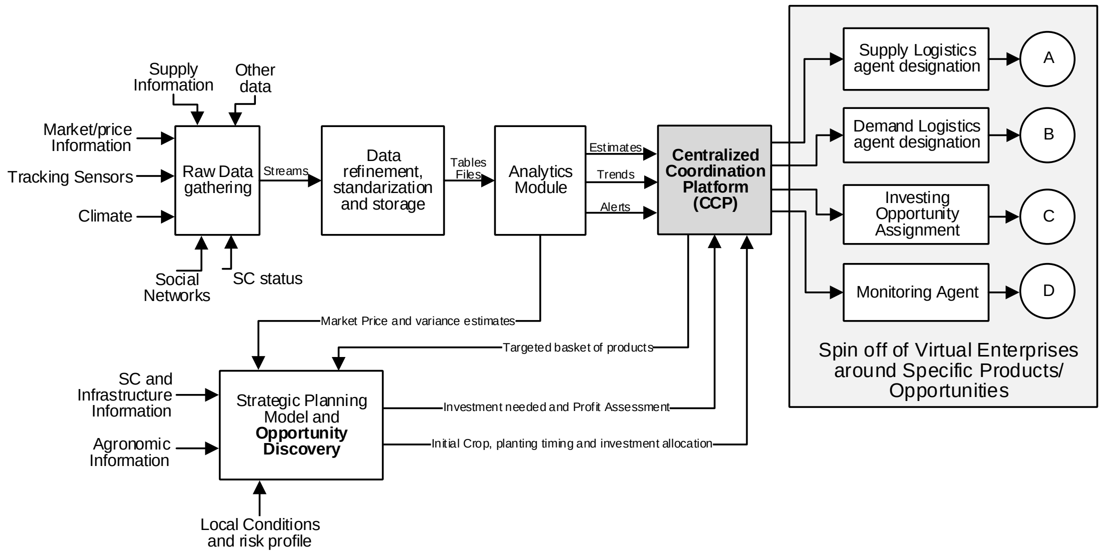


Figure 1-1: Envisioned Integrated Environment.

The research presented in this document is a continuation and expansion of the work done by Ahumada (2008), Ahumada & Villalobos (2009, 2011a, 2011b) Mason (2015), Mason and Villalobos (2015), and particularly Flores (2017) and Flores & Villalobos (2018, 2020) regarding planning and coordination activities for the fresh produce supply chain. Flores (2017) developed strategic decision-support tools focused on two main aspects: first he developed an analysis framework that allows the identification of zones with hidden agronomic potential using information obtained from weather stations. With this data he identified and clustered regions that present similar weather patterns throughout the year, and then he used this information to predict production yields for different crops based on the temperature profiles at different locations/clusters. The second part of his work used this information to select a portfolio of complementary zones that can supply fresh produce as a response to market signals. He developed a strategic optimization model that also accounts for variability in the climate conditions and expected prices. He also explored how the option to invest in technology (protected field or greenhouse) affects the expected yields in the different zones and the profitability of the opportunity. This work can be summarized by the Initial Opportunity Analysis presented in Figure 1-2.

This dissertation addresses the planning decisions that follow the work done by Flores (2017) in order to capture a specific market opportunity. The specific parts of the problem that are addressed in this work corresponds to the second, third, and fourth steps presented in Figure 1-2 below. These activities are crucial to the applicability of the designed tools to the real world, and they focus in breaking down the strategic decisions into the tactical and operational plans required to articulate the SC and take advantage of an identified market opportunity. Another important part addressed in the last part of this research is the issue of how to share the captured value or profit among the different SC participants. In the next section we define the research problem that is being addressed by the research presented in this document.

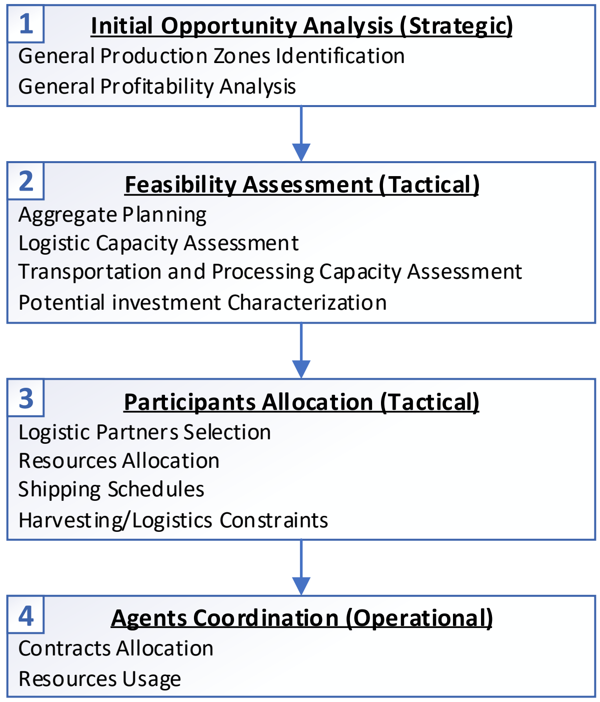


Figure 1-2: Strategic, Tactical and Operational Decisions Needed to Address Growers' Problem

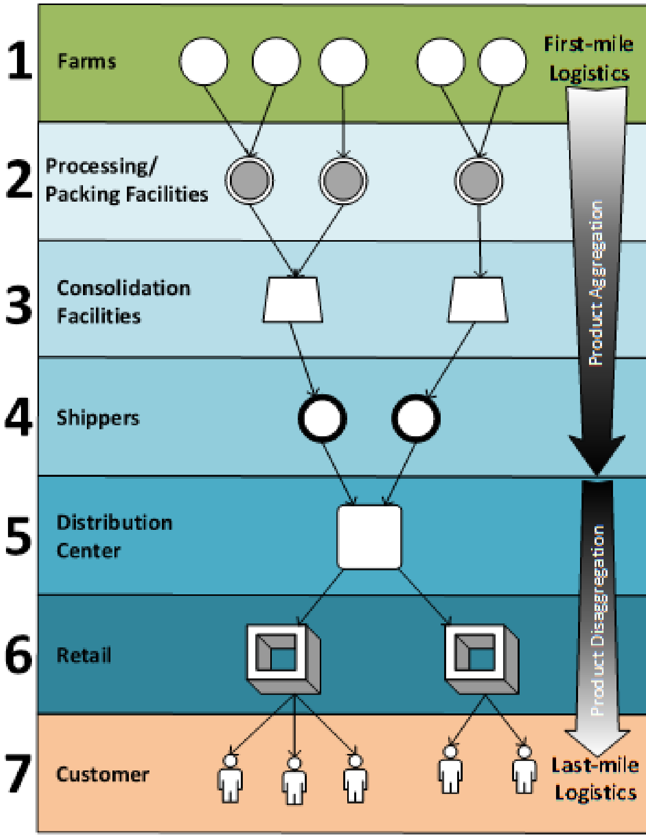
1.1 Problem Definition

In order to coordinate and articulate the SC as a response to a market opportunity, there are several steps that need to be considered. The main general steps are the ones presented in Figure 1-2. The first part consists of the identification of the market opportunity and an initial assessment of the economic potential of producing the demanded crops. The second step is to perform a feasibility assessment that determines, from a tactical perspective, if with the current set of resources and potential participants regions is possible to articulate an integrated supply chain in a timely manner. This means to be able to plan and execute all the required actions (planting, harvesting, transportation, processing, etc.) within the time windows that allows to capture the value associated to the identified market opportunity. Once the feasibility of capturing the demand opportunity and a corresponding initial profit assessment have been established, the third stage of the process consists of the allocation the activities required for the opportunity in terms of volumes and timing of production in such a way that the profit can be maximized. This is a more detailed tactical planning activity that considers different costs, capacities, and preferences of the participant regions represented though their articulation agents. The last stage is closely related to the allocation of the opportunity among the participant growers to entice the collaboration required for SC articulation. Partners' allocation and contract generation is a negotiation process among each pair of consecutive echelons on the supply chain which, under the current conditions, usually results in limited visibility and difference in the leverage power among the participants. These myopic interactions result in suboptimal contracts between the parties, sub-optimality that increases when considering the multiple participants who are negotiating in the whole SC. When considering an integrated approach to coordinate the supply chain, the negotiation process becomes more complex for the Supply Chain Articulator who will be in the middle of a double negotiation process: on one side there is the demand allocation to the potential production zones; and on the other, the coordination of the individual participants within each production region. For each of these negotiation processes there are different interests and decisions that the SCA has to make, and there is the complexity of one negotiation process being centralized (demand allocation to regions) and the other decentralized (coordination within each region), both affecting the information and resources available when making the coordination decisions.

So far, there has been some previous research focusing on the first stage of Figure 1-2, in terms of demand forecast and production allocation to different geographical zones by considering expected yields (Ahumada and Villalobos, 2011; Flores and Villalobos, 2019).

But there is not a lot of previous research on modelling the next steps of the supply chain articulation towards an implementation of the planning decisions. About how to make production and market assignments in a centralized manner one can find the works by Ahumada (Ahumada, 2008; Ahumada and Villalobos, 2009; Ahumada and Villalobos, 2011a; Ahumada and Villalobos, 2011b; Ahumada et. al., 2012) and Flores (Flores, 2011; Flores, 2017; Flores and Villalobos, 2019). In terms of decentralized planning there is the work done by Mason (Mason, 2015; Mason and Villalobos, 2015). All these previous works have focused on increasing the profit of fresh produce growers by improving the planning and harvesting processes, while considering the logistics aspect as an available service that can be paid as needed. There have been additional efforts towards increasing growers' profit from a centralized perspective, but with few advancements on how the total profit could be distributed among the supply chain participants while keeping efficiency and transparency of the resulting coordination and contractual terms. However, these efforts are usually towards increasing production yields, reducing operational costs, developing tools to help schedule planting and harvesting activities, and evaluating the use of new technologies to improve products quality through the SC (Byrum et. al., 2016; Jedermann et. al., 2014; Zang et. al., 2019; Tsolakis et. al., 2014, Banasik et. al., 2016). A more thorough literature review about previous work regarding the research areas covered within this research is provided in Section 2 of this document. A common factor in previous research works is that they assume that a single producer, or a set of growers, have the critical mass required to access and use the logistic resources, and therefore the postharvest logistics can be coordinated in an efficient manner. Another common consideration is not accounting for the effect on the prices or how much of the final price of the product is captured by the growers by coordinating the SC. This means that even if the farmers increase their production in terms of volume harvested, the percentage of the value captured by them will stay at a similar level (Cook, 2011; Jang and Klein, 2011). This suggests the need for a different integrated approach not focused exclusively on the production side, but also in the implications and decisions related to the coordination and the compensation of all the growers taking part of a coalition to supply the market needs.

To get a better understanding of the different echelons of the supply chain being considered a characterization of the fresh produce supply chain is required. This characterization is done in terms of the different agents involved as the products advance downstream and how they interact, in terms of price and contract negotiation, product ownership, costs, etc. Also, a special consideration is required regarding the aggregation logistics of produce when it is being introduced to the SC, and the disaggregation when it is being delivered to the final customers. The supply chain design may vary depending on the considered product and location, but a general characterization is shown in Figure 1-3 to consider the most common participants and structure starting from the farm and ending in the final customers. Note that this is a general example, and the specific interactions and characteristic are case specific in terms of agents involved, product ownership and how the value is distributed among the SC agents. It is important to mention that depending on the product there may be other actors and additional specific processes in the SC such as wholesalers, brokers, etc.



Description	Product Ownership	Product Value Change
The crops are planted and harvested. Once the crops are harvested, they are sent to the consolidation facilities to be aggregated with the production from other producers.	Usually the grower owns the produce until it's harvested. Under a production contract scenario the Contractor (DC owner) owns the produce.	Lowest value as the produce hasn't being processed (depends on the crop).
The first part of the logistics processes consists of processing the produce that comes from the farms, and packaging it into the logistic unit that will be moved further in the SC.	In general the Contractor takes ownership after harvesting. In some cases the grower owns the product as it's being processed.	Value increases at least by 50% as the product is packaged and labeled.
The packaged product is consolidated to reach the required volumes to be transported through the rest of the SC. It can be stored at these locations for a period of time that depends on the perishability.	In general the Contractor takes ownership after harvesting. In some cases the grower owns the product as it's being processed.	Value remains the same, and the costs of this stage are usually paid by the Contractor
The product will be prepared to be shipped longer distances to the Distribution Centers from where the distribution process to its final destination will begin.	In general the Contractor takes ownership after harvesting. In some cases the grower owns the product as it's being processed.	Value remains the same, and the costs of this stage are usually paid by the Contractor
The DC will receive the product and start its disaggregation to be prepared to be sent to the corresponding retail store or final distribution. The product is stored until its final destination is allocated.	The Contractor takes ownership of the product after inspection and relieves the grower of any responsibility.	Value remains the same, and the costs of this stage are usually paid by the Contractor
The product will be received and allocated inside the store to be bought by the for final customers. If it needs to be stored, this should be for a short period of time.	Retail takes ownership of the product.	Highest value, as consider all the costs and the margins for the retailer. The value can be around 3 times the value captured by the grower.
The final customer will buy the product from the retail store at the end of the supply chain.	Customer buys the product.	Pays the final value for the product

Figure 1-3: Simplified Fresh Produce Supply Chain Structure.

Note that every participant of the SC performs a certain task that allows the product to reach the final customer. Some of these tasks are crucial for the process (i.e., packaging, consolidation, disaggregation), while others are not strictly required in terms that are only performed to allow the current SC structure to operate (i.e., storage, product handling). Based on this common structure and the Food Supply Chain operation scheme, the problem addressed in this research is defined from the perspective of a Supply Chain Articulator that represents a set of independent small growers and have access to different logistic services providers within a region. By representing the growers, the SCA can provide strategic, tactical, and operational support to the planning and coordination of the forming coalitions, and to provide transparency to their participants throughout the planning stages and the opportunity value distribution. Another characteristic of the SCA is that they serve as a connection point between the production side of the supply side, directly related with the growers, and the demand side of the SC, more related with the customers and demand signals. The SCA has two main operational functions that allows the allocation of strategic aggregated plans to tactical and operational decisions within each producing region:

- **Demand Side Articulation**: This function corresponds to receiving the market signals and translating them into specific opportunities for products (time, prices, and volumes) that are allocated to different potential producing regions.
- **Local Supply Side Articulation**: This component corresponds to the coordination and matching of the requested produce volumes from the demand side with the local producers and logistics providers within potential regions. The SCA will have a fiduciary responsibility with the growers and their interests in terms of maximizing their profit while satisfying the requirements from the demand side.

Part of the elements of this component is the negotiation of contracts that will allow to properly entice the growers to take part of a coalition capable of capturing the market needs in a timely manner.

Note that the SCA is not physically a participant of the supply chain. This agent constitutes a virtual echelon of the SC located between the supply side and the demand side of the SC as shown in the central part of Figure 1-4, and explained in the next paragraph. The SCA seeks to match supply and demand by allocating demand signals or market opportunities to producing regions, while considering the required transportation and logistics capacities and costs.

After the production is allocated to different growers, there are additional components of the supply chain that will need to be coordinated to take the produce from the field to the costumers. Depending on the level of aggregation of the products being transported, the SC components can be divided into two parts. First, the **Supply Side**, corresponding to the first four stages of Figure 1-3 which are usually located within a specific producing region. These processes are required for the planting, harvesting, recollection, aggregation, and consolidation of the production. The second part corresponds to the operations that take place once the produce is already aggregated into the logistic format that allows it to be stored and transported longer distances for the posterior distribution to the customers. Usually this corresponds to the operations after the product reaches the Distribution Center, this part corresponds to the **Demand Side** of the supply chain. These two sides of the supply chain are connected through an information-based decision support system managed by the SCA as depicted in Figure 1-4.

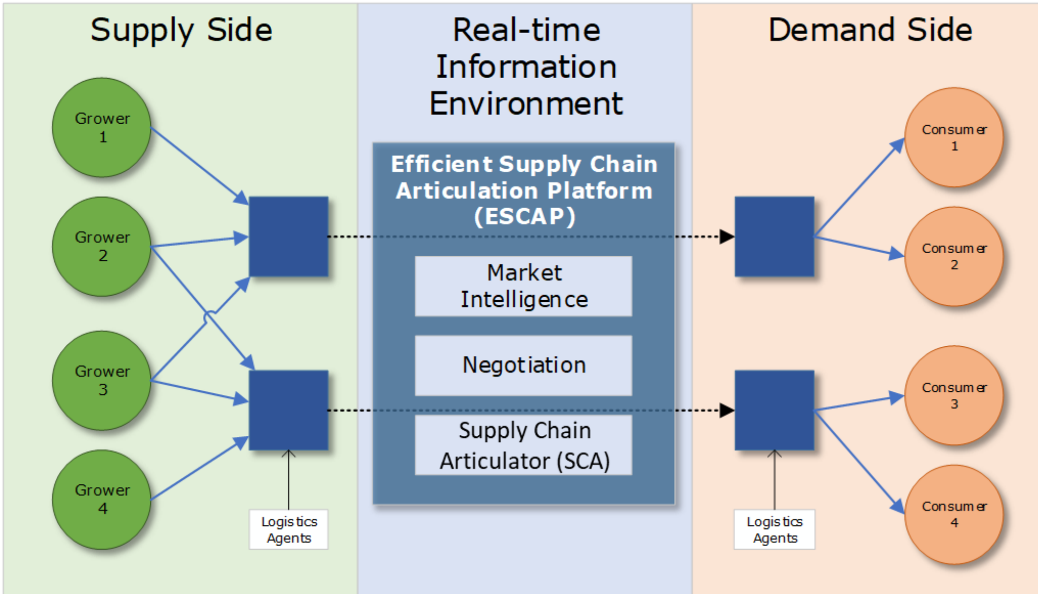


Figure 1-4: Structure of Envisioned Environment.

The focus of this research involves both the supply and the demand side of the SC, where the demand side is considered in such a way that the market demand and requirements are taking into consideration when designing a supply plan for the growers in the supply side. With respect to the supply side, this research deals with the complexities related to collection and aggregation of the produce from different growers, as it has been found to be critical to the performance of small growers (Kauffman et. al., 2000; Ahumada, 2008; Ahumada and Villalobos, 2011b). The research presented in this document takes the perspective of the SCA, which in his effort to match supply and demand also needs to incorporate the production of different regions and to plan and coordinate how the growers in each of these regions can supply the required produce. The SCA will seek to transform the market needs, or a market opportunity, into regional level plans which then will be allocated to specific growers within each region. For this, the SCA will address the planning and coordination process as a two-level process: first, at an strategic-tactical level there is the need to identify producing regions that based on their resources and climate conditions can provide the best production match to the market needs; then, a second level there is the tactical coordination of the growers within each of the regions, for which the SCA will need to also account for each grower individual characteristics when designing the production plan and finally contracts that ensures their participation in the emerging supply chain. There are different complexities present at each of the planning levels that the SCA will have to overcome, such as: the agronomic potential and resources available at each potential location that will affect their production windows and how they are positioned to supply a given market needs, this could be partially addressed by considering and coordinating potentially complementary regions that will enable to alternate production needs during longer seasons. On the other hand, each farmer has its own characteristics such as expertise, production constraints, incentives, risk tolerance, etc. In both cases the production plan and value that could be captured from a market opportunity will depend on the specific service details such as the time when it is requested, seasonality, the type of service, etc.

Therefore, the scope of this dissertation is the development of a set of tools and the underlying theoretical concepts for: a) a feasibility assessment of the SC articulation considering market needs and consumer preferences. This tool helps to identify and evaluate potential supplying region, or set of regions, to articulate a supply chain regarding the production, transportation and logistics processes required to react and supply an identified market opportunity; b) contract allocation and revenue distribution mechanisms to coordinate the growers in the supply side from both a strategic and a tactical perspective.

This tool also assists the negotiation and coordination processes required to guarantee the collaboration of the SC participants, and to provide transparency of the negotiation and coordination processes. The development of this tool requires to make advances in the theoretical design of the envisioned environment and the technical development of the tools itself. These advancements and tools address the need of decision-support mechanisms for the tactical planning stages matching supply and demand in the aforementioned environment. A special consideration and effort are invested on capturing and representing the business needs for a market opportunity into the appropriate planning, coordination and negotiation decisions, and the applicability of the developed tools. They considers the availability of resources and services providers within each region and entices the involvement and collaboration of the SC participants while satisfying the requirements defined by the market representative.

1.2 Research Contribution

The research presented in this document seeks to close the gap between the current situation of small growers and the goals of the envisioned environment. This work is an essential part of the development of the data-enabled, rapid-response fresh supply chains. This work contributes to the definition of the theoretical framework required for the envisioned environment to be applicable and implementable, and the development of some of the tools required for its success. The theoretical design of the proposed environment sets the basis of collaboration and interactions among the different modules presented in Figure 1-1. This proposed design provides specific tools that are required for the different modules to operate, and for the SCA to be capable of managing the SC design, coordination, and articulation activities. This framework and its associated tools, based on mathematical optimization modeling and solution methods, as shown in the third chapter of this document, improve the availability of information, transparency, business practices and the value that the growers receive for their products. As shown in the previous section, there is a need of research on how small growers, and the business around them, can adjust to the changing market requirements. This implies the design of new a business model capable of react rapidly to changes in the markets, while allowing small growers to be part of it in a successfully and a profitable way. This need is addressed with the development of a functional environment and a set of tools that enables the efficient implementation of planning decisions. This framework helps small growers to compete in an industry that it is demanding higher production volumes and more efficient practices to satisfy consumer's demand. The following paragraphs describe how this research contributes to this goal by identifying some of the main existing gaps, and how each of them is addressed.

The first part of this work directly addresses an issue that resulted from the work started by Flores (2019) regarding the articulation of the SC as a reaction to a market opportunity. His solution allows a centralized coordination of production by allocating demand to complementary producing regions based on climate conditions. This approach needs to be enhanced to be practical: first, the required supply chain participants are not involved when making the decisions; second, the planning level presented still must be transformed into the required tactical and operational activities; and third, his model does not consider the limited resources available in each of the producing regions. Therefore, the contribution of the work presented in this document directly addresses these issues by focusing on the development of practical tools that allows the formation for virtual supply chains to take advantage of a specific opportunity without necessarily meaning a permanent establishment of the SC. First, within this work we include the development of a method capable of assessing the readiness of a region to react and allocate resources once a market opportunity is identified. From the perspective of the growers, this means to be able to produce and aggregate their production. This means that the region where they are located must satisfy certain conditions in terms of land availability, weather conditions (which directly affects the expected yields), and transportation and logistics resources. For a specific region all these parameters are limited, and the methodology presented in this document accounts for these limitations when assessing the region to check whether an opportunity can be deployed there in a profitable manner. This is particularly important when considering denomination label preferences such as “local”, “fair-trade”, “organic”, and similar, as the competitiveness of a region is directly be affected by how these preferences are defined. The importance of this initial analysis is to determine the readiness of the growers and logistic agents within a region before starting to allocate resources and contracts and creating production commitments. Sometimes this initial step is left aside under the assumptions that the resources and logistic capacities can be outsourced, which is not always the case within a limited participants framework. A secondary use of this tool is to obtain an initial profitability assessment of the opportunity, and a general production plan recommendation that allows an opportunity to become feasible, or profitable, for a set of complementary production region. This tool allows a centralized entity, the SCA, to allocate the produce demand from a market opportunity to different regions and negotiate how and from where the crops will be supplied.

The second part of this work addresses the problems arising after the producing regions are evaluated, and the general production plan determined by the SCA is to be allocated to the growers in different producing regions. The contribution of this part is twofold: first there is the theoretical design of this part of the envisioned environment that no one else has done before and determines the adequate conditions for fast response SC to be articulated once a market opportunity is identified. Second, this research provides a tool capable of identifying and allocating the value of a market opportunity to the growers in each candidate production region. This, while considering the characteristics of the growers present in each region when allocating contracts, and the determining compensation scheme to distribute the opportunity's value. The outcomes of this part of the dissertation will allow the decision makers (i.e., the SCA) to identify among a pool of available growers who are the ones that best match the specific requirements that a given opportunity requires. This part of the research includes a negotiation and coordination component that capture each grower's individual profile the decision-making process and to help in the contract generation problem when allocating the different tasks, participants, and revenue. A special emphasis is on providing transparency to the SC participants on how the planning and coordination stages are performed, and how the value of the captured market opportunity will be distributed among the coalition participants. This is done by providing a tool that aims to the practical implementation of the developed plan, by addressing part of the issues required to get the commitment of the involved parties from a very early stage (while planning).

The last of the main contributions of this dissertation is the integration of both methodologies mentioned above. This provides a useful framework on which two different planning level tools are working together towards the articulation of the supply chain. It addresses the complexities of a double negotiation process on which the same agent is involved in a centralized negotiation and, at the same time, in a decentralized negotiation process with the growers in each of the regions. For practical purposes this results in the development a coordination tool which in a first stage consists of the adaptation and expansion of independent models that are required to simulate a negotiation process, like the model developed by Mason (2015). They present a tactical planning tool that allows a central entity to coordinate the production of fresh produce from different independent growers by using an auction mechanism. As part of the research contribution of this dissertation, it expands their work to include a revenue sharing mechanism that allows the transfer of the additional revenue captured by the opportunity articulation to the growers. A special consideration is taken in designing a mechanism that allows a stable position for the participants, this means to entice the collaboration of the participants while aligning incentives to prevent deviations from the contracted agreement. This part of the research considers risk profiles, expected revenues and available resources to generate different contracting schemes that are used to coordinate the independent agents. This results in a contract generation support tool consisting of optimization models that seeks to maximize the willingness to collaborate considering the involved parties’ preferences.

The presented research brings issues that have been studied extensively from a theoretical perspective to a practical level. Most of the previous research that precedes this work was focused on strategic and tactical planning levels while considering both centralized and decentralized planning activities (Ahumada, 2008; Ahumada & Villalobos, 2011a, 2011b; Mason, 2015; Mason & Villalobos. 2015; Flores, 2019; Flores & Villalobos, 2020). The research presented in this document tries to address some of the issues arising from the previous works. For instance, there is the issue of revenue sharing among the supply chain participant, arising from the work done by Mason (2015) and Mason & Villalobos (2015) that is addressed with the development of a revenue sharing contract generation mechanism. Another concern arises when a specific production zone and the limited producing, logistics and transportation capacities when planning the supply chain articulation are considered. This was theoretically studied by Ahumada & Villalobos (2011a) and is more deeply studied in this work with an opportunity assessment tool to consider complementary producing regions. Another issue is the design of an environment that will allow centralized and decentralized planning activities to coexists in such a way that the planning decisions can be transformed into practical actions. It is expected that this will allow the emergence of new responsive supply chains as mentioned before. Part of the research addresses this issue by integrating many previous studies that have tackled the problem from different perspectives into a system that focuses on practical applications.

1.3 Benefits of the Research

The objective of this research project is to provide implementable, yet theoretical sound, solutions to start closing the gap between high level strategic planning decisions, tackled in previous works, and the actual implementation of a planting/harvesting plan. These solutions will enable the articulation of the supply chain as a response to a demand signal or market opportunity. The different methodologies and phases of this research will help transform the strategic plan into the tactical and operational decisions required to coordinate the different participants in the new opportunity.

As a first direct outcome of this research there is the development of a tool that will help to assess the feasibility of a market opportunity to be articulated in a specific region. This is a direct step towards the implementation of the strategic plan, as it serves as a first analysis to determine how and where the required demand can be served. The use of an aggregated planning methodology provides a first idea about the readiness of a region to react and articulate the production, transportation and logistics required to satisfy the demand. This considers general characteristics such as location, capacities, and climate data (which are treated as expected yields) to obtain a first result. Another direct benefit from this part of the research is the identification of potential complementary producing regions that might be in adequate position to form a coalition capable of capturing a market opportunity, considering consumers' needs and preferences. In the proposed framework, this tool will directly benefit the SCA as the entity who is looking to match supply (from different regions) and demand (from customers). By using this tool, the SCA will be able to allocate the demand to different producing regions in an efficient way in terms of harvesting and deliveries schedules, while considering operational costs and capacities of each region.

The second set of models to be developed addresses the issue of identifying and coordinating the partners that will be involved in the SC opportunity articulation. This considers different potential growers within a region and their characteristics resulting in a model capable of being applied in different regions and under different sets of potential partners. This helps to obtain an idea about how each candidate can contribute in an optimal way to satisfy the required demand. As a secondary outcome of this part of the research the proposed models will allow to evaluate and recommend different contractual conditions to allow the proper SC articulation considering different preferences of the parties involved such as risk aversion, expected profit, preferences profiles, etc.

It is expected that the set of tools resulting from this research will be applicable to the real environment and will help achieving the objectives of increasing the profit received by the small growers and generate the required environment for them to thrive in an increasingly challenging environment. It is believed that opportunistic coordination can be achieved without the need of creating cooperatives, and the set of tools that are developed will allow the creation of this responsive supply chains able to support the successful participation of small growers in the growing fresh produce market.

1.4 Dissertation Overview

The rest of this dissertation is structured as follows: Chapter 2 presents a brief review of the current literature related to different planning models, supply chain design and articulation and the relevant existing negotiation and coordination methods that will allow the proper supply chain articulation. In Chapter 3, the focus is on presenting the proposed methodology, the optimization models that are used, and their expected outcomes. In Chapter 4, a centralized formulation of the agricultural planning problem accounting for consumer's preferences is developed along with a case-study applied to growers in Arizona, New Mexico, and Colorado. Chapter 5 expands on these results to account for how a market opportunity can result in the formation of a grower's coalition, and how its value could be distributed among the participants in the form of contracts designed to be efficient. Chapter 6 presents a mathematical approach to address the coordination problem between the SCA and a buyer who must agree in certain production commitments for the upcoming season, resulting in a demand contract. Finally, Chapter 7 presents a final discussion and areas of future work.

Chapter 2

LITERATURE REVIEW

The problem subject of this research is related to many different areas of research, two of which are aggregated planning decisions and supply chain coordination and negotiation. Since the first step towards supply chain articulation is to identify if the available resources are enough to capture a market opportunity including planting, harvesting, processing, transportation and logistics, a preliminary feasibility analysis must be performed. The main purpose of this initial feasibility assessment is to verify that a producing region can deliver the needed product at the time and with the volumes demanded. In this aspect, this research is geared toward the development of models that will help to assess the readiness of a region and identify how external financial resources can be allocated in an efficient way. A region is considered ready for the articulation if it satisfies all the requirements for the SC articulation and operation: growers available and capable to produce within the specified time windows, transportation and aggregation capacities, and the availability of the required logistics services when they are required. Most of the previous research done in this area has taken the approach of a specific echelon/participant of the SC assuming the rest of the echelons are available and can be contracted with a certain cost or these services performed by the farmers themselves. As far as we know, no previous research has dealt with analyzing the current condition of a SC considering resources availability within a region. Previous related research efforts have focused on how to allocate already available resources to be able to articulate supply chains. The novelty of the research contained in this document consists of assuming that the potential participants in the same region act as independent agents, which means they will have their own decision-making process using private information that it is not shared with the rest of the participants within the region. Another consideration of this dissertation is that because of the existence of a set of participants in a potential producing region, there is a limited amount of service providers, and thus limited capacity for planting, harvesting and the distribution processes.

The second area of research addressed by the research presented in this document deals with the identification and coordination of potential partners to perform the specific tasks that are required to articulate the SC once a market opportunity is identified and deemed economically feasible. This problem has two main components, the first one is related to the decisions relating to the allocation of different processes and tasks among the potential agents available while considering capacities, location, and costs. This section presents a review of the relevant literature in terms of supply chain design and how to allocate the logistic decisions required for the SC to work properly and efficiently. The second part of this issue is how to achieve the coordination between the identified partners. This requires finding and designing a revenue sharing mechanism that will provide the right incentives for all the participant to entice and guarantee the collaboration and ensure that they will be abiding by their commitments. The research in this area has been done mostly from a theoretical perspective, using game theory approaches. there is also some previous research with specific applications in terms of mechanism design. Another issue that the presented work is planning to address is the multi-level negotiation problem that is covered in the third phase of this research. This is the case where there is an agent in the middle of two negotiation processes, who needs to account for both counterparts during his negotiation processes. The last part of this section refers to some previous research related to this issue to identify what is the current state of the art in this area, and to obtain a better understanding of the used methodologies and modeling techniques that will help to tackle this part of the problem.

Before presenting a literature review related to the main related research areas, a brief review of the state of the art on agricultural supply chains is required. For instance, Ahumada & Villalobos (2009) provided a review of different planning model applied to agricultural supply chains. They classified the reviewed literature according to the planning level and the perishability of the products being considered. In addition, they identified that the increasing regulations and monitoring that is been required for agricultural supply chains will require changes and modifications to that traditional supply chains' structure and operations. These changes will mostly affect the way planning activities and coordination are performed, and the design of the SC in terms of who are the participants and how they interact. Another review was presented by Shukla and Jharkharia (2013) who classified the research related with fresh produce supply chain management based on the problem context, the methodology and the products considered. They found that most of the literate was interested in consumer satisfaction, while revenue maximization and post-harvest waste reduction played a secondary role. Another major finding was that the literature is very fragmented in the way the problem is tackled: there is lack of demand forecast tools, mismatch of demand and supply. This suggests the need of an integrated approach on how to design and manage the fresh produce supply chain, as the one presented on this document. In a more recent work, Routroy & Behera (2017) presented a review on the agriculture supply chain regarding its scope, objectives, outcomes, etc. They found no consensus on how the post-harvest performance, measured by the waste generation is measured, and accounted when considering an integrated approach. They found that inventory policies, demand forecasting and supply chain integration are important areas of agriculture supply chain, but there is a lack of focus, studies, and research on these areas. Another recent work by Kamble et. al. (2020) provided a review on research regarding data-driven agriculture supply chains. They identified that the use of data, and the related technology such as Big Data, Blockchain and Internet of Things (IoT), contributes to the performance of the SC in different aspects. They identified that there are multiple sources of data being generated throughout the SC, but there are currently not many works on how this information can be used. They suggest that there is still research to be done regarding how these technologies will benefit the farming community. All these surveys related with the agricultural supply chain identified similar gaps: lack of integration when designing supply chains, there is a need on revise how SC are being planned and coordinated based on the changing context where they are inserted, the use of technology and data will improve the performance of the supply chains, but there is still no specific way to include it in a systematic way. As these needs are just general research directions, the research presented in this document expects to partially address them and define some initial guidelines for further work on this area.

The literature review presented below is not meant to be exhaustive, but to provide a general direction of relevant research related to the different aspects of this problem. It consists of areas of research that have been identified as closely connected with the previously defined problems. The following part of this section is divided according to the three main areas of research identified in the paragraphs above.

2.1 Agricultural Production Planning

A key component of the research presented in this document is supply chain design, which consists of identifying who are the participating agents, processes, and interactions to be performed at different planning levels: strategic, tactical, and operational (Jang & Klein, 2011). A compiled review of optimization models applied to agricultural supply chain planning was provided by Ahumada & Villalobos (2009). On their work, they classified the relevant literature according to the planning level as strategic, tactical and operational, and by their focus on perishable or non-perishable products. Another extensive review on quantitative models applied to agribusiness supply chains, with a focus on risk management, was done by Behzadi et al. (2018). There is some previous research from the perspective of supply chain design, like the recent work done by Singh et. al. (2018) who presents a model to solve the location-allocation of warehouses considering the expected shelf life required by different customers. On their work, they allowed different products to share space in the warehouse, but without considering the operational/biological complexities that some products may require. They assumed that all the products have similar shelf life when they arrive at the warehouse, and the loss of shelf life will be given by the time taken to deliver the product to the customers. They also included the energy cost of storing different products per unit of time in the warehouse.

From a perspective of agri-food supply chains different mathematical programing models have been proposed and used to address part of the SC design issues (Esteso et. al., 2018). Among some specific relevant models, there is the work done by Ahumada & Villalobos (2011b) who provides a tactical model that serves for partner identification and provides general guidelines about how the logistic decisions can be made for multiple growers to place their products in the supply chain. Their Mixed Integer Programming model seeks to maximize profits from selling the product, salvaging unshipped costs and considering transportation, planting, harvesting, holding and purchasing products from other vendors (first part of the objective function of the model). In addition, they penalize the quality decay of the crops during the transportation (second part of the objective function). Below is a reduced version of their formulation to address this problem, considering both parts of the objective function and the main constraints which are related to the research proposed in this document. For the specific definition of variables and parameters the reader is referred to Ahumada (2008) and Ahumada & Villalobos (2011b).

Main variables:

$Plant_{pjl}$: Area to plant of crop *j*, in period *p* at location *l*

$Harvest_{phjl}$: Harvest (pounds) of crop *j* in period *h*, planted in period *p*, at location *l*

$Pack_{hfk}$: Quantity of product *k* packed at facility *f* in period *h*

$MenL_{lt}$: Seasonal laborers required at location *l* in time *t*

$HourF_{hf}$: Operator hours allocated at facility *f* and harvest time *h*

$Hire_{tl}$: Number of workers hired at period *t* in location *l*

$Fire_{tl}$: Number of workers terminated at period *t* in location *l*

$MenT_{tl}$: Number of temporal laborers hired at period *t* in location *l*

SP_{hjlf} : Pounds of crop *j* to ship from location *l* to facility *f* in period *h*

SC_{tkqfir} : Boxes of product *k* with color *q* shipped to customer *i* from facility *f* in *t* by mode *r*

$SPD_{htkqfdr}$: Boxes of product *k* harvested in period *h* with color *q* shipped from facility *f* to DC *d* in period *t* by transportation mode *r*

$SPW_{htkqfwr}$: Boxes of product *k* harvested in *h* with color *q* shipped from facility *f* to warehouse *w* in period *t* by transportation mode *r*

$SD_{htkqdir}$: Boxes of product *k* harvested in period *h* with quality *q* shipped from DC *d* do customer *i* in period *t* by transportation method *r*

$SWD_{htkqwdr}$: Boxes of product *k* harvested in *h* with color *q* shipped from warehouse *w* to DC *d* in period *t* by transportation method *r*

$SW_{htkqwir}$: Boxes of product *k* harvested in period *h* with color *q* shipped from warehouse *w* to customer *i* using transportation method *r*

$Invw_{htkqw}$: Inventory of product *k* harvested in *h* with color *q* in warehouse *w* during time *t*

$Invd_{htkqd}$: Inventory of product *k* harvested in *h* with color *q* in DC *d* during time *t*

SK_{hj} : Surplus of crop *j* at time *h*

Z_{tkw} : Boxes of product *k* to purchase on period *t* for warehouse *w*

TC_{tkfir} : (**binary**) Transp. mode *r* selected (=1) or not (=0) to transport product *k* from *f* to *i* at *t*

TPW_{tkfwr} : (**binary**) Transp. mode *r* selected (=1) or not (=0) to transport product *k* from *f* to *w* at *t*

TWD_{tkwdr} : (**binary**) Transp. mode *r* selected (=1) or not (=0) to transport product *k* from *w* to *d* at *t*

TPD_{tkfdr} : (**binary**) Transp. mode *r* selected (=1) or not (=0) to transport product *k* from *f* to *d* at *t*

TW_{tkwir} : (**binary**) Transp. mode *r* selected (=1) or not (=0) to transport product *k* from *w* to *i* at *t*

TD_{tkdir} : (**binary**) Transp. mode *r* selected (=1) or not (=0) to transport product *k* from *d* to *i* at *t*

Y_{jpl} : (**binary**) Crop *j* is planted (=1) or not (=0) at period *p* at location *l*

First part of the objective function:

$maximize$:

$$\sum_{tki} Price_{tki}\left(\sum_{f} SC_{tkfir} + \sum_{h}\sum_{w} SW_{htkwir} + \sum_{h}\sum_{d} SD_{htkdir}\right)$$
$$+\sum_{hj} Psalvage_{j}SK_{hj} - \sum_{tkqfir} CT_{fir}SC_{tkqfir} - \sum_{htkqwir} CTW_{wir}SW_{htkqwir}$$
$$-\sum_{htkqdir} CTD_{dir}SD_{htkqdir} - \sum_{htkqfwr} CTPW_{fwr}SPW_{htkqfwr}$$
$$-\sum_{htkqfdr} CTPD_{fdr}SPD_{htkqfdr} - \sum_{htkqwdr} CTWD_{wdr}SWD_{htkqwdr} \qquad \text{Eq. 2.1}$$
$$-\sum_{fhk}(Ccase_{k} + Coper_{k})Pack_{hfk} - \sum_{pjl} Cplant_{jl}Plant_{pjl}$$
$$-\sum_{tl} CLabor * MenL_{tl} - \sum_{tl} Chire * Hire_{tl} - \sum_{tl} Ctemp * MenT_{tl}$$
$$-\frac{1}{40}\sum_{tf} CLabor * HourL_{tf} - \sum_{tkw} Chw_{kw}Invw_{tkw}$$
$$-\sum_{tkd} Chd_{kd}Invd_{tkd} - \sum_{tkw} Pavg_{tk}Z_{tkw}$$

Second part of the objective function:

$$-\sum_{tkqfir}\frac{SC_{tkqfir}Price_{tki}Time_{fir}}{SL_{k}} - \sum_{htkqwir}\frac{Price_{tki}TimeW_{wir}SW_{htkqwir}}{SL_{k}}$$
$$-\sum_{htkqfwr}\frac{Pavg_{tk}TimePW_{fwr}SPW_{htkqfwr}}{SL_{k}}$$
$$-\sum_{htkqfdr}\frac{Pavg_{tk}TimePD_{fdr}SPD_{htkqfdr}}{SL_{k}} \qquad \text{Eq. 2.2}$$
$$-\sum_{htkqwdr}\frac{Pavg_{tk}TimeWD_{wdr}SWD_{htkwdr}}{SL_{k}}$$
$$-\sum_{htkqdir}\frac{Price_{tki}TimeD_{dir}SD_{htkqdir}}{SL_{k}}$$

Most relevant constraints to this research:

$$\sum_{jp} Plant_{pjl} \leq Totland_l \qquad \forall l, j \qquad \text{Eq. 2.3}$$

$$\sum_{jpl} Cplant_{jl} * Plant_{pjl} \leq Totinvest \qquad \text{Eq. 2.4}$$

$$\sum_{jpl} Water_j * Plant_{pjl} \leq Totwater \qquad \text{Eq. 2.5}$$

$$Min_j * Y_{jp} \leq Plant_{pjl} \leq Max_j * Y_{jp} \qquad \forall j, p, l \qquad \text{Eq. 2.6}$$

$$Harvest_{phjl} = Yield_{phjl} * Total_{pjl} * Plant_{pjl} \qquad \forall p, h, j, l: h \in TH(j, l) \qquad \text{Eq. 2.7}$$

$$\sum_{f} SP_{phjlf} = Harvest_{phjl} \qquad \forall p, h, j, l: f \in PF \qquad \text{Eq. 2.8}$$

Expanding their work to consider the operational decisions involved in the planning activities, Ahumada & Villalobos (2011a) presents an operational planning model for the harvesting and distribution of perishable agricultural products from a perspective of labor management and considering the freshness at the delivery of the produce. They obtained that by managing the trade-off between freshness, labor and transportation significant savings can be obtained for the growers. Another example is the study done by Amorim et. al. (2012) who worked in an integrated approach to consider production and distribution decisions at an operational level for perishable products. They compare the integrated approach versus the decoupled case to show that an integrated approach can achieve higher freshness levels for the products with lower costs.

For small growers, who are harvesting small volumes, there is a particular challenge in terms of transportation. As the volumes are small, there is a challenge in the utilization of transportation services in a cost-effective way to allow the aggregation and logistics to be economically feasible and attractive. The transportation and inventory management problems have been extensively studied for different industries. Among the specific related research applied to fresh produce there is the work done by Coelho & Laporte (2014) who developed a model for optimal vehicle routing and inventory management applied to perishable products. They explore different policies such as Fresh First, Old First, and optimal policy (mixed). They use the Branch and Cut algorithm to solve different scenarios of the problem, considering different periods of time, available vehicles, and number of clients. Their model considers products of different ages which all can be used to satisfy the demand, but with different expected revenue. They also considered waste costs and salvage revenue. Another related work was done by Nakandala et. al. (2016) in terms of the transportation of multiple products for local fresh food supply chain considering a single truck which will be picking up different products from different farmers. They use genetic algorithms, fuzzy genetic algorithms, and simulated annealing heuristics to solve the model. They consider transportation costs as function of the speed, cooling cost with fixed and variables components depending on the outside temperature, and quality decay costs depending on the temperature settings and the time of the trip. The model they presented is flexible to allow different products and farmers characteristics. Another model which considers quality decay in a two-echelon supply chain was developed by Yan et al (2011), who obtain and compare optimal inventory policies for individual SC agents and for both considered as a whole.

In terms of the aggregation and distribution an important component is the vehicle routing problem. This problem has been studied for different type of goods and with different variants (Kumar et. al., 2012; Braekers et. al., 2016), but some special focus is put into the research applied for fresh produce, for which distribution times will have a significant impact on its quality. The most common approach is to consider the vehicle routing problem with time windows and time-dependent travel times while considering quality decay as part of the distribution costs or the restrictions (Hsu et. al., 2007; Osvald et. al., 2008; Vahdani et. al., 2017).

2.1.1 Aggregated Planning for Agricultural Applications

Before providing a review on the work of aggregated planning applied to an agricultural environment is important to begin with relevant work that has been done for general applications. For instance, from a perspective of supply and processing of fresh produce Munhoz & Morabito (2014) developed a robust optimization model to obtain a supply and processing schedule for a citrus company, their aggregated model can determine when to process the fruit and generate a blending plan to minimize the operational costs under a contracted fruit supply. They consider uncertainty in the acidity of the fruit coming to be processed, and the impact it will have in the blending requirements. Guide & Spencer (1997) applied a bill-of-resources approach to perform a Rough-Cut Capacity Assessment for a remanufacturing firm. They first estimate the overall capacity requirements based on the processing times and efficiencies, and then estimate the available capacity at each of two workstations. Another work that is more related to the research presented in this document can be found in Mirzapour et. al. (2011). They developed a robust multi-objective stochastic aggregated planning model to allocate SC resources in a tactical level under demand uncertainty. They present a case study in Iran for the paper manufacturing industry to obtain an aggregated production plan, workforce allocation and SC interactions for four demand scenarios.

In the context of using aggregated planning methods for farming activities planning and coordination Tan & Çömden (2012) developed a tactical model to allocate production contracts to different farms considering yields and demand as normal random variables. Their model tries to match supply from the farms with retailer's demand for one product by aggregating all the logistics operations and considering them as an operational cost depending on the time when the product is harvested. They do not consider multiple SC echelons or perishability of the products. Ahumada & Villalobos (2011b) presents a tactical level optimization model which integrates planting, harvesting and distribution decisions. They consider different yields based on planting/harvesting weeks, and the option to hire/fire workers to accomplish the required labor requirements. They assume that the growers have some control over the logistic decisions and consider the obtained profit from a vertically integrated point of view, without allocating it to the specific SC participants. These previous works focus on determining the optimal production plans for growers in a single region, even when yields variability is considered they do not account for different seasonality occurring in different geographical locations. In the next paragraphs we focus our literature review on the previous work that accounts for different complementary producing regions and what has been done to find and coordinate the production from these regions.

2.1.2 Complementary Producing Regions

The issue and benefits of considering complementary producing regions has been explored recently. For instance, Flores & Villalobos (2020) explore the discovery of complementary producing regions based on expected yields considering temperature and precipitation of multiple locations from a strategic planning perspective. Using the expected climate conditions, they create clusters to reduce the number of planning units to a small set of locations, each representing multiple zones with similar weather conditions. They show the value of using complementary regions, particularly when considering the variability in climate conditions and market prices. In a more recent study Hajimirzajan et. al. (2021) presents a planning framework for large-scale crop planning while accounting for climate diversity with a focus on minimizing costs and resources usage. They present a case study for Onions, Potatoes and Tomatoes in Iran. In general, using climate data, yield estimates can be obtained to assess the productivity of a certain location for different planting alternatives, particularly in presence of climate variability (Birthal and Hazrana, 2019). This becomes more relevant for regions with different, or opposite, weather patterns which will result on complementary productive seasons where production that can be coordinated to expand the windows of fresh produce availability (Gaup et. a., 2019; Villa et. al., 2019; Ahumada et. al. 2021). Having alternative production windows can be very advantageous from a planning perspective, when the market demand is not completely aligned with the production season of a single region, or in cases where the consumers present additional preferences for the produce they demand.

Some of these additional preferences may come in the form of special denomination labels (organic, local, etc.), and if only a single location is supplying the market, there might be produce scarcity outside the producing season. Therefore, it becomes important to identify and characterize these additional preferences ahead of time in such a way that they can be considering while planning the next production season.

2.1.3 Planning Considering Denomination Labels and Consumer Preferences

The topic of non-monetary or special denomination preferences or incentives has gained some interest lately by considering the different preferences that consumers may have at the time of selecting the products to be purchased (Bond et.al, 2008a). One of the main special denomination preferences in agri-food SC planning that has gained a lot of attention is that of “local” label (Gumirakiza et. al, 2017). These products are preferred because they are grown close to where they are being sold, very often this preference is derived from the belief that they have a lower energy/carbon footprint and support local, usually small, growers. However, the definition of “local” is elusive (Feldman & Hamm, 2015). For instance, Martinez et. al (2010) label “local produce” as that sold directly by the farmer to the consumers at farmers markets. Another way to define whether a product is “local” is based on the distance from where it is grown to the selling point. However, as pointed out by Feldman & Hamm (2015), there is no consensus on what distance should be used to consider a product as local. They report distances used from 10 up to 100 miles to consider a product as local. These authors also identify some other definitions of “local” such as considering who grows the produce (i.e., homegrown) or political boundaries (i.e., states). For instance, a report from USDA mentions different programs using alternative definitions for local produce as: crops produced by farms located in the same state as the consumers, crops produced less than 275 miles from the consumption point or produce grown less than 400 miles from the consumers (Low et.al, 2015). Meyerding et. al, (2019) argue that the interest for local produce usually comes from two angles: support local communities who grow these products; and, from a sustainable point of view, favor produce locally grown that is not exposed to long-distance transportation, thus, lowering its carbon emission footprint.

Particularly, the concept of sustainability based on the carbon/water footprint associated with food supply chains has advanced rapidly in the past few years (Akkerman et. al, 2010; Yue et. al, 2011; Marx-Pienaar & Erasmus, 2014; Bortolini et. al, 2016; Han, 2021). Some authors emphasize that consumers are more aware of the effect of climate change associated with carbon emissions, as well as the projected scarcity of water which has raised the awareness on how water is used (Müller, 2020; United Nations, 2021; Marx-Pienaar and Erasmus, 2014). In particular, the presence of an environmentally conscious consumer affects the demand of those products commonly associated with sustainable practices such as: energy and water use, carbon emissions, etc. (WWF, 2012). Regarding agricultural products, Bortolini et. al (2016) look at the fresh food distribution problem and analyze different distribution networks from a multi-objective problem considering: operating costs, carbon footprint, and delivery times. Despite the attempts to improve the sustainability practices related to agricultural production and distribution, there is not a lot of consciousness about how its production and post-harvesting activities affect the aggregated carbon, energy, or water footprint. This is mostly because there is no standard metric to account for these factors (Colantouni et. al, 2016). Currently, consumers tend to relate "local" production with low carbon footprint based on the logistics and transportation processes, but not considering the emissions that may be related with the production of the product itself (Meyerding et. al, 2019). In the same line, Onozaka & McFadden (2011) shows that when there are multiple labels, particularly regarding local production and carbon footprint, consumers tend to give preference to low carbon emissions over being locally produced. They also highlight the potential negative effect of production investments for local production (i.e., greenhouse to extend the harvesting season, or cold storage to extend the product shelf life) as might increase the energy consumption resulting in the need for the consumer to reconsider the value of local produce with higher carbon footprint.

Another common factor affecting consumers preferences is the “organic” label of the products (Huang, 1996; Bond et. al, 2008b; Oberholtzer et. al, 2013). According to many researchers, there is an increasing interest or preference for this type of products by the consumer as they associate these products with healthier properties (Yiridoe et. al, 2005; Yue and Tong, 2009; Hu et. al, 2011; Gumirakiza and Curtis, 2013), mostly because of the assumption that producing these products is free of the use of chemicals and are more naturally grown (Herrnstadt et. al, 2016; Howard and Allen, 2008; Oberholtzer et. al, 2013).

2.2 Supply Chain Coordination

An important part of the SC articulation is the coordination of the participating agents in terms of who will be performing each of the required tasks, how the prices will be defined, how to allocate the responsibilities and how to guarantee the collaboration. This usually requires a negotiation process that will serve to identify preferences, establish contracting prices, allocate risk, and determine the interactions among the different participants. In this section a literature review of the relevant research done regarding the coordination and negotiation of the supply chain is presented. First, there is some relevant work that has been done in terms of agricultural supply chain coordination, followed by previous research related with negotiation and contracts design.

2.2.1 Supply Chain Coordination

There are multiple ways to achieve the coordination among independent agents that are seeking to collaborate, but generally they take the form of contracts that seek to guarantee that each part will do what is expected in terms of timings and quality of the service provided. This approach requires to understand the interactions and behaviors of the participating agents when negotiating and agreeing into collaborate, which have been extensively studied in the area of game theory. The focus of this review is on the work that has been done in general to coordinate different supply chain agents, with a specific focus on the coordination mechanisms used. This review is not meant to be exhaustive, but to provide a general review of the main contributions related to the research presented in this document.

In terms of coordination of independent agents that are willing to collaborate, extensive research has been done using auctions as a coordination mechanism. The main benefit of this type of mechanism is to allow the participants to express their own interests independently by bidding on a product or service. This approach maintains the independence of the participants in terms of the information they have and how they estimate the value of a certain good. A starting point in research on auctioning mechanisms is the work done by Vickrey (1961) who analyzed the case of multiple buyers bidding for one unit of a product with one unit available, and the case when more than one unit is available. On the first case, under a second-highest bid price the pareto-optimal solution of the price allocation is reached. On the case of multiple units, the pareto-optimal is reached under a price allocation on which all the winners pay the price corresponding to the first rejected bid. This is only valid if each bidder is buying only one unit, thus they cannot have access to additional information to leverage their offer to change the expected bidding process outcome. An important result of his analysis is that even under information asymmetry this policy encourages the participants to offer their true value, as they do not know what other's valorization of the product is. The coordination agent - who can be seen as a seller - is the entity responsible of designing an auction game that will result in a Nash equilibrium that will provide the highest possible benefit to the participants. Depending on the application, different auction mechanisms can be designed (Myerson, 1981). For example, one application is the bargaining problem between one buyer and one seller for a single object, which can be addressed by different allocation mechanisms that are incentive compatible (Myerson and Satterthwaite, 1981). Different is the case when multiple goods are being auctioned simultaneously analyzed by Ausubel & Cramton (2004) for many goods being auctioned simultaneously. They consider goods that can be divisible and present some methodologies that can be used to reach the price equilibrium (no excess of demand). The main type of auction they present is the Clock Auction, on which for any given price the bidders express their desired quantity for the product being auctioned, then the price is increased, and the buyers adjust their demand. After a while there is no excess of demand, and the auction ends. They also present some methods that can be included during the auction to ensure the efficiency.

This type of public offering auction structure is known as the English system, on this system the prices are being increased and the bidders decide whether they accept the new price or not. The auction ends when none of the bidders accepts a new price. Then, the participant who placed the last bid wins the auction and pays the accepted price. Another common public auctioning mechanism is the Dutch System, on which as opposed to the English system, the price starts high, and it is being decreased until it gets a bid. The first bid made is the winning bid and the corresponding bidder buys the item. Another type of structure used for auctions is the sealed auction. On this structure there are two main mechanisms: first-price auction, where the highest bidder wins the bid and pays the price, he/she offered; and the second-price auction, on which the highest bidder wins the bid, but pays the price offered by the second highest bid (Vickrey, 1961). Even if all these mechanisms serve the purpose of selling an item, the interaction among the participants are different, and thus the expected dynamics of the auctioning system will be affected. For the research presented in this document, the type of interactions and the bidders' behavior will be considered when designing a coordination mechanism.

In a topic more related to the coordination of agents in the context of a supply chain, Sohdi & Tang (2013) reviewed the situation for micro-entrepreneurs who are playing the role of suppliers and distributors and identified an opportunity in studying different types of contracts. This approach attempted to improve the leverage capabilities and risk allocation for small producers and distributors when working in a big well-established supply chain. Even if they did not provide full models, they provide general guidelines that will serve for further modeling-based research in terms of price definition and price search when the suppliers (micro entrepreneurs in their case) are receiving offers. Another case study was presented by Lehoux (2014) for the planning, forecasting and replenishment activities for the forest industry; in her research she proposed three incentive modes used to share the benefits between partners: first, bonus if order optimized regarding the number of orders and their size; second, transportation saving sharing if its capacity is well used; and third, a quantity discount for bigger lot sizes. She found that the benefit based on savings is the most promising for better coordinating purposes, but the extra profit was not necessarily fairly distributed, as they did not consider its distribution as a key component while modeling. In a more recent work, there is research done to coordinate the production and supply between a single manufacturer and retailers using different types of option contract such as commitment-options, revenue-sharing options, and backordering (Li et al., 2017;

Vafa Arani et al., 2016; Hu et al., 2014). In these research works there is an agreement on the improvements on collaboration achieved by an option contract under market demand and production uncertainty, but none of those research works consider the risk profiles of the participants in the SC. Another conclusion is that a revenue-sharing mechanism can reduce the double marginalization and will entice the collaboration as all the participants will benefit of the successful operation. In the case of contracts with backorders, it allows more flexibility in terms of the risk allocation among the retailer and manufacturer, which also influences the initial order quantities and option order quantities.

An extensive analysis on collaborative planning and coordination mechanisms is presented by Albretch (2010). Related to the purpose of this research it is worth to mention that the excess of profit (surplus) obtained by the coordination and collaboration of different parties can be allocated with the right incentives. For the parties to collaborate the allocation of the surplus must be such that is at least the equivalent to the surplus that each of the party members could get from any possible sub coalition. He also outlines tree contractual frameworks based on compensation payments among parties as incentives for the implementation of coordinated solutions. These are:

- Surplus Sharing Determined by the Informed Party: Under this mechanism the surplus is divided according to a rule defined by a single party who recombines the proposals coming from the bidders. Then, the surplus is shared based on the cost changes for the involved parties, and an allocation rule using the total profit to allocate (i.e., everyone receives the same, profit proportional to the costs, etc.). The main problem with this approach is that the participants can lie about their real costs and benefits to receive a higher part of the surplus. Also, the resulted distribution may not be high enough to some of the participants to incentivize future collaboration.

- Surplus Sharing Determined by Lump-Sum Payments: In this approach, the participants pay a lump-sum at the beginning of the coordination process, even before reporting their costs. And they also agree to the payment to pay back the lump-sum if the solution from the coordination is implemented. Later, the party with the information can choose to accept the coordinated solution and pay the lump-sum, or to reject it the reported costs are too high. This mechanism encourages to tell the truth as exaggerating the costs will increase the risk of losing the lump-sum for the bidders.
- Surplus Sharing by Double Action: In this case, the approach considers a double auction mechanism on which the bidders place sealed bids for different proposals offered by the coordinating agent. Then all the bids are open at the same time and the best overall benefit is estimated. If the best configuration provides systemwide gains, then this proposal is implemented, and a compensation payment is used to share the benefits among the participants.

In the context of multiple agents' coordination there are some relevant concepts to define and keep in mind when seeking to negotiate such as Individual Rationality, Budget Balance, and Incentive Compatibility. The first one refers to the case on which the agents are collaborating without obligation, but because they see an individual benefit from the collaboration (Sandholm, 1991). Budget Balance refers to the idea of a coordination mechanism which doesn't need any external subsidies, i.e., from the government, to be implemented (Chu & Shen, 2006). Lastly, Incentive Compatibility refers to a mechanism on which the parties have no incentive to lie during the negotiation process, and act differently than accorded (Myerson, 1979). It is important for the research work in this dissertation to account for these conditions when designing a coordination mechanism. A common coordination mechanism that is explored because it has these properties is a revenue sharing contract under which the involved parties will receive benefits from the final price of sale. If one of the involved parties act differently than accorded, it may impact the final price and demand of the product, which will directly affect the profits that the participant will be receiving as part of his/her share (Cachon and Lariviere, 2005). The use of this type of mechanism will serve two purposes on this research: 1) will provide a coordination mechanism that satisfy the desired properties required for a contract to have the three conditions previously listed, and 2) it will directly address the issue of sharing the revenue captured by addressing the market opportunity with the growers.

2.2.2 Agricultural Supply Chain Coordination and Negotiation

For the specific case of fresh produce, most of the previous work in the area of planning has been done assuming centralized decision-makers. For instance, Bikhchandani et al. (1998) analyses the case of individual growers making their own decisions about when to plant and harvest without considering other people's behavior. Under these circumstances, they may end up harvesting at the same time, which may result in an excess of supply that will have an impact by lowering the prices for everyone. To provide more information for the growers when deciding their production schedule some research has been exploring the situation of providing a forward contract and demand information to farmers to ensure a product supply that meets their requirements in terms of timing and quality (Huh & Lall, 2013). A different approach was taken by Yu et. al. (2018) who modeled a risk-neutral company and n risk-averse farmers who are collaborating under a principal-agent leasing model. In their work, incentives are given by the company to each of the farmers to achieve the coordination for the use of the land. These authors found that depending on the collaboration mode (centralized or decentralized) the preferred incentives by the growers are different. In the same line of research, Mason & Villalobos (2015) presented a methodology for negotiation and coordination of the SC in a Fresh Produce environment considering the growers as independent agents. They present an auction mechanism on which the coordination agent publishes the schedule of prices that he can offer for the produce, and the growers responds with their optimal delivery schedule. They show that the coordination can be achieved by modifying the prices vector in an iterative process, but this process may take a high number of iterations to reach the right configuration. The mechanism developed is formulated using a Mixed Integer Linear Programming model and presents a structure that allows the use of Dantzig-Wolfe decomposition (Danzig and Wolfe, 1960). In addition, they included a parameter λ_l^k that serves to communicate the prices offered for the to the growers for their products by the coordinating agent. These two components allow the decomposition of the problem into a master problem (MP1) and a set of sub-problems (SP1), and the communication between them through the negotiation process. To illustrate this, below is a reduced version of the formulation used by Mason (2015) to address this problem, for the specific definition of variables and parameters the reader can refer to their work.

Most relevant constraints to this research:

$$\sum_{jp} Vplant_{pjl} \leq Land_l \qquad \forall l \qquad \text{Eq. 2.9}$$

$$Min_j * Y_{jpl} \leq Vplant_{pjl} \leq Max_j * Y_{jpl} \qquad \forall j, p, l \qquad \text{Eq. 2.10}$$

$$Vharv_{hjl} \leq \sum_{p} Vplant_{pjl} * Yield_{phj} * Total_{jl} \qquad \forall h, j, l \qquad \text{Eq. 2.11}$$

This work by Mason (2015) provides a good starting point in terms of modeling the negotiation process between the growers and a coordination agent. Their focus was on the overall profit achieved by the opportunity articulation but without a lot of emphasis on how the profit (surplus) would be distributed among the participants and without considering the limited resources that may be available in terms of logistics, in particular when addressing the aggregation problem. The research presented in this document will address these two gaps by defining a specific revenue sharing mechanism among the SC participants through contracts and considering the issues related with the production aggregation while accounting for the limited logistics resources available to the growers.

Another work related with the coordination of different growers was done by Flores & Villalobos (2019) who develop a centralized strategic level optimization model to consider complementary production zones that can be coordinated to supply the required crops through different seasons. They present a model that seeks to maximize the profit of the SC articulation after a demand signal is identified while considering the variability on two random variables: 1) prices, which will affect the demand side component; and 2) in the weather conditions, which will directly affect the expected yields for the crops. They also considered the variability of these parameters by using a stochastic programming optimization model, which can become very large given the number of scenarios required to solve the problem in a statistically meaningful manner. To address this issue, they used Stochastic Decomposition (Higle, 1996), a technique to separate the problem into sub-problems, given as scenarios or realizations of the random variables, and achieve efficiencies in the solving algorithm running times. They also consider the use of alternative technologies that can be used to modify the expected yields from the crops. Their model provides a strategic decision-support tool providing general guidelines about when to plant and harvest the required crops in different complementary producing regions. Below a reduced version of the formulation used by Flores & Villalobos (2019) to address this problem is presented. Their formulation decomposes the problem into a Master Problem (MP2), which provides the first stage decisions made before the growing session, and the Sub-Problem (SP2), which correspond to the second stage decisions that are made once the values for the random variables become known. For the specific definition of variables and parameters the reader can refer to their work.

Main decision variables:

$X_{jfu}^{t_p}$: Yield of crop *j* by farmer *f* when planted at t_p using technology *u*

B_{jfu} : (**binary**) Technology *u* is available (=1) or not (=0) to farmer *f* for crop *j*

$SLZ_{jfz}^{t_h,t}$: Quantity of crop *j* shipped from farmer *m* to region *z* at time *t* harvested at t_h on mode *m*

$STZD_{jzdm}^{t_h,t}$: Quantity of crop *j* shipped from region *z* to DC *d* at time *t* harvested at t_h on mode *m*

$SDC_{jdcm}^{t_h,t}$: Quantity of crop *j* shipped from region *z* to DC *d* at time *t* harvested at t_h on mode *m*

$Invw_{jz}^{t_h,t}$: Inventory in warehouse of crop *j* at zone *z* at time t_h

$Invd_{jz}^{t_h,t}$: Inventory in DC of crop *j* at zone *z* at time t_h

$WA_z^{t_p,t_h}$: Additional water allocated to region *z* between t_p and t_h

$AddWCap_z$: Additional warehouse capacity used at zone *z*

$Microharv_{jz}^{t_h}$: Amount of crop j harvested during t_h within zone z

Master Problem (MP2):

$maximize$:

$$\sum_{t_p jfu} X_{jfu}^{t_p} * Cplant_j + \sum_{t_p jfuz: f \in F(z)} X_{jfu}^{t_p} * (Ctech_{uz} + Coper_{uz}) + \boldsymbol{\eta}(\boldsymbol{x}) \qquad \text{Eq. 2.12}$$

Most relevant constraints to this research:

$$\sum_{juf: f \in F(z)} B_{jfu} * Ctech_{uz} \leq Cavail \qquad \text{Eq. 2.13}$$

$$\sum_{t_p} X_{jfu}^{t_p} \leq Land_f * B_{jfu} \qquad \forall f, j, u \qquad \text{Eq. 2.14}$$

$$\sum_{uf} B_{jfu} \leq CropOper_j \qquad \forall j \qquad \text{Eq. 2.15}$$

$$X_{jfu}^{t_p} \leq maxl_j * B_{jfu} \qquad \forall j, f, u, t_p \in T\_p \qquad \text{Eq. 2.16}$$

$$\boldsymbol{\eta}(\boldsymbol{x}) \geq \alpha_s + \beta_s x \qquad \forall s \in CUTS \qquad \text{Eq. 2.17}$$

Sub-Problem (MP2):

$maximize$:

$$\begin{aligned}
&\sum_{jdmt_h tc: t = t_h + LT_{dc}} SDC_{jdcm}^{t_h,t} * Mpr_{jc}^{t,k} - \sum_{jqzt_h t} Invw_{jz}^{t_h,t} * Cw_z \\
&- \sum_{jqdt_h t} Invd_{jd}^{t_h t} * Cd_d - \sum_{t_p t_h z} WA_z^{t_p t_h} * Cwater_z \\
&- \sum_{jdmt_h tc} SDC_{jdcm}^{t_h,t} * CTDC_{dcm} - \sum_{jzt_h td} SZD_{jzdm}^{t_h,t} * CTZD_{zd} \\
&- \sum_{jft_h tz: f \in F(z)} STLZ_{jfz}^{t_h,t} * CTLZ_z - M * \sum_z AddWCap_z
\end{aligned} \qquad \text{Eq. 2.18}$$

Most relevant constraints to this research:

$$MicroHarv_{jfu}^{t_h} = \sum_{t_p} X_{jfu}^{t_p} * YDist_{jzu}^{t_p,t_h} * yield_{jzu}^{t_p,k} \qquad \forall t_h, j, z, u, f \in F(z) \qquad \text{Eq. 2.19}$$

$$\sum_{t_h zmc: t_h + SL_j \geq t \geq t_h} SDC_{jdmc}^{t_h, t_p + LT_{dc}} \leq MaxDem_{jc}^{t} \qquad \text{Eq. 2.20}$$

Even if this later approach is more robust in terms of considering the variability of prices and weather (which is reflected as its effect on the expected yields), it is still a high-level strategic planning tool. The authors put a lot of attention in the first stage of the process, which has to do with allocating resources to the producing regions and less attention to the logistics aspects, which are assumed as available at a known cost. As mentioned in the introductory session of this dissertation, the work proposed in this document addresses the issues that arises after a strategic plan is defined with a focus on the final implementation of the production plan and the logistics required. This is done while considering the resources availability and looking towards the allocation of production schedules to specific growers within each producing region

2.3 Revenue Distribution in SC

A third component of the supply chain coordination process is related with how the revenues are distributed among its participants. The benefits of coordinated supply chains have been extensively studied, with respect to the higher level of profits that can be achieved. In the case of a coordinated agricultural supply chain, multiple growers can collaborate to achieve higher profits, but there is a set of factors that must be considered to achieve an implementable coordinated plan, as discussed in this paper. One of the main factors that must be considered is how different growers may perceive the coordinated solution, particularly with respect to the expected revenues and the risk associated to engage in a collaborative endeavor. A second consideration has to do with how the revenues achieved with the collaboration are distributed among the supply chain participants. This, because the participants (farmers) must perceive a benefit from the collaboration prior to engage in the plan's acceptance and implementation. A third, and closely related, consideration has to do with how the growers perceive the coordination mechanism, this in terms of the expected value, risk associated and fairness of the plan and revenue distribution. In the next paragraphs, a brief overview of the relevant literature related to these three research areas is presented.

2.3.1 Agricultural Risk Assessment

A recent review by Behzadi et. al. (2018) provides a comprehensive analysis of quantitative models for agribusiness supply chain risk management. They found inconsistencies in the meanings of Supply Chain Risk management terms, particularly on agribusiness. They highlight the complication for perishable agriculture products given the additional level of vulnerability associated with perishability. They conclude that in general agricultural risk is defined as variable costs, yields or prices, with different approaches used to model these risk definitions. Some of the approaches that have been used to model agricultural risk include: variability in the outcomes, used the most in farm planning problems; efficient frontier between expected profit and variance of the profits, common in crop planning problem; negative deviations from an income target; game theory, introducing different metrics in the coordination game to share/reduce the risk for each player; linear programming, through goal programming, multi-objective, MIP, etc., widely used to maximize profits under certainty; stochastic programming, to capture relevant variability sources and enable to model the risk associated with the solutions; and simulation, mostly used in scheduling and parameters estimation problems. With respect to risk management strategies, most of the literature uses diversification as the main response to risk in agriculture, particularly at the production level, and inventory-based strategies may not be effective given the perishability components of the produce.

In a more recent review regarding how risk in considered in agriculture, Komarek et. al. (2020) identify the five major types of risk in agriculture: production risk, which is attributed to the uncertain natural growth process of crops and livestock; market risk, related with uncertainty of prices, costs, and market access; institutional risk, related with unpredictable changes in policies and regulations that affect agriculture; personal risk, related with human health or personal relationships affecting the farm; and financial risk, associated with how far the operation is financed and their economic stability. They also highlight that there is no consensus on the interpretation of risk, where the most common interpretations are the chance of bad outcome and the variability of the outcomes.

Particularly to how farmers perceive the risk and benefits of the production plans, Backus et. al. (1997) analyzes the decision-making process for a farmer under risk and uncertainty reviewing the theory of Subjective Expected Utility, which states that the decision maker's expected utility depends on the individual's utility function and the variability of the outcomes. They conclude that this can be modeled following the Prospect Theory, which assign values to gain and losses weighting the outcomes according to their probability. In their review, Schieffer & Vassalos (2015) talk about two types of contracts: a production contract, on which buyer specifies aspects of production and keeps ownership of the product throughout it; and marketing contract, where the buyer focus on the end product, price, schedule, quantity, and quality. In terms of type of risk, they also refer to two: production risk, as the uncertainty in quantity and quality of the product, basically affected by yields, diseases, water availability, etc.; Market risk, refers to the uncertainty of the prices, and the demand (placement risk). They identify that reduced-price risk and secured income are the most common reasons for growers to engage in a contract.

With respect to the inclusion of risk metrics in the decision-making process, Huh & Lall (2013) uses a stochastic modeling approach to model the problem of land allocation for a single grower, given irrigation, rain and prices variability. They consider a case study with two crops under three scenarios: risk neutral without contracts, risk averse grower without contract, and risk averse grower with forward contracts for one of the crops. They conclude that even if the contract provides price certainty (preferred by the farmer), it also provides uncertainty about the yields and penalization for not fulfilling the contract. This results on the farmer requiring a premium from the contract to compensate for the quantity risk for the contracted crop. Another attempt to assess the effect of grower's risk preference in the planning stages is found in the work by Ahumada et. al. (2012). In their work, they use stochastic programming to solve the agricultural planning problem under prices uncertainty for a single grower. They use stochastic linear programming, introducing a risk penalization term in the objective function, considering the downside deviations from a target profit to model the risk for a grower.

Besides the inclusion of the risk as a metric that affects the decision-making process, particularly in the agricultural supply chain planning stages, there is also the issue of coordinating the supply chain participants. Participant's coordination becomes critical when the planning decisions are transformed into contractual commitments, and the design of these contracts and how each participant will be compensated will determine the success or failure of the plans.

2.3.2 Revenue Sharing Mechanisms

In their work to coordinate a general supply chain using revenue sharing contracts, Cachon & Lariviere (2005) studies the case of these type of contracts under a deterministic and stochastic scenario. They work on a vertical revenue sharing policy, but do not allocate profits among participants at the same level of the supply chain. They identify that the major limitation of a revenue-sharing contract is that it does not coordinate competing players in the same level of the supply chain (i.e.: in a two-echelon supply chain it does not coordinate multiple suppliers competing to supply a single buyer).

In a more recent work, Xu et. al. (2018) explores the use of risk as a metric that can be used to share revenues among the participants in a coordinated green supply chain. They use a modified version of the Shapley Value method considering that the revenues are proportional to the risk each participant is taking, and to the contribution to lower the supply chain carbon emissions. The Shapley Value method is commonly used to suggest "reasonable" allocation of the revenues under cooperative scenarios considering the marginal contribution of all the participants (Roth, 1988; Winter, 2002). In a similar problem, from the perspective of costs allocation, Tittlechild & Thompson (1977) introduce the airport runway problem. They try to define the optimal policy defined as "efficient" if the airport breaks even after the aircrafts pay their fees. They search for a pricing scheme where all aircrafts have the incentive to use the airport within their ability to pay, which they define as fair if smaller aircrafts pay no more than the larger ones. In addition, Tijs & Driessen (1986) worked in the cost allocation problem, identifying different methods from Game Theory that can be used to solve the problem: the egalitarian method, which distributes equally but is not individually rational; methods based on marginal costs (i.e., Shapley Value), which are efficient and anonymous; methods that minimize the maximum unhappiness; and methods based on separable and non-separable costs.

More specifically related to the agricultural supply chain coordination, Mason & Villalobos (2015) approached the farmers coordination problem from a decentralized perspective using an auction mechanism. They were able to model both the buyer and the growers decision-making process using an iterative process to adjust the prices offered to the growers to coordinate the supplied volumes. They maximized the supply chain total profits but did not explore how the revenue is distributed among the participants. Regarding increasing the revenue captured by the supply chain, there is research regarding revenue management, which focuses on how pricing strategies can be used to maximize revenues. For an extensive review on this area, we refer the reader to the recent reviews by Strauss et. al. (2018) and Klein et. al. (2020). The authors of these works focus on revenue management strategies and summarizes previous works on the use of revenue management for products under different industry settings, such as: innovations, upgrading, overbooking, personalization, and risk-aversion. They survey relevant industry applications of revenue management methods in industries such as air transportation, air cargo, hotel, car rental, home delivery, and manufacturing, highlighting the importance of specific revenue management-related challenges on each of them.

From a more theoretical perspective, some authors present certain characteristics that must be present in a mechanism for it to achieve coordination, such as: *Efficiency*, *Incentive Compatibility*, and *Budget Balance*. Particularly, Albrecht (2010) puts these concepts together under his definition of a coordination mechanism as a game where involved parties achieve an improved outcome (*Efficiency*) without violating individual rationality or budget balance. Attaining all these characteristics in a coordination mechanism is generally not achievable, Myerson & Satterthwaite (1983) showed that in the case of bilateral trade no mechanism implements all these requirements. In the case of multilateral trade, there is usually a compromise between these characteristics. For instance, in their work, Babaioff & Walsh (2005) consciously lose efficiency to secure the other requirements. How these characteristics are considered will directly determine if the coordination becomes successful or not, regardless of the specific mechanism used to coordinate the SC participants and distribute the revenues.

With respect to how revenues can be allocated in a fair manner, different approaches have tackled the problem from a theoretical perspective but without consensus on the definition of a "fair allocation". Yue & You (2014) focus on a revenue sharing policy using a transfer price between the buyer and the supplier in a biofuel supply chain. They define a fair profits allocation as one that is symmetric (equal participants, receive the same), feasible (allocation does not excel total profits), pareto optimal (two participants can't improve their solution at the same time), and preserved under linear transformation. Pan et. al. (2019) identify that the issue of fair profits allocation has not been properly addressed in previous works and propose to quantify each bidder's contribution to a coalition and use this metric to achieve a fair allocation. They use the Shapley Value allocation to guarantee a fair profit allocation among the participating bidders. In their work, Molnar et. al. (2018) analyses the case of profit allocations for a supply chain under revenue-sharing rates, or transfer price, they found that when a long-term cooperation approach is considered the revenue-sharing approach can result in fairer allocation than a short-term coordination. With respect to a fair farmer's share of the value of their products, Busch, and Spiller (2016) used a survey to find that the consumers are interested in increasing the position of farmers with respect to the value captured for their products, but there is no clear methodology to achieve this. They suggest empowering farmer's voices and provide closer access to the consumers via farmers markets, cooperatives, direct to consumer sales, etc. They did not discuss how profits can be distributed within a cooperative or collaborative structure.

To the best of our knowledge, and as pointed out by recent reviews, there has been no attempt to analyze how the profits generated under a coordinated supply chain can be distributed among its participants. With respect to how the revenue distribution mechanism can contribute to the actual practical coordination of the supply chain participants and to get them engaged in the collaboration under contractual agreements. In the paragraphs below we present a brief review of the literature regarding contract farming and the approaches that has been made to model and coordinate potential growers with the use of procurement or production contracts.

2.3.3 Contract Farming

When an agreement is needed between a producer, or a group of growers, and a potential buyer it usually comes in the form of a production contract. This contract details a production commitment agreed by the grower(s), and a purchase commitment by the buyer(s) for a certain volume and a certain price. A critical part of the coordination process is the definition of this contract, as both parties may not always have the right incentives to come into an agreement that will be efficient from the perspective of the value generated for both participants (Huh & Lall, 2013; Federgruen et. al., 2019).

For a general supply chain, Zhao et. al. (2013) studies the case of a manufacturer-retailer supply chain with a bidirectional option contract with a general demand distribution. They were able to determine the definition of the bidirectional option contract, in terms of prices, to achieve the supply chain coordination. Another related work is by Wan & Chen (2018), who uses a stochastic dynamic approach to approach the problem of multi-period replenishment with option contracts and a spot market. They find that the inclusion of the option contracts provides more flexibility and better expected profits for the retailer. Under low inventory costs and high prices variability the firm prefers call option contracts; and when the inventory costs are high with low prices volatility, put option contracts are preferred.

With respect to specific applications to contracts to coordinate the agricultural supply chain with the use of contract, there is the work by Wang et. al. (2015), who uses a newsvendor approach to model a supply chain facing demand uncertainty. Their approach consists of a mix between option contracts and the retailer adjusting the final sales price to achieve an optimal ordering policy. In a posterior work, Wang et. al. (2017) uses a newsvendor model to coordinate a fresh produce supply chain consisting of a single supplier and a single retailer. They consider stochastic demand faced by the retailer during the selling season and use an option contract between the supplier and the retailer and achieve the coordinating by finding a wholesale price that allows the coordination. In their work, Brown & Lee (1998) analyses the coordination of a seller and buyer negotiation process using real options, while considering both agents profit functions under independent decision making processes, and under a vertically integrated scenario. They found a single price for the options contract that could achieve the coordination of both agents maximizing the integrated SC profits. For a more extensive review on real options and their applications, the reader is referred to the recent reviews by Trigeorgis & Reuer (2017) and Trigeorgis & Tsekrekos (2018).

To the best of our knowledge there has been no attempt to integrate a contract negotiation process within a planning framework capable of converting an identified market opportunity into implementable production plans. Most of the current research in the area of defining contracts focuses in maximizing the overall SC's profit, but without accounting for each participant's perception of the negotiation nor the creation of a practical implementable contract.

2.4 Conclusion and Literature Contribution

The main findings in the literature confirm the hypothesis that some specific components of the growers planning, and coordination problem has been addressed from different perspectives. However, there is not a lot of work previously done considering an integrated approach, which is required to close the gap between the strategic planning decisions and the operational activities that will allow the actual production, transportation, and sale of fresh produce. Regarding the first part of the research presented in this document, there is no literature on the use of a feasibility assessment methodology considering consumer preferences such as denomination labels ("organic", "local produce", etc.), as explained before most of the approaches consider the market demand just in terms of volumes, pricing and time when is required by the market.

In terms of supply chain design and coordination there is some previous works in terms of planning activities, but not a lot of effort has been done in considering the different participants as independent entities that has to be coordinated. There are also previous efforts tackling the problem from a planning perspective at different levels, but without specific results or focus on the practical implementation of the plans besides some theoretical results and general guidelines. No work was found related to implementing the planning decisions to its most operational level (commitments from the involved parties in the forms of contracts). The proposed innovative approach of this research seeks to fill this gap by integrating planning, negotiation, and contract generation in the same framework. This framework consists of applicable mathematical models, particularly optimization models, that will capture the main requirements and constraints to model the interactions required to plan, negotiate, and coordinate the participants in the emerging SC. All of this will allow the development of plans while seeking to achieve a coordination that can be converted into specific responsibilities, expectations, and commitments for the participants. The work presented in this research contributes theoretically to the design of an environment on which small growers in the fresh produce business will be capable of react and articulate their operations as a response to market signals. From a more technical perspective, this work advances the state of the art in at least four directions:

- Develop an optimization-based assessment tools to assess whether a plan can be executed in presence of limited resources and multiple complementary producing regions, which in this case will result in an application to the production planning decisions in the fresh produce industry.

- Develop an integrated planning and negotiation optimization model that allows to allocate tasks to independent agents while seeking to achieve the coordination using contracts to guarantee the collaboration. This is done by also addressing the issue of surplus allocation as an important research component.
- Explore how different tools can be integrated in the context of a double negotiation on which a single entity is part of a centralized and a decentralized negotiation process at the same time.
- Define a negotiation framework for the buyer(s) to negotiate a production contract with a group of growers, represented by the Supply Chain Articulator, while considering each party's condition and preferences. The resulting contract are created in such a way that it could be used as an input for the different planning stages required to fulfil that contract.

Chapter 3

METHODOLOGY

3.1 Background on Fresh Produce Supply Chain Articulation

Given the nature and the purpose of a fresh produce supply chain there are different participants who will be performing specific roles, depending on the specific activities and processes required for the product that it is flowing through the SC. As the main activities in a supply chain, there are the production of the goods, packaging, transportation, storage and finally, the delivery to customers. In general, there are specialized agents who have these tasks as their core business activity resulting in multiple participants who interact to reach the coordination required for the SC to operate. Given the independence of the participation agents, it is common that they do not share information and do not integrate their operations, resulting in a myopic planning and operation with the consequent lack of efficiency and waste. As reviewed in the previous section of this document, there has been previous research work attempting to achieve the coordination, but very often it takes the perspective of one individual echelon of the SC, or the approach is to consider a theoretically centralized decision-making process. In this dissertation, the coordination is pursued as an alternative to centralized SC planning by considering a decentralized process with multiple independent participants of the SC. The primary focus is on the design of an environment capable of transforming market signals, obtained from market intelligence methods, in the articulation of responsive supply chains to take advantage of the identified opportunities. This work contributes to the theoretical design of this environment, and to the development of specific tools that will allow the envisioned framework to operate. The main focus of this dissertation is on the growers and how they will benefit from the coordination and opportunity articulation.

The lack of integration result also in a lack of visibility, and in problems to plan the production and the required logistics decisions as explained in the introductory section of this document. For instance, there are many times when the producers do not have reliable information about the final demand of their products which result in the growers planning the production just based on the immediate demand they receive from the following agent in the SC (i.e., buyer). This results in longer reaction times after a demand signal is observed by the last echelons of the SC, the ones closer to the customers. Once they identify a new opportunity or change in the demand pattern the way to communicate this to the Supply Side requires a considerable amount of time for the producers to adjust their plans if there is no efficient way to communicate. A common way to address the variability in the demand is by keeping inventory at different stages of the SC, which may not be possible for products that are highly perishable like fresh produce.

Another issue is the availability of resources such as capital and infrastructure that affect the feasibility of a grower or a group of growers to respond to a market opportunity. In the case of fresh produce, the growers who can identify a potential opportunity have to struggle to insert their products in the SC given that the required infrastructure may not be completely available when they need it. As the establishment of new infrastructure and technologies usually requires a high investment and greater volumes of produce to become economically feasible, this ends up being adopted after a couple of seasons of production when the risk and the market seems to be more likely for investors.

Besides factors like the number of participants, the integration level among them and the availability of infrastructure there is the issue of the product ownership and the risk allocation. As mentioned in the introductory section (Section 1), the sparsity of the participants and the levels of independence and access to information results in growers to making decisions that may not be aligned with the markets. This, at the same time, and may force them to take the risk of losing their production, or get low prices, if the scenario ends up being unfavorable (i.e., low prices or demand).

Most of the aforementioned issues can be addressed by using the envisioned environment. The main characteristic of this new approach is the consideration of a coordination entity, the SCA, that seeks to put together the different independent SC participants in an environment that will provide access to information, planning tools, and negotiation/coordination support tools. The plan to address these issues is presented in the following sub-sections. This is done by developing a methodology and a set of tools that will help to achieve the coordination and planning of the multiple agents involved in the Fresh Produce Supply Chain

3.2 Vision of the Coordination Environment

As mentioned before, there are many issues that needs to be addressed by the SCA to articulate the SC. Some of them are in a strategic-tactical level, and some are more tactical-operational oriented within each production region, and the coordination among all the SC participants is something that can get very complex if everything is centralized. To address these issues and complexities to articulate a SC as a response to a market opportunity, the SCA's role lies between both sides of the supply chain: The supply side, representing the growers in the producing regions; and the demand side to identify and aggregate the market needs.

The interaction between these two sides can be seen as a negotiation process on which the SCA has identified an opportunity and is looking forward to seeing how this opportunity should be deployed among different potential producing regions. To do this, he gives an initial offer to the growers in the different regions so they can analyze if they can meet the produce required by the markets, and how it can be done. The growers' response will be a supply schedule based on the specific characteristics of the regions they are located such as weather, logistic capacity, etc. With all the responses from the different regions, the SCA will start a negotiation process to see the best way he can supply the required produce from the different regions to match the supply and demand while keeping costs as low as possible.

The research presented in this document seeks to help the decision-making process required to articulate a supply chain as a response to market signals. As mentioned before there are different stages that are required to plan, allocate resources, and coordinate the required resources to make this happen. The vision of this work is to keep this in mind and develop the required tools that addresses the main issues present at each of the planning and coordination stages. The following part of this section explains the main tools that are developed and how they are oriented towards the final goal which is the SC articulation.

3.2.1 Local Supply Chain Articulations

Once a market opportunity - which can be seen as a certain produce demand in terms of volume and prices - is identified, the first step is to evaluate if the current partners, capacities, and available resources are enough to articulate a new emerging SC as a response to the demand signal. This assessment estimates, in terms of general capacities, how different regions can respond to the opportunity. This is done by analyzing if the appropriate resources such as processing, storage and transportation are available within each region to meet a certain demand. This is addressed by developing a general aggregated planning optimization model that will serve as an initial indicator of the readiness of a region to react in response to a market signal. This tool is also be capable of providing an initial profitability analysis and recommendations on how to allocate new resources in an optimal way considering the different market signals and current region SC structure and conditions. An initial model is developed to address an individual region from the perspective of the SCA. The response from multiple regions will be used by the SCA to allocate the total demand and resources to each of the regions.

3.2.2 Revenue Distribution and Contracts Creation

After the market opportunity value is identified and an initial set of locations and growers is identified as candidates to collaborate and articulate a production plan capable of efficiently capture the market opportunity, a new set of challenges arise as the growers in each production region will have to be coordinated and offered contracts that will formalize the agreed commitments. These contracts must be such that they consider each of the grower's preferences and determine how the opportunity's value will be allocated to each of them. The design of the contracts is done by considering the whole value that could be captured by the growers and distribute it via contracts consisting in two payments: a first payment corresponding to the production contract itself (volumes and prices), and a second payment corresponding to an allocation of extra revenue after the produce is delivered to the SCA. This is done by enabling the SCA to keep some of the contract value aside as coordination budget that can be used to incentivize the participation of all the growers. We analyze the effect, benefits, and possible drawbacks of multiple revenue distribution mechanisms, to determine under which circumstances they would allow to coordinate the participating growers. This mechanism is then complemented and integrated with a contract negotiation tool similar to the one developed by Mason (2015) that will allow the SCA to individually negotiate with each of the growers in each region while considering the commitments that must be fulfilled by that region.

3.2.3 Multi-Level Coordination

The last part of this research tackles the supply chain coordination problem from the perspective for the negotiation between the buyers and the SCA. It is commonly assumed that a contract or demand is already agreed or determined before the beginning of the planning for the supply side of the SC. Usually the demand either takes the shape of a volume contract that must be supplied by one or more growers, or as a probability distribution in the case of considering the open market's variability. A very important aspect to determine the value of a market opportunity is what are the buyers actually willing to pay for the produce, and when. In this part of the research, we focus on the negotiation between a buyer representing a certain market, and the SCA representing a set of growers. The outcome of this high-level negotiation are general contracts in terms of the volume of produce needed for the season and the prices that the buyer is willing to pay for the crops. We analyze the case of an option purchase contract on which the buyer can procure the produce by using a mix of fix commitments and supply options. Prior the production season, a negotiation takes place on which the SCA, representing the growers, determines the offered price for the fix commitments, the price of the supply option, and the cost to exercise the option after the demand is realized for the buyer. With this information, the buyer can determine the mix of fix purchases and options to buy that maximizes his profits during the season, while considering the variability in the demand. This process is analyzed from the perspective of both the SCA and the buyer, with a focus on the quantity of options purchased by the buyer, particularly with respect to the optimal quantity that maximizes the profits for each party as independent agents, and as part of the same SC. A coordinated solution is found to align both parties' decision-making process to agree in the optimal quantity that maximizes the benefit for the whole SC.

3.3 Objectives of the Research

This research provides a set of tools, based on optimization models, that attempts to connect fresh produce supply with demand opportunities from a transportation and logistics coordination perspective. To achieve this, there are three main objectives to be pursued:

1. Development of a deterministic tactical model that performs a rough-cut capacity assessment of the readiness of different regions to articulate a production plan as a response to a market signal while considering consumer preferences such as "Local Produce" or other denomination labels. The goal of this centralized initial model is to identify if the available resources and agronomic conditions are enough to allow to articulate a plan that can capture most of the market opportunity's value under different consumer preferences. This tool also provides an initial assessment of each region's readiness and competitiveness to supply a certain market and estimates the profitability of the identified opportunity before committing to a production and supply plan. On the other hand, this initial model allows to analyze the effect of different denomination labels definitions on the region's

competitiveness and the effective allocation of resources (such as land). This becomes critical for regions where the agronomic resources are already available, but given the definition of some labels, such as “Local Produce”, the region may be in disadvantage.

2. The second tool consists of a stochastic tactical model that attempts to help the SCA to allocate the identified market opportunity to a set of producing regions while considering each region resources and agronomic potential, and the market opportunity value. This approach focuses on the distribution of the value of the market opportunity to the growers, particularly in the definition of contractual terms and revenue allocation between the participating regions in the solution. The expected outcome of this mechanism is to determine how the market opportunity can be allocated to different regions, and under which conditions an agreement can be achieved in such a way that the growers in each region are enticed to participate in the forming coalition.
3. The last part of the research consists of the negotiation process between the SCA and the buyers. This allows to model the interactions between these two agents when determining the value of a market opportunity, particularly in terms of demanded volumes and offered prices. The outcome of this negotiation will serve as a basis for the SCA to determine the market opportunity’s value when looking at the coordination of the growers in the supply side of the SC. The goal in this part of the research is to develop a framework able to connect the identification of a market opportunity, with the planning stages required to articulate the supply plan to capture its value.

In this research effort, a modeling formulation for each of the objectives described above is presented. To validate the proposed models, farmers, and logistic agents in the states of Arizona and New Mexico contributed and provided data and relevant information to construct realistic, feasible solutions.

3.4 Part I: Supply Chain Articulation Considering Consumer Preferences

The first phase of this study consists of determining the effect of consumer preferences in the articulation of responsive supply chains. Usually, these preferences come in the form of denomination labels, such as “Local Produce”, or preferences for lower water or carbon footprint. To include these preferences in the planning stages of the supply chain we develop optimization models that consider agronomical (i.e.: yields, crop budgets, etc.) and resource (i.e.: land, labor availability, etc.) parameter of different regions. The model attempts to match these characteristics to the requirements of the market for a particular crop in terms of supply calendar and consumer preferences. The initial overall objective is to maximize the profitability of an optimal selection of geographical regions by finding the best production plan. A secondary objective, which is embedded in the optimization problem, is to account for the market preferences while designing the supply plan. To solve this problem, we develop a deterministic linear programming model that simultaneously considers different candidate producing regions and determine the best way to allocate production plans according to their production season. We also explore the effect of the consumer preferences in the resulting plan and the regions’ profitability, as depending on where the market is located and what characteristics the consumers in that market are looking for, different regions may be better positioned to serve that market. In addition, we analyze the effect of the definition of the definition of a denomination label currently very popular: “Local Produce”. The developed model allows us to determine the importance of a clear definition, as the resulting plan and growers’ profitability is highly affected by how “Local Produce” is defined.

One key contribution of this part of the dissertation is the consideration of denomination labels and other consumer preferences that are beyond the price offered to the consumers. As part of this research, we investigate the effect of these consumer preferences and assess their impact on the competitiveness of potential producing regions. Furthermore, we identify that region that can be very efficient in terms of the use of resources and expected yields for a certain crop, may not be adequate to supply a market under certain definitions of “Local Produce”. This highlights the importance of a clear definition for labels that are actually representing what the consumer is looking for when choosing a crop with a specific denomination label.

3.5 Part II: Tactical Opportunity Allocation Considering Revenue Distribution Mechanisms

While the regional allocation of an opportunity provides a general idea of the profitability that could be achieved in the different regions, it does not account for the distribution of the value of the opportunity itself and the coordination mechanism required to entice the growers in each of the regions to participate in the emerging coalition. Once a general idea of the profitability of an opportunity is identified, the decision-maker (i.e.: the SCA) will have to determine how the value of the opportunity will be distributed among the potential participants. Furthermore, a critical requirement of the opportunity allocation is to determine who are the participating growers and how they will be compensated. In this part of the dissertation, we develop a coordination framework that explores the use of different revenue distribution mechanism based on the likelihood of achieving a solution where the growers are enticed to collaborate. To properly capture the risk inherent to the agronomic planning problem, we include the stochasticity in both the expected yields and prices that the growers in different regions may experience. This results in a model that accounts for both the agronomical and the risk-aversion characteristics of the growers to determine if the proposed plan provides enough incentives for them to participate in the coalition. The first part of this process is to determine the value that can be allocated to the growers, which depends on the potential growers selected to participate in the coalition. From a centralized perspective, this provides an upper-bound to the opportunity value that can be captured if the coalition is formed. Another component is the definition of the compensation mechanism, for which we propose the use of a two-payment scheme on which the first payment corresponding to the income coming directly from the production contract (volume and prices required from the growers), and the second payment corresponding to a distribution of the extra surplus generated from the opportunity.

With the framework obtained from this research we can determine the baseline of the growers' preferences, or in other words, what is the minimum benefit they would expect from the offered contracts to be willing to take part of the coalition. A key contribution of this part of the dissertation is the methodology to assess the growers perceived benefit by considering both the expected incomes and the risk exposure under both the un-coordinated and the coordinated scenarios. A second contribution of this work is the exploration of different revenue distribution mechanisms, which depending on the circumstances may be useful or detrimental to achieve the coordination.

3.6 Part III: Negotiation with the Buyer

As a critical part in the SC articulation process, there is the issue of transforming the market needs (i.e.: a buyer) into a demand contract that will trigger a supply chain planning process, and ultimately a supply plan. The definition of the demand contract is the result of a negotiation process between the buyers, representing different markets, and the SCA, and it is generally defined in terms of required volumes, prices, and timing for each of the crops. In this part of the research, we explore the decision-making process for both the buyer and the SCA when negotiating a demand contract before the season begins. We model the profit functions for each agent to be able to find their own preference, in terms of the amount of supply options for the buyer to obtain. This model includes the profit function for both participants as considered together as a SC to find the optimal quantity that maximizes the overall profit. By comparing the optimal decisions for both the buyer and the SCA, and the overall optimal as well, we could find the optimal option pricing combination (with respect to the purchase and exercise price) that results in an alignment in each party's profit function in such a way that their optimal decisions correspond to the one that maximizes the SC's profit. Furthermore, we explore the existence of multiple configurations that could result in the alignment of incentives for both parties, and with the inclusion of an additional consideration, such as a minimum expected profit level for each party, we can determine a subset of possible combinations that will be initially acceptable for both parties.

The contribution of this last part of the research is twofold: first, it allows to determine the optimal quantities that a buyer should commit to purchase from the SCA; and second, it allows to determine the option prices (purchase price and exercise price) that maximizes the overall SC's profit while satisfying each party's minimum profit levels.

Chapter 4

PART I: SUPPLY CHAIN ARTICULATION CONSIDERING CONSUMER PREFERENCES

"Local food" movements have gained a lot of traction in the last two decades. Part of the appeal of local food to certain segments of the population rests on perceived environmental benefits such as lower energy and carbon footprint, while promoting economic development of local growers. However, this and other "special denomination" labels such as "organic", "fair-trade" and other, may increase the complexity of an already complex supply chain and result in unintended consequences such as less food affordability and waste.

The supply chains of fresh fruits and vegetables present the added complication, over other food supply chains, of managing the perishability of these products through using special facilities and transportation which together are known as cold chain. While the cold chain preserves the shelf life of the products, it also introduces another level of complexity and results in the use of high levels of energy. Perishability makes the planning and coordination of this supply chain particularly difficult. Thus, special denomination labels may have unintended consequences such as consuming fresh produce that use high levels of fossil-fuels based energy and incentivizing the development of agricultural activities in less-than-ideal places such as urban settings.

In this paper, we explore the effects of the some of these unintended consequences from the perspective of supply chain planning and coordination strategies for matching supply and demand. We base our analysis on models that seek to optimize the procurement of fresh produce directly from different growers in the surrounding regions. This procurement will be in the form of direct connections between the demand points and the growers. These direct connections, or short supply chains, have also been the focus of a lot of attention because they allow the implementation of strategies that result in the efficient operation of the supply chain in terms of metrics such as overall cost, food waste and carbon footprint (Bartolini et. al, 2016).

The development of specific and limited scope short supply chains has been the norm in the recent past, examples of those developments can be found in multiple regions in the form of programs such as community supported agriculture and other subscription programs. However, the efficient deployment of larger scope, more encompassing, direct connections grower-consumer, that include multiple growing regions and multiple demand regions is a complex endeavor that requires careful planning through the judicious use of decision support tools, and the most recent advances of information technology. In this paper we introduce some decision support tools that contribute to the emergence and maturation of efficient supply chains for the direct procurement of special denomination crops, particularly fresh vegetables by making the most efficient connections between a market demand and the suppliers of products with the required characteristics.

One of the underlying premises of special denomination programs is that enough interest exists among the consumers of a region to generate a demand for the deployment of direct supply chains for these products to make economically attractive for growers to embark in the production of those crops meeting the required special denomination. In this paper, we assume that potential buyers, who are procuring produce for specific markets, act according to hard and soft preferences for special denomination crops. A hard preference is one that must strictly be met for the consumer to buy a product, while a soft preference is one that the consumer is willing to relax the denomination if no such a product is in the market or a more attractive price for a substitute product is available. Note that in the case of a soft preference, the market will determine the consumption rather than the buyer enforcing a certain volume to be supplied from local sources. Thus, the preferences limit the feasible choices for potential sources that can be used to satisfy a demand signal. These preferences very often signal the consumers' willingness to pay a higher price for these types of products. Therefore, this or any other consumer preference, should be considered in the planning stage of the supply chain, particularly when deciding from where the crops will be sourced to satisfy a given market signal. To take advantage of this consumer behavior, the consumer's preference can be considered in the planning stages, for example, by either considering different prices, or through a penalization for produce deviating from the targeted consumer preferences. In terms of planning models, these additional considerations would imply either to consider multiple objectives or to incorporate the proper constraints into the models. In either case, this would create sub-optimality conditions (in terms of overall income) with respect to the expected income not subject to these preferences. One of the objectives of the work presented in this document is to account for these additional considerations during the planning stages of the supply chain design.

The tools developed in this work address the problem of identifying and coordinating potential producing regions with the use of optimization-based planning models, particularly in presence of consumer preferences such as benefiting local produce or supporting environmentally friendly practices, in the form of a reduced carbon footprint. This planning process includes the assessment of each candidate region's competitiveness considering their productive potential and available resources, and an assessment of the impact of consumers' preferences in the planning activities and growing locations selection. To quantify this impact, different scenarios are considered such as supply chain profit maximization (with no special consumer preferences), carbon footprint reduction, local production maximization, etc. This tool helps a decision maker, or coordination agent, to select and/or refine the supply chain configuration that aligns the best to his/her needs, according to the market preferences.

4.1 Model Formulation

The model presented below consists of an adaptation and expansion of the tactical planning model presented by Ahumada and Villalobos (2011). On the initial model, they considered a set of growers in a single region with focus on allocating the available land among a set of potential crops with unlimited demand and which expected purchase prices that are either known or can be estimated with a high level of certainty. It is also assumed that the yield (tons/acre), and resources needs (labor, water, etc.) and their availability are known. In in the present work, the original model is expanded to include the perspective of potential buyers who have the need to satisfy certain demand, expressed as weekly volume requirements and have the choice to procure the products needed from multiple potential producing regions. These regions present distinct weather, and production seasons. Furthermore, in the model to be presented we introduce the figure of a coordination agent (Supply Chain Coordinator), whose role is to work with the suppliers to fulfill a certain demand expressed in the form of a contract with the final buyer, in the best manner possible from these potential locations, as depicted on Figure 4-1. We assume that this agent has a fiduciary responsibility to the growers, that is, it operates to provide the most benefits to the growers. It is also assumed if the demand reflected in the contract cannot be fulfilled, then the coordinator will acquire this produce from the spot market. We then expand this model to account for potential special consumer preferences. As an example of these special consumer preferences, we consider preferences that favor local produce and reduced carbon emissions products.

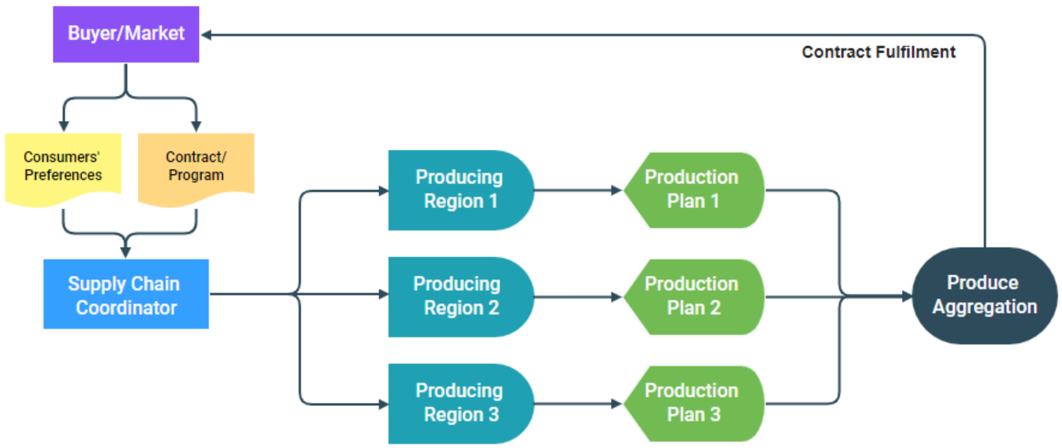


Figure 4-1: Diagram of the Decision-making Process.

The initial model considers a single demand source, in the form of a contract or program from a buyer which the Supply Chain Coordinator must fulfill from multiple potential producing regions. With respect to the considered supply chain configuration, we consider multiple producing regions, a set of processing/aggregation facilities, and the final consumers or destinations. This can be seen on Figure 4-2, where the produce flows from the producing regions to the consumers passing through the packaging facilities. As captured in the figure, the buyer sends a demand requirement to the coordinator, who allocates a production requirement to the potential producing regions. Fresh produce can be grown in different locations and when harvested is shipped to processing facilities, where the produce is consolidated from bulk form coming from the fields into pallets that are shipped to the buyers. The planning model considers the contract in terms of level and timing of the demand and the characteristics of the different producing regions, to render a supply plan with the minimum cost subject to meeting constraints on the regular and stated buyer's product preferences. The solution from the model provides a production plan for each of the selected regions, considering production resources and costs, expected yields, and logistics parameters such as transportation costs and distances.

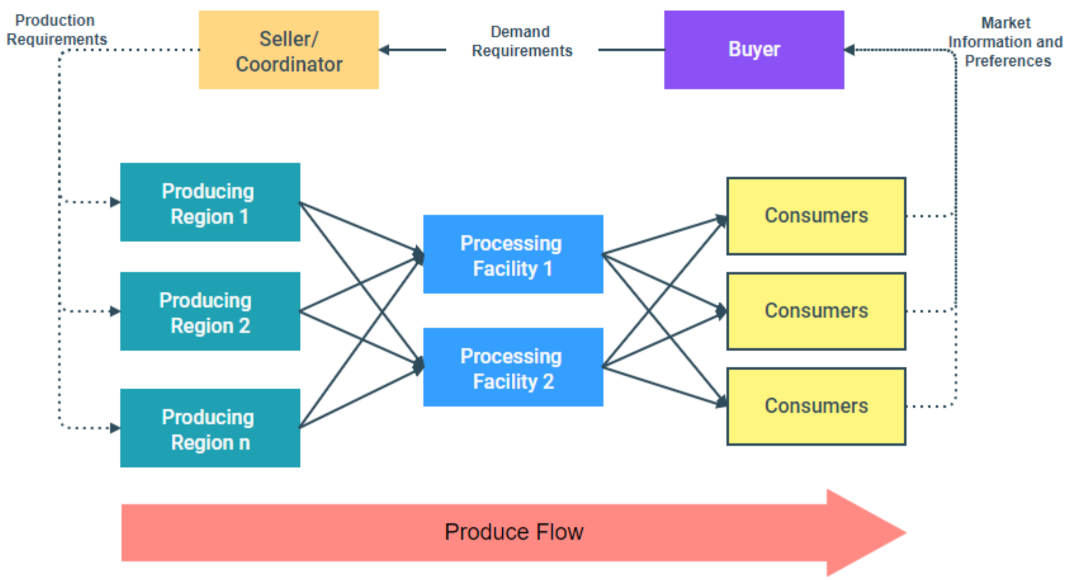


Figure 4-2: Scheme of the Considered Supply Chain, and the Coordination Agents.

The outline of the mathematical formulation of the initial planning model follows.

Model Indices and Sets:

$t \in WEEK$	Planning weeks
$p \subset WEEK$	Planting weeks
$h \subset WEEK$	Harvesting weeks
$j \in K$	Crops

$i \in I$	Destinations or Markets
$f \in F$	Processing Facilities
$l \in L$	Locations where produce can be grown

Model Variables:

$Plant_{j,l,p}$	: Acres of crop *j* planted in location *l* during week *p*
$Harvest_{h,j,l,p}$	: Pounds of crop *j* planted in week *p* being harvested during week *h* in location *l*
$Pack_{f,h,j,l}$	: Pounds of crop *j* packed in facility *f* in location *l* during week *h*
$OPL_{l,t}$	: Labor (permanent) available at location *l* during week *t*
$OPF_{f,t}$	: Labor required at facility *f* during week *t*
$Hire_{l,t}$	: Labor hired at location *l* during week *t*
$Fire_{l,t}$	: Labor dismissed from location *l* during week *t*
$OPT_{l,t}$	: Labor (temporary) hired at location *l* for week *t*
$TransP_{f,h,j,l,p}$	: Pounds of crop *j* planted in week *p*, harvested during week *h* transported from location *l* to facility *f*
$TransC_{f,i,j,l,t}$	: Pallets of crop *j* transported from facility *f* in location *l* to destination *i* during week *t*
$TC_{f,i,j,l,t}$	: (**binary**) Determine if crop *j* is transported from facility *f* in location *l* to destination *i* during week *t*
$Y_{j,l}$	: (**binary**) Determine if crop *j* is planted in location *l*
$Land_{l}$	: Land required to plant in location *l*
$Spot_{i,j,t}$	: Demand of crop *j* supplied to destination *i* during week *t*

$Sell\_mkt\_C_{f,i,j,l,t}$: Pallets of crop *j* supplied from facility *f* in location *l* sold to open market prices in destination *i* in week *t*

$Sell\_con\_C_{f,i,j,l,t}$: Pallets of crop *j* supplied from facility *f* in location *l* sold to contract prices in destination *i* in week *t*

Note: All the previous variables are assumed to be non-negative.

Model Parameters:

$Weight_j$: Conversion from weight to pallets for crop *j*

$LabReqFac_j$: Labor required at the processing facility for crop *j*

$ShelfLife_j$: Shelf-life of crop *j*

$CostPack_j$: Packaging cost for crop *j*

$CostPlant_j$: Cost to plant one acre of crop *j*

$LabPlant_j$: Labor (hours) required to plant one acre of crop *j*

$LabHarv_j$: Labor (hours) required to harvest one acre of crop *j*

$MinLand_j$: Minimum acres to plant of crop *j*, if it is selected

$MaxLand_j$: Maximum acres to plant of crop *j*, if it is selected

$CostLab_l$: Labor cost ($/hr.) for permanent workers at location *l*

$CostHire_l$: Fixed cost to hire a permanent worker at location *l*

$CostLabTemp_l$: Labor cost ($/hr.) for temporary worker at location *l*

$LabMaxTemp_l$: Maximum temporary workers to have at any time at location *l*

$LabMax_l$: Maximum total workers at any time at location *l*

$MaxWeekPlant_l$: Maximum acres to plant in a week at location *l*

$CapPF_f$: Processing capacity (in planning units) at processing facility *f*

$Yield_{p,h,j,l}$: Expected yield for crop *j*, planted in week *p* and harvested in week *h*, at location *l*

$Demand_{i,j,t}$: Demand in pallets of crop *j* requested by the buyer for destination *i* during week *t*

$Price_{t,j,i}$: Price for a pound of crop *j* to be paid by the buyer for destination *i* during week *t*

$PriceSpotSell_{i,j,t}$: Expected price to sell a pound of crop *j* in the open market at *i* during week *t*

$PriceSpotBuy_{i,j,t}$: Expected price to buy a pound of crop *j* from the open market at *i* during week *t*

$LeadTime_i$: Leadtime allowed by the buyer to reach destination *i*

$Time_{f,i}$: Time to transport a unit from facility *f* to destination *i*

$CostTrans_{f,i}$: Transportation cost per unit from facility *f* to destination *i*

H_0 : First week of the harvesting season

H : Last week of the harvesting season

Objective Function:

$maximize$:

$$\sum_{l,j,i,t,f} Sel\_mkt\_C_{j,f,l,i,t} * PriceSpotSell_{t,j,i} + Sell\_con\_C_{j,f,l,i,t} * Price_{t,j,i} - \sum_{l,j,p} Plant_{p,j,l} * CostPlant_{j,l} - \sum_{h,l,j,f} Pack_{l,h,j,f} * \left(CostPack_j + LabReqFac_j\right) - \sum_{l,j,f,i,t} TransC_{l,t,j,f,i} * CostTrans_{f,i} - \sum_{l,t} (OPL_{l,t} * CostLab_l + HIRE_{l,t} * CostHire_l + OPT_{l,t} * CostLabTemp_l) \qquad \text{Eq. 4.1}$$

Constraints:

$$\sum_{j,p} Plant_{j,l,p} - Land_l \leq 0 \qquad \forall l \qquad \text{Eq. 4.2}$$

$$\sum_{p} Plant_{j,l,p} - MinLand_{j,l} * Y_{j,l} \geq 0 \qquad \forall j,l \qquad \text{Eq. 4.3}$$

$$\sum_{p} Plant_{j,l,p} - MaxLand_{j,l} * Y_{j,l} \leq 0 \qquad \forall j,l \qquad \text{Eq. 4.4}$$

$$\sum_{j} Plant_{j,l,p} \leq MaxWeekPlant_l \qquad \forall l,p \qquad \text{Eq. 4.5}$$

$$Harvest_{p,h,j,l} - Yield_{p,h,j,l} * Plant_{p,j,l} \leq 0 \qquad \forall j,h,l,p \qquad \text{Eq. 4.6}$$

$$\sum_{j,p:p=t} LabPlant_{j,l} * Plant_{p,j,l} + \sum_{h:h=t} LabHarv_{j,l} * Harvest_{p,h,j,l} - OPL_{l,t} - OPT_{l,t} \leq 0 \qquad \forall l,t \qquad \text{Eq. 4.7}$$

$$HIRE_{l,1} - OPL_{l,1} = 0 \qquad \forall l \qquad \text{Eq. 4.8}$$

$$HIRE_{l,t} - FIRE_{l,t} - OPL_{l,t} + OPL_{l,t-1} = 0 \qquad \forall l,t : t > 1, t < H_0 \qquad \text{Eq. 4.9}$$

$$HIRE_{l,H_0} - OPL_{l,H_0} + OPL_{l,t-1} = 0 \qquad \forall l,t : H_0 \leq t \qquad \text{Eq. 4.10}$$

$$\sum_{t} OPT_{l,t} - LabMaxTemp_l \leq 0 \qquad \forall l \qquad \text{Eq. 4.11}$$

$$\sum_{t} HIRE_{l,t} - LabMax_l \leq 0 \qquad \forall l \qquad \text{Eq. 4.12}$$

$$OPL_{l,t} - OPL_{l,t-1} + FIRE_{l,t} \geq 0 \qquad \forall l,t: t > H_0 \qquad \text{Eq. 4.13}$$

$$\sum_{f} TransP_{p,h,j,l,f} - Harvest_{p,h,j,l} \leq 0 \qquad \forall p,h,j,l \qquad \text{Eq. 4.14}$$

$$\sum_{p:p\leq h} \frac{TransP_{p,h,j,l,f}}{Weight_j} - Pack_{f,h,j,l} = 0 \qquad \forall f,h,j,l \qquad \text{Eq. 4.15}$$

$$\sum_{j} Pack_{f,h,j,l} \leq CapPF_f \qquad \forall f,h,l \qquad \text{Eq. 4.16}$$

$$\sum_{i} TransC_{f,i,j,l,h} - Pack_{f,h,j,l} = 0 \qquad \forall f,h,j,l \qquad \text{Eq. 4.17}$$

$$\sum_{f,i,j} TransC_{f,i,j,l,t} \leq 0 \qquad \forall t > H \qquad \text{Eq. 4.18}$$

$$\sum_{f,l} Sell\_con\_C_{f,i,j,l,t} + Spot_{i,j,t} = Demand_{i,j,t} \qquad \forall j,i,t \qquad \text{Eq. 4.19}$$

$$Time_{f,i} * TC_{f,i,j,l,t} \leq LeadTime_{i} \qquad \forall f,i,j,l,t \qquad \text{Eq. 4.20}$$

$$Sell\_mkt\_C_{f,i,j,l,t} + Sell\_con\_C_{f,i,j,l,t} - TransC_{f,i,j,l,t} \leq 0 \qquad \forall f,i,j,l,t \qquad \text{Eq. 4.21}$$

Equation 4.1 represents the profit to be maximized, consisting of the sales from the contract and the market, while accounting for the costs of planting, packaging, transportation, and labor in each of the locations. Equation 4.2 limits the land to plant to what is available at each location. Equations 4.3 and 4.4 binds the minimum and maximum acreage to plant of a crop if selected. Equation 4.5 limits the maximum weekly acres to plant. Equation 4.6 limits the harvested volume based on the expected yields for that week. Equations 4.7 through 4.13 are used to manage the labor required to perform the required field tasks each week. Equation 4.14 ensures that no more than what is harvested is transported to the processing facility. Equation 4.15 converts the total weight into the equivalent logistics units needed to transport the product. Equation 4.16 limits the amount to be processed to the capacity of each processing facility. Equations 4.17 and 4.18 represent conservation of flow restrictions which ensure that the volumes being transported to the customers correspond to the processed units, and that no product is being shipped once the harvesting season is finished. Equation 4.19 ensures that the consumer's demand is satisfied from either the crop harvested or from the product acquired in the spot market. Equation 4.20 ensures that the allowed lead-times from each destination are satisfied. Finally, Equation

4.21 limits the total product shipped to the consumer, either to satisfy the contract or to the open market, by what was previously harvested. Note that this is the initial basic planning model used for this work. This model is modified to properly include, model, and compare different metrics and consumer preferences through the inclusion of new variables and constraints. These new model elements are introduced and explained next.

To be able to compare the performance of a supply chain configuration under different scenarios and consumer preferences, the basic model is expanded to account for these preferences and other restrictions. The scenarios considered in this work are:

1. **No special denomination preferences or restrictions**

   This corresponds to the base case, where no special considerations or preferences are included or required from the buyer. The model used for this scenario, is the base model explained above. The purpose of this scenario is to analyze the benefit of having complementary producing regions when meeting the contract terms with production from different growers.

2. **Hard preference for local produce (in the model's constraints)**

   This first expansion of the model captures the consumer's preference for local sources. This is implemented as a requirement on a certain percentage of the production that must be supplied from locations that are within a certain distance range (i.e.: 40% of the produce must come from a radius of 100 miles). Two main parameters are affecting these constraints: the percentage of the demand affected which is represented by the constraint (λ), and the distance at which a producing region is considered local ($DistLoc$). Figure 4-3 below shows the area of coverage for six locations under a definition of local produce as 50, 150, and 300 miles. The map shows six locations: Yuma, Tucson, and Phoenix in Arizona; Las Cruces and Albuquerque in New Mexico; and Aspen in Colorado, which are the six regions that we use later as part of the case study introduced in the next section of this document. The circles around each one of these cities represent the boundaries for definition of "local food" drawn using the different definitions. The map illustrates how the flexibility of each one of the cities has when changing the distances used to denominate food as local.

Figure 4-3: Example of the Area of Coverage under a Definition of Local Produce of 50, 150, and 300 Miles.

To expand the planning model to account for this preference it is necessary to introduce new variables and constraints. These are explained next.

<u>Nomenclature of added model variables and parameters</u>:

- $TransLoc_{f,i,j,l,t}$: (variable) Number of pallets of crop *j* to be shipped from facility *f* in region *l* to consumer *i* at time *t* considered local production.
- $IsLoc_{i,l}$: (binary variable) Define if location *l* is considered local or not for consumer *i*.
- $Dist_l$: (parameter) Distance between location *l* and the market.
- $DistLoc$: (parameter) Distance used to label a product as "local".

The new restrictions added to the model to capture the preference for local produce are the following:

$$DistLoc - Dist_l \geq -M * (1 - IsLoc_{i,l}) \qquad \forall l \qquad \text{Eq. 4.22}$$

$$DistLoc - Dist_l \leq M * IsLoc_{i,l} \qquad \forall l \qquad \text{Eq. 4.23}$$

$$TransLoc_{f,i,j,l,t} \leq M * IsLoc_{i,l} \qquad \forall f,i,j,l,t \qquad \text{Eq. 4.24}$$

$$TransLoc_{f,i,j,l,t} \leq Sell\_con\_C_{f,i,j,l,t} \qquad \forall f,i,j,l,t \qquad \text{Eq. 4.25}$$

$$\sum_{f,l} TransLoc_{f,i,j,l,t} \geq \lambda * \sum_{t} Demand_{i,j,t} \qquad \forall i,j \qquad \text{Eq. 4.26}$$

Where Equations 4.22 and 4.23 identify if a region can be labeled as "local" based on its distance to the market and the definition of local producer 1. Equations 4.24 and 4.25 ensure that the maximum amount of produce that can be shipped labeled as "local" from each location is limited by the total produce being supplied from that location. Finally, Equation 4.26 ensures that the λ percentage of the demand is supplied with local production.

3. **Soft preference for local produce (in the objective function)**

This alternative expansion of the model also captures the preference for local production, but not as a hard requirement (in the model constraints) but as a penalization to produce being supplied from farther locations. This is included in the model as an additional cost or price penalization on crops supplied from outside of certain limits (based on distance) or can be seen as consumer willing to pay less for these products.

<u>Nomenclature of added model parameters</u>:

- γ: (parameter) Penalty factor per pallet of produce being supplied from outside the "local" area.

The penalization term on the objective function takes the form of:

$maximize$:

$$(Original\ Objective\ Function) - \gamma * \left(\sum_{f,i,j,l,t}\left(Sell\_con\_C_{f,i,j,l,t} - TransLoc_{f,i,j,l,t}\right)\right) \quad \text{Eq. 4.27}$$

Where the term inside the sum corresponds to the volume of produce being supplied from outside the "local" boundaries.

4. Penalization on carbon emissions

The third expansion of the base model consists of including the preference for reduced carbon emissions related to fresh produce. In this case we incorporate this as a "soft" preference in the form of a penalization on the carbon footprint of the total supplied products. Note that carbon emissions are produced mainly at two parts of the supply chain: field operations and in the cold chain logistics to move and store the product from the production to the consumption point. With respect to the logistics part, we only focus on transportation by considering a per-mile emissions estimation. These factors together are penalized by a parameter β in the model objective function as depicted below.

<u>Nomenclature:</u>

- $C02\_plant_{j,l}$: (parameter) Emissions per acre of crop j planted and grown at location l
- $C02\_mile$: (parameter) Emissions per mile per pound being transported.
- β : Penalization parameter for emissions

The original objective function is expanded to:

$maximize$:

$$(Original\ Objective\ Function) - \beta * \left(\sum_{p,j,l} Plant_{p,j,l} * CO2\_plant_{j,l} + \sum_{f,i,j,l,t} TransC_{f,i,j,l,t} * Dist_l * CO2\_mile\right) \quad \text{Eq. 4.28}$$

Note that the CO2 emissions parameters can be estimated based on the average emissions of CO2 per gallon of diesel, the mileage per truck and estimated load (in lb.) for a refrigerated truck.

With these four different models we are able to incorporate and analyze the effect of consumers' preferences in the decisions related with the Supply Chain design and coordination. These models also allows us to obtain insights on the competitiveness of the different producing regions and the supply strategy required to satisfy the different demand and preferences. In the next section we introduce a case study used to analyze how the inclusion of non-traditional consumer's preferences can impact the supply chain configuration and performance.

4.2 Case Study

To validate and analyze the proposed models, we present a case study for each of the scenarios considering multiple production locations and crops. We consider six producing regions, in three states: Albuquerque, NM; Aspen, CO; Las Cruces, NM; Phoenix, AZ; Tucson, AZ; and Yuma, AZ. These regions were selected as they are relatively close to each other and present different climate conditions which translate to potentially complementary production seasons. Climate conditions have a direct effect on the expected yields obtained for different planting timing. In this paper we estimate yields based on an expanded version of the SIMPLE yield model (Zhao et al. 2019) introduced by Ahumada et al. (2021). As an example, Figure 4-4 presents the weekly expected yields (lb./acre) for tomatoes that can be expected throughout the harvesting season for each of the six locations previously introduced, considering their local environmental conditions (weather and solar radiation). It can be observed that at the beginning of the season, regions such as Phoenix, AZ and Tucson, AZ provide the highest yields. Then, there is a transition towards Albuquerque, NM and Las Cruces, NM which have longer harvesting seasons. Finally, the availability of harvest moves to Aspen, CO, which is the location that can achieve higher yields during the summer season. These complementarity of productive potentials present potential advantages when planning how to supply the market demand of a particular location. Depending on the volumes, prices, costs, and production seasonality, different regions may be better positioned to produce and deliver at a given time; and multiple regions can complement each other to maximize the benefits of a group of growers working together. Note that each of the selected locations have different local conditions such as available resources and their costs which affect the volumes and costs that they can supply and thus, their competitiveness when supplying different markets.

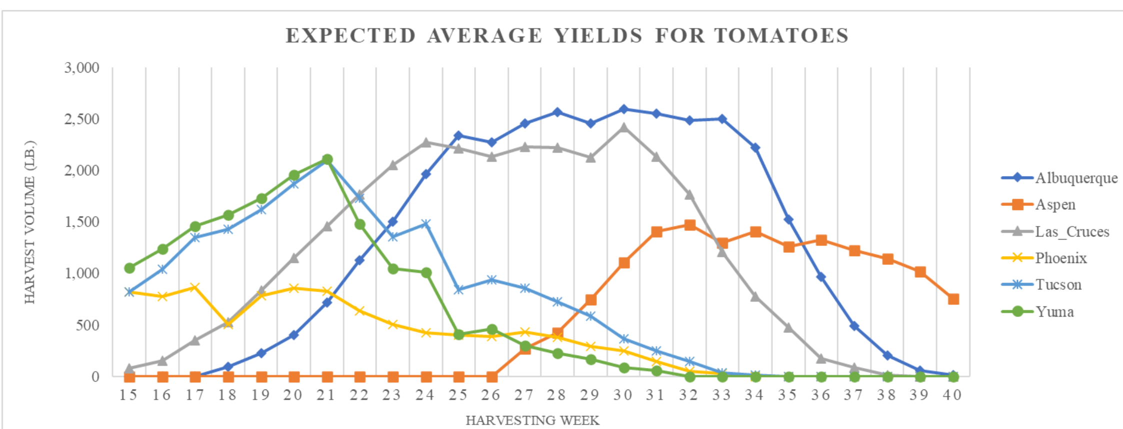


Figure 4-4: Total Yield Estimates for Tomatoes in Six Complementary Regions.

For this case study, we considered Las Vegas, NV as the location whose demand needs to be fulfill through contracts issued by a buyer. This fictitious buyer is requesting a certain volume of produce throughout the year in the form of a contract. This contract represents the aggregated demand, prices, and preferences of the consumers in the targeted market, in this case Las Vegas. The portfolio of crops being considered consists of green beans, cauliflower, celery, cucumbers, lettuce, bell peppers, and tomatoes. It is assumed that the total demanded volumes and prices for each crop are known in advance and the same for the different scenarios to be analyzed, so that the only change between the different scenarios is given by the consumer's preferences. The weekly prices and volumes considered under the contract are show in Figure 4-5.

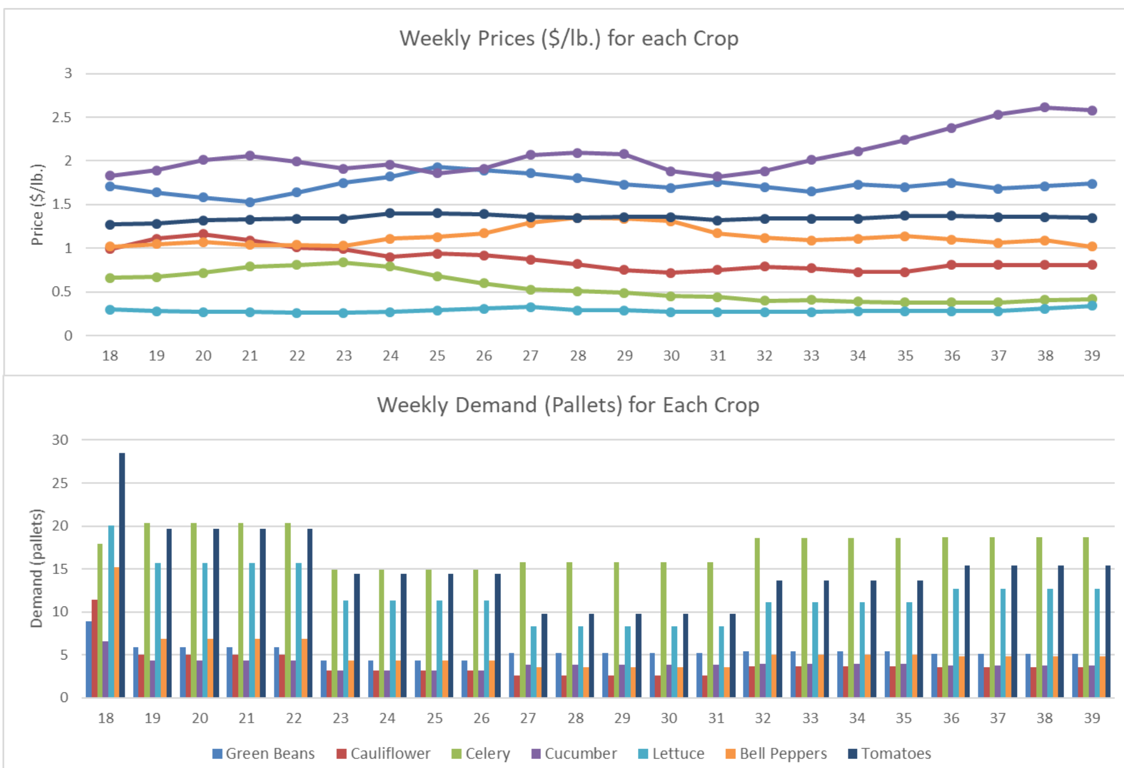


Figure 4-5: Contract (Volume and Prices) Used to Represent the Market Demand.

We also assume that if there is demand that cannot be supplied economically from any of the producing regions, it will be supplied from the open market at the destination. This will result in incurring in a higher cost for the locally grown produce obtained in the open market, which it was assumed to be 10% higher than the price if the same product had been obtained under the contract with the buyer (Onozaka and McFadden, 2011). Thus, given the distance between the producing regions and the market, certain regions may have an advantage, particularly when the effect of some customers preferences on different scenarios is evaluated. Table 4-1 includes the distance from each of the producing regions to Las Vegas, NV. This distance becomes relevant when considering the preference for "local" produce, and the distance used to label a region as "local" producer.

Table 4-1: Distance from Each of the Producing Regions to the Market.

Region	Distance from Market (miles)
Albuquerque, NM	576
Aspen, CO	624
Las Cruces, NM	690
Phoenix, AZ	301
Tucson, AZ	414
Yuma, AZ	295

Based on the assumptions of the previously introduced case study, several experiments were designed to test and validate the proposed models. The main goal of the analysis was how the complementary conditions of the different regions interact and become relevant with or without the presence of consumer preferences. Another goal was to assess the impact of these preferences on profitability of each of the candidate region under the different scenarios. The experiments considered for this work are the following:

1. **Experiment 1: No special denomination preferences from the consumers, producing only in Arizona.**

In this experiment we run the planning model by considering only Arizona (AZ) as a potential producing region. This will result on the best solution of how the contract can be supplied from growers in three cities in Arizona: Phoenix, Tucson, and Yuma. Each of these cities has specific resources and conditions (i.e., expected yields) that will determine how each city can contribute to the contract fulfilment.

2. **Experiment 2: No special denomination preferences from the consumers, producing only in New Mexico.**

   In this experiment we run the planning model by considering only New Mexico (NM) as a potential producing region. This will result on the best solution of how the contract can be supplied from growers in three cities in New Mexico: Albuquerque, and Las Cruces. Each of these cities has specific resources and conditions (i.e., expected yields) that affects how each city can contribute to the contract fulfilment.

3. **Experiment 3: No special denomination preferences from the consumers, producing only in Colorado.**

   In this experiment we run the planning model by considering only the state of Colorado (CO) as a potential producing region. In this case, the only region considered in the state of Colorado is Aspen, and the model provides the most efficiency producing plan to fulfil the contract considering its available resources and conditions (i.e., expected yields).

4. **Experiment 4: No special denomination preferences from the consumers, producing in all regions.**

In this case we run the model including all locations simultaneously (ML) and compare the results. In this experiment the decision maker corresponds to the Supply Chain Coordinator who plays the role of a coordination agent who wants to maximize the total profit captured by the growers as a group. We refer to the scenario with all regions included in the model as the coordinated solution. This experiment allows to assess the benefits of collaboration between multiple producing regions, particularly in presence of complementary harvesting seasons and a fixed minimum demand requirement.

5. **Experiment 5: Consumer preference for Local Produce (hard preference).**

   In this case, we explore the case when the buyer prefers produce labeled as “local”. For this experiment, we run the model for the coordinated solution with the preference for local produce as a hard preference (in the constraints). For this we use different values for the percentage of the demand required to be supplied from local sources (λ), and the distance under which a producing region is considered a local producer ($DistLoc$). The values for the parameters used in this experiment are depicted on Table 4-2:

Table 4-2: Parameters for Experiment 5, changing $\boldsymbol{\lambda}$ and *DistLoc*.

Parameter	Lower Limit	Upper Limit	Step-size
λ	0	1	0.05
$DistLoc$ (miles)	250	725	25

6. **Experiment 6: Consumer preference for Local Produce (soft preference).**

   This experiment consists of running the model for the coordinated solution incorporating the preference for local produce as a soft preference by adding it to the objective function in the form of a penalization factor (γ). A value of zero means that no penalization for buying "nonlocal" food is applied. The values for γ and distance to the market ($DistLoc$) used for this experiment are shown on Table 4-3, and corresponds to values such that, in the upper limit, the stability of the solution is achieved (increasing the value of γ does not change the solution):

Table 4-3: Parameters for Experiment 6, changing $\boldsymbol{\gamma}$ and *DistLoc*.

Parameter	Lower Limit	Upper Limit	Step-size
γ	0	2,000	100
$DistLoc$ (miles)	250	725	25

7. **Consumer preference for reduced carbon emissions.**

   For this experiment, we run the model for all locations including a preference for reduced carbon footprint as a penalization in the objective function. The values for penalization factor for carbon emissions (β) used for this experiment are shown on Table 4-4:

Table 4-4: Parameters for Experiment 7, changing $\boldsymbol{\beta}$.

Parameter	Lower Limit	Upper Limit	Step-size
β	0	50	1

The results of the different experiments are analyzed and compared with respect to different qualitative and quantitative metrics. On the qualitative metrics, the analysis focuses on the selection of different regions, the revenue allocation to each region and how the contract is being supplied. In a more quantitative aspect, some metrics are used in the analysis such as total profit and costs observed, and costs incurred for a given supply chain configuration. For these experiments, we assume that the total profit is captured by the overall supply chain, without specifically determining how it is distributed among the producing regions. Note that under the scheme presented in this work, all the demand stipulated by the contract needs to be met, requiring the collaboration of multiple growers. Usually, growers are compensated based on the crops they deliver and the corresponding prices: if a grower only delivers tomatoes, he will be compensated based on the volume and price for that crop; whereas if a second producer delivers cucumber and lettuce, he will be compensated accordingly. This scheme does not account for the extra benefit of coordinating operations to supply the whole contract, and how this profit is distributed. The design of a revenue distribution mechanism for the coordinated supply chain corresponds to a different problem that has its own complexities, and it is out of the scope of this work.

In next section the main results obtained from the different experiments are presented. We also present some insights about the significance of these results and the impact the different scenarios have on the solution.

4.3 Results Analysis

C# integrated with Gurobi integrated as a solver were used to find solutions to the optimization models associated with the different experiments. We ran all the experiment on a system equipped with an Intel Core i5-8500 @ 3.00 GHz processor, and 16GB of RAM. Table 4-5 gives a summary of the resulting model complexity. We can observe that for experiments consisting only of a single region (Experiment 1, 2, and 3), the problem size is relatively small, since each of the locations is considered individually. Thus, with just relatively few iterations the problem is solved to optimality. When all the locations are considered under the coordinated scenario (Experiment 4), the resulting model size is slightly larger, since more iterations are required to achieve optimality. Still, for

Experiments 1, 2, 3, and 4 all the model runs were solved within 1 second. Different is the case when we start adding consumer preferences in Experiments 5, 6, and 7 where the model complexity is a bit higher resulting and requires higher computational times. We describe next the main results and insights obtained from running the experiments.

Table 4-5: Model Complexity for the Different Experiments.

Experiment	Number of Variables	Number of Constraints	Iterations	Computational Time (s)
Exp. 1	7,354	6,757	5,304	0.5
Exp. 2	5,755	5,384	5,149	0.4
Exp. 3	1,676	1,490	1,565	0.1
Exp. 4	14,787	13,519	13,110	1.0
Exp. 5	11,386	13,526	14,627	2.4
Exp. 6	14,573	13,495	14,303	2.4
Exp. 7	14,753	13,502	6,772	2.1

First, from Experiments 1, 2, and 3 we determine that if the contract, without additional consumer preferences, is to be filled from only one of the possible locations, the expected profits are $606,915, $599,471, and $184,533 for AZ, NM, and CO, respectively. It is important to note that for this experiment, because of the timing of the harvesting periods, none of the regions can individually supply all the demand. We notice that the maximum volume of demand covered is 75% when the contract is supplied only from Arizona. We also notice that a minimum of 24% of the contract is filled if only production from Colorado is used. Given each region's conditions, if only a single region is chosen by the supply chain coordinator to fill the contract, then it will be necessary to obtain the extra produce from the open market to meet the contract, incurring in extra costs. Furthermore, in the scenario of all regions being considered as candidates to produce (Experiment 4), a maximum profit of $755,862 is achieved. This corresponds to a 92% contract fulfillment being captured by the growers and only 8% with purchases in the spot market. Under this scenario the coordination agent is taking advantage of the complementary production conditions of the multiple regions to maximize the volume of the contact to be captured by these growers. This can be observed on Figure 4-6 that shows the number of pallets being shipped from each producing region in the coordinated scenario in Experiment 4. We can also see that is to the advantage of the overall group that certain regions specialize in some crops, such as celery in Las Cruces, NM and Phoenix, AZ; while other regions a larger variety of crops such as the case Albuquerque, NM, Aspen, CO, and Tucson, AZ. The summary of the results obtained from the first four experiments are presented on Table 4-6.

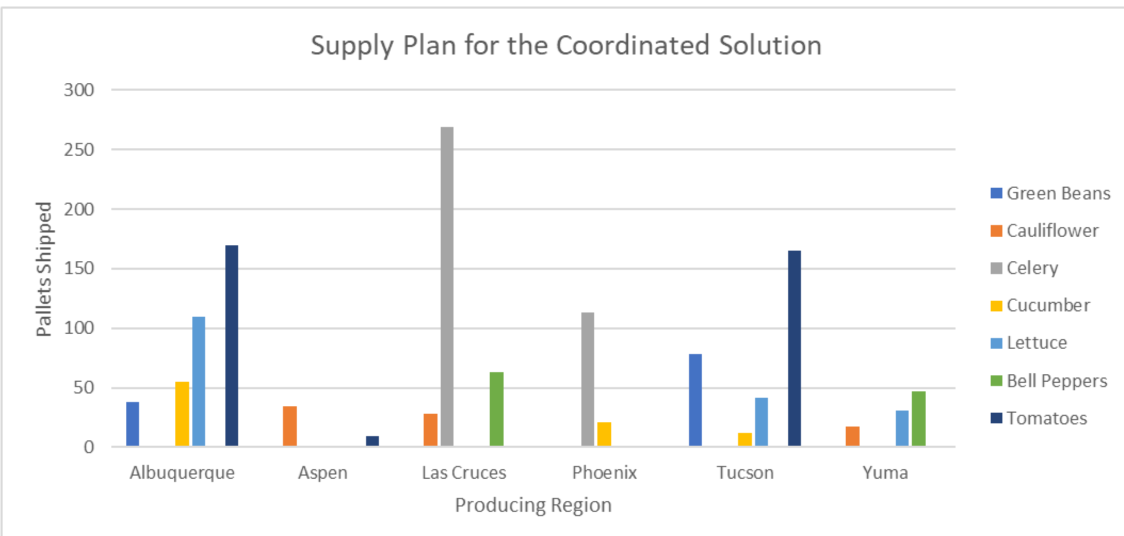


Figure 4-6: Number of Pallets Shipped from Each Production Region in the Coordinated Scenario (Experiment 4).

Given that for Experiments 1, 2, and 3 all the planning and production activities are executed within the corresponding region, without considering partnering with other regions, the model is restricted to find the best solution given the resources and costs of the locations within that region. As observed in Table 4-6, metrics such as the expected profits for each region, the average profit per acre, and how the contract is supplied is also affected from where the contract is to be supplied. Note, with respect to the percentage of the contact being captured by the growers, when each region is supplying the contract alone, the percentage of the contract to be captured is of 75%, 72% and 24% for AZ, NM, and CO, respectively. When considering the best solution considering that all regions can supply products (Experiment 4) and the optimization model determine the best supply combination, the average profit per acre of $13,179, and a contract fulfilment level of 92% using production from the different growers of the participating regions. Note that when looking at the individual profits expected for each of the producing regions, one can see that some locations such as Aspen, Las Cruces, and Yuma will receive lower total profits when they participate in the coordinated scenario (ML), than if they supplied the products individually, without the coordinated participation of the other regions. This is true if we only consider the profit resulting from the contract without accounting for the efficiency in the use of available resources, such as the land. If one analyzes how the land in each location is used, one can see that there is a significantly smaller amount of land required for each of these locations under the ML scenario: in the case of Tucson, AZ there is a land usage reduction from 21 acres to 15 acres in the coordinated scenario; for Las Cruces, NM the reduction is from 28 acres to 8 acres. This can be seen as an additional benefit for these locations as they may use the additional available land for other type of contracts (i.e.: produce for the open market). This suggests that the decision of allocating the demand to one, or multiple, locations will not only depend on the individual profits that can be achieved as there is some indirect hidden value on how efficiently the opportunity can be captured. This type of coordinated solution is more efficient from the perspective of resources utilization in each of the producing regions, thus more environmentally friendly.

Table 4-6: Summary of Results from Experiments 1, 2, 3, and 4.

Region	Metric	Albuquerque	Aspen	Las_Cruces	Phoenix	Tucson	Yuma	Total
AZ (Exp. 1)	Land	0	0	0	27	21	5	54
	Income	$ -	$ -	$ -	$ 428,126	$ 252,108	$ 68,792	$ 749,026
	Total Cost	$ -	$ -	$ -	$ 69,882	$ 59,069	$ 12,986	$ 141,937
	Profit	$ -	$ -	$ -	$ 358,244	$ 193,039	$ 55,807	$ 607,089
	$/Acre	$ -	$ -	$ -	$ 13,060	$ 9,229	$ 10,250	$ 10,846
NM (Exp. 2)	Land	9	0	28	0	0	0	37
	Income	$ 191,311	$ -	$ 520,696	$ -	$ -	$ -	$ 712,007
	Total Cost	$ 20,814	$ -	$ 90,111	$ -	$ -	$ -	$ 110,925
	Profit	$ 170,497	$ -	$ 430,586	$ -	$ -	$ -	$ 601,082
	$/Acre	$ 19,961	$ -	$ 15,374	$ -	$ -	$ -	$ 17,667
CO (Exp. 3)	Land	0	33	0	0	0	0	33
	Income	$ -	$ 284,273	$ -	$ -	$ -	$ -	$ 284,273
	Total Cost	$ -	$ 98,568	$ -	$ -	$ -	$ -	$ 98,568
	Profit	$ -	$ 185,705	$ -	$ -	$ -	$ -	$ 185,705
	$/Acre	$ -	$ 5,626	$ -	$ -	$ -	$ -	$ 5,626
All Regions (Exp. 4)	Land	12	4	8	6	15	6	49
	Income	$ 342,156	$ 25,091	$ 128,540	$ 87,116	$ 255,117	$ 48,927	$ 886,947
	Total Cost	$ 31,161	$ 10,894	$ 18,297	$ 12,926	$ 43,728	$ 14,003	$ 131,009
	Profit	$ 310,995	$ 14,197	$ 110,243	$ 74,190	$ 211,389	$ 34,924	$ 755,938
	$/Acre	$ 26,876	$ 3,931	$ 14,453	$ 13,422	$ 14,506	$ 5,884	$ 13,179

Captured Volume	1,064
Total Volume	1,420
% captured	75%
Total Profit	**$ 606,915**

Captured Volume	1,023
Total Volume	1,420
% captured	72%
Total Profit	**$ 600,687**

Captured Volume	343
Total Volume	1,420
% captured	24%
Total Profit	**$ 184,533**

Captured Volume	1,301
Total Volume	1,420
% captured	92%
Total Profit	**$ 755,862**

These results showed the benefits of coordinating multiple regions, particularly in presence of complementary production capabilities, where regions are allocated to what they are more efficient in producing. In the previous experiments, we only considered the demand as a price and volume vector that must be satisfied from one or more of the potential producing regions. This setting is usually a common case, but as explained before there are current trends that indicate that retail and consumers are given preference to some other features of the produce such as local production or reduced carbon footprint. The purpose of the following experiments is to explore how these preferences affect the supply chain configuration and the competitiveness of the potential regions.

In Experiment 5, the inclusion of a preference for local produce as a supply requirement (a percentage of the demand must be satisfied from local sources) in the form of a hard preference is considered. This preference is modeled by the inclusion of the percentage of the demand that must be satisfied from local production (λ), and the definition of “Local Produce” ($DistLoc$). In Figure 4-7 a summary of the effect of the λ parameter on the results is presented. We can observe, that given their location and weather, locations such as Albuquerque, NM and Tucson, AZ are well positioned to capture most of the profits independently of the percentage of the demand required to be supplied from local sources. But, depending on the values of λ, growers in Albuquerque, NM may be exposed to receive less benefits because other regions, such as Phoenix, AZ will become better positioned to supply part of the demand for that market preferences (as seen in the center are of Figure 4-7) as the definition of the consumer preferences change.

The effect of the definition of the distances to be used to label a product as a “Local Produce” can be observed in Figure 4-8. We observe that Albuquerque, NM is well positioned to capture most of the profits under any definition of distance of “local produce”, while for some of the regions this definition will have a greater impact on their profits. Note that under a very limiting definition of local produce (250 miles), none of the candidate regions fall under this distance requirement to supply the targeted market (Las Vegas). A direct effect of changing this definition can be observed particularly for the locations in Arizona: Phoenix, Tucson, and Yuma. When the definition of local produce is increased from 275 miles to 300 miles, the competitiveness (products shipped from) of Tucson is reduced, as Yuma becomes better positioned to supply a higher part of the contract, as it now falls under the definition of local producer. This effect on Yuma’s position is lost when the definition of local produce is increased to 325 miles, under which Phoenix, AZ becomes part of the allowable sourcing regions, thus taking part of the allocation of products previously captured by Yuma. This effect is reversed when the definition of local production is increased from 400 miles to 425 miles, as now Tucson also becomes part of the regions considered local producers. These results suggest that the definition of which crops are considered "Local Produce" will have a direct impact on the competitiveness of the producing regions. Furthermore, depending on the definition of "local" to be used by a certain market, it may be convenient for a region to supply that specific market or another whose "local" definition encompasses that producing region. The combined effect of both parameters is show in Figure 4-9 for each of the candidate locations, where we can observe that locations such as Albuquerque or Las Cruces are better positioned to supply a market with a strong preference for local produce, while regions such as Aspen, Phoenix or Yuma are competitive in a few specific cases of how this preference is designated.

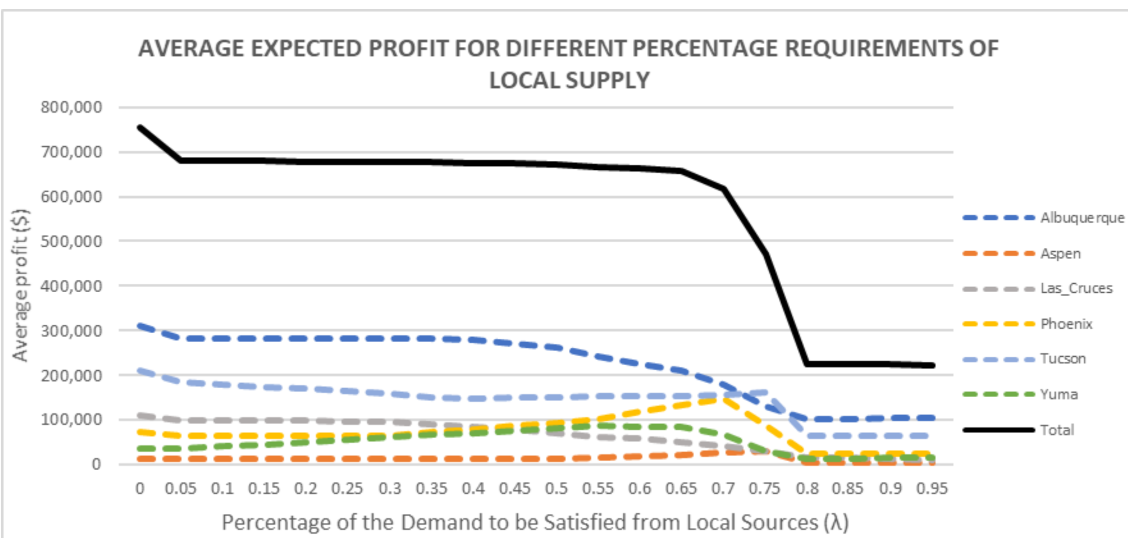


Figure 4-7: Effect of the Percentage of the Demand Required to Be Supplied from Local Sources (Lambda) on the Expected Profits (Experiment 5).

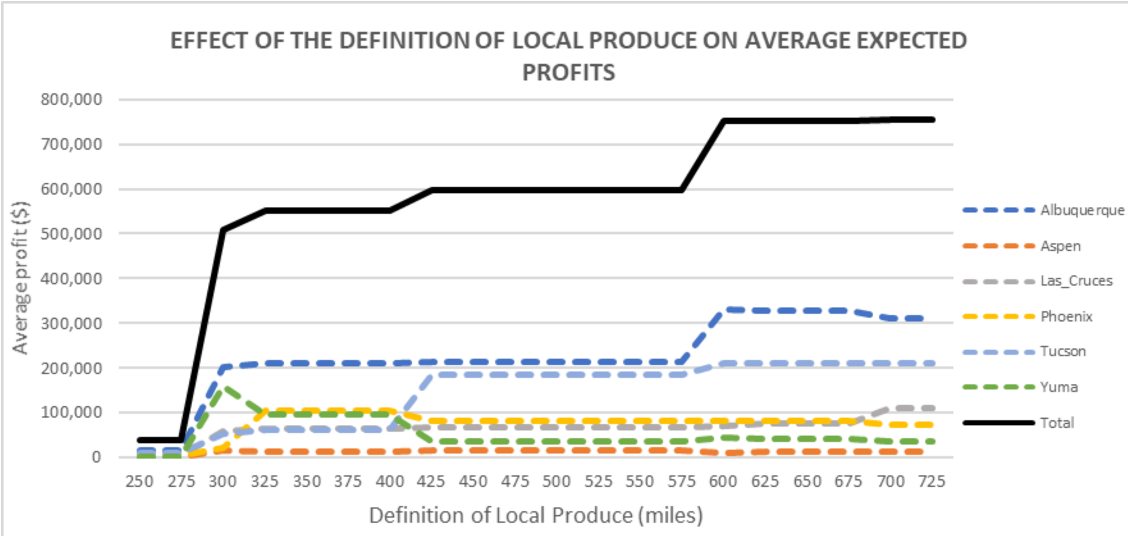


Figure 4-8: Effect of the Definition of Local Produce (Distance in Miles) on the Expected Profits (Experiment 5).

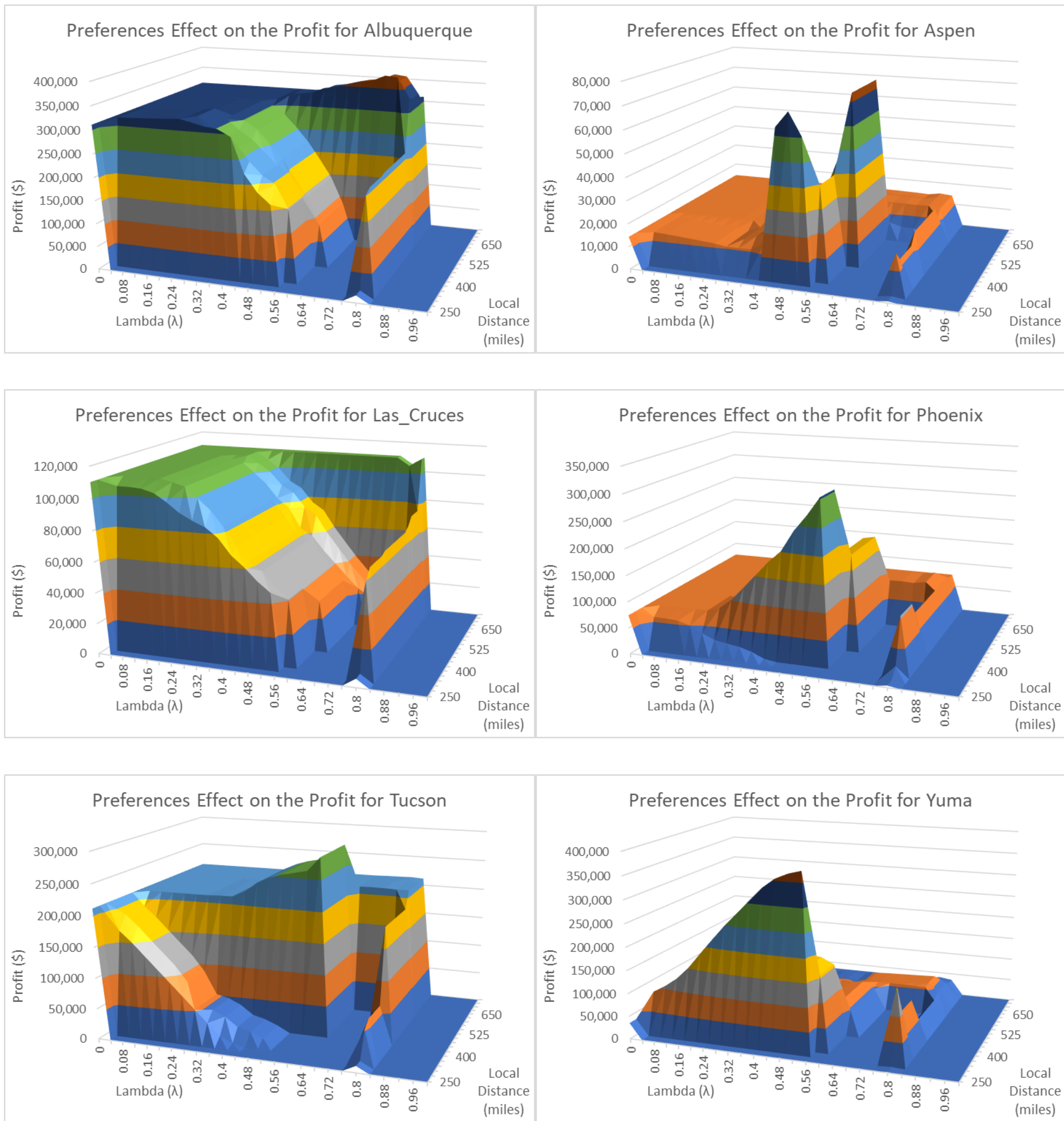


Figure 4-9: Combined Effect on the Profits for Experiment 5.

When the local produce preference restriction is "soften" by considering it in the objective function in the form of a penalization (Experiment 6) of the income, the results obtained are different from those obtained when this preference was represented as a hard constraint, since now, the model can violate what was before a hard restriction on the source of the supplied product. The results obtained for this experiment are summarized in Figure 4-10, which shows that when there is no penalization for non-local produce, the results look very similar to those obtained on Experiment 5. But when we start increasing the penalization term γ to favor local sources, then the results show how the competitiveness of the different regions considered start to change. For instance, Las Cruces, NM, being the farthest to the targeted market, suffers a quick loss of its competitiveness. Albuquerque, NM and Tucson, AZ also start losing their market share as the penalization is increased, but at a slower rate. Phoenix, AZ, being closer to the market, quickly receives a better position increasing its profit substantially at the left side of Figure 4-10. Interestingly, the closest location to the market (Yuma, AZ) observes a fast increase on its profit, but given the available resources and expected yields in the region it does not gain considerable advantage when we keep increasing the penalization term.

Besides the individual effects that the penalization may have on each of the locations, there may even be a negative effect in the whole supply chain profit as seen in Table 4-7. Even if this term does not affect the price of the products, it affects the competitiveness of the whole supply chain, as some of the produce will not be "as desirable" for the market. This will result on less production being required and less demand being captured by these producing regions. These results suggest that the penalization term will influence the coordinated production plan, affecting the profitability and the regions chosen to supply products to the targeted region. Note that this penalization term can be directly related to the degree of preference that the consumers may have: a low value when consumers are not very concerned about local produce, and a higher penalization term in the case of a high preference for local produce by the consumers. Similar is the case of the definition of Local Produce as can be observed in Figure 4-11, depending on how "local" is defined, the planning decisions will be different. Since this may have unintended consequences on the resulting supply chain performance such as less availability or more expensive products, the definition of "local" should be carefully analyzed by each region, since a definition that may be appropriate for one region given its local characteristics, the same definition may not be appropriate at all for another region. In fact, the effects of a definition of "local" may change throughout the season and across seasons. The latter is particularly true under the presence of climatic changes.

The results from Experiments 5 and 6 show how the preference for Local Produce can affect the competitiveness of a supplying region. Furthermore, having an unclear definition of what is considered local may affect the development of growers in remote locations, even if there is more availability for land and water. If the label "Local" is very restrictive then there is an incentive for growers to move their operations close to the urban centers, particularly large cities with some unintended consequences such as competing for land, water and other resources with the residents and business of the cities, considerably increasing the cost of production. Therefore, it is important to try to understand what drives the preference for Local Produce.

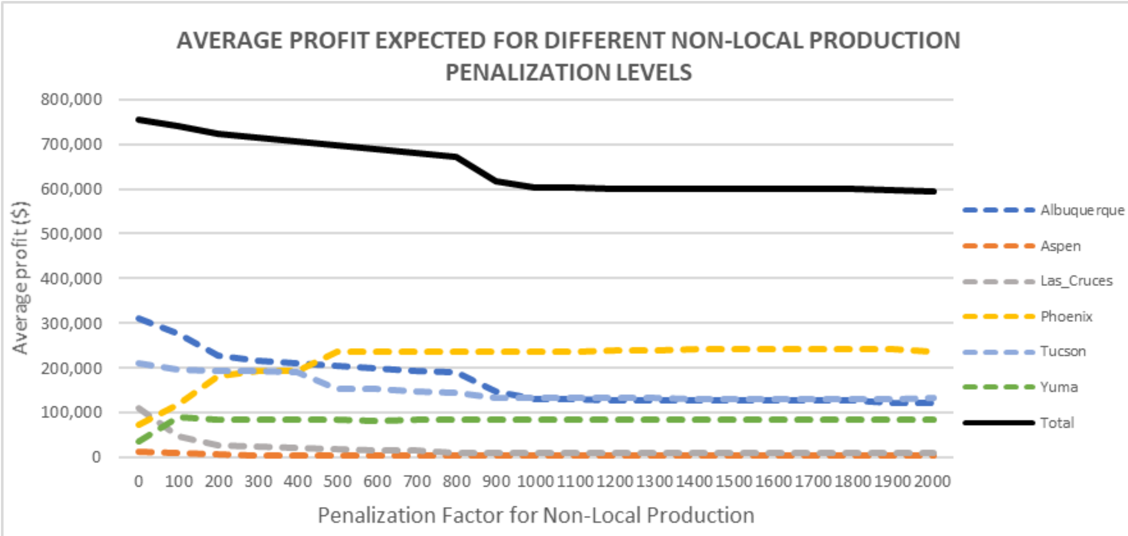


Figure 4-10: Effect of the Penalization Parameter (Gamma) on the Expected Profits (Experiment 6).

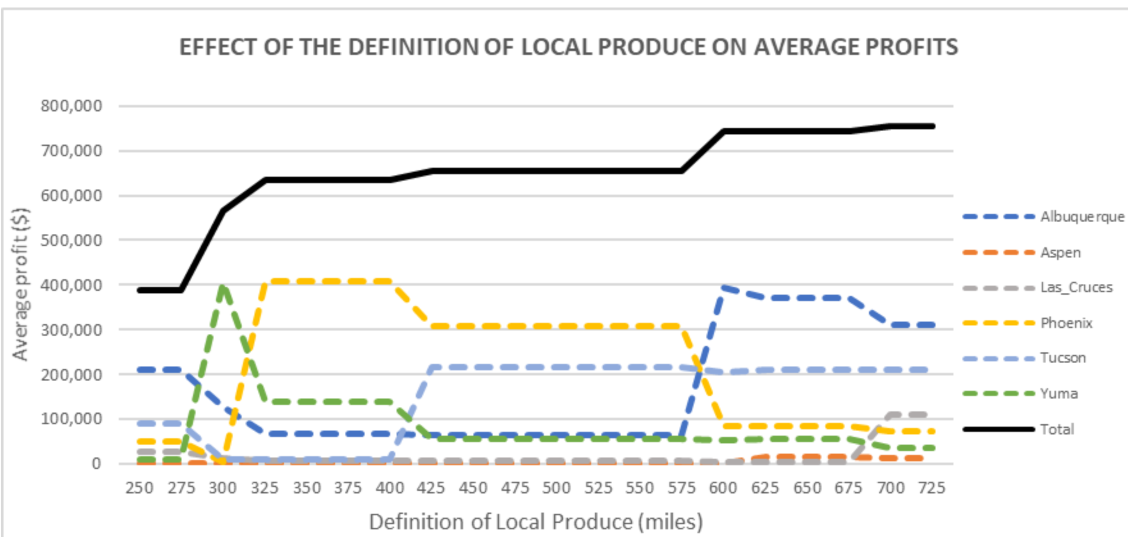


Figure 4-11: Effect of the Definition of Local Produce (in Miles) on the Expected Profits (Experiment 6).

Table 4-7: Effect of the Penalization Parameter (Gamma) on the Total SC Profits (Experiment 6).

γ	Total Profit	γ	Total Profit
0	$ 125,990	1100	$ 602,229
100	$ 740,219	1200	$ 600,649
200	$ 723,749	1300	$ 600,649
300	$ 715,224	1400	$ 600,391
400	$ 705,851	1500	$ 600,268
500	$ 697,909	1600	$ 600,268
600	$ 690,013	1700	$ 600,188
700	$ 681,470	1800	$ 600,152
800	$ 670,390	1900	$ 596,255
900	$ 617,799	2000	$ 593,966
1000	$ 602,229		

In the next experiment we explore the preference for fresh produce with reduced carbon emissions, which sometimes is indirectly associated with Local Produce. Besides the effect that the definition of local produce can have over the level of advantage that different regions may have to supply the demand, there is also another factor related with sustainability concerns that consumers may have, in particular, carbon footprint, or CO2 emissions, associated with how a product is produced and transported from a "non-local" region. This means that the market may prefer produce with reduced carbon footprint, resulting in customers preferring these products over other with higher carbon footprint. To account for this preference, two sources of emissions were considered in Experiment 7: emissions directly related to production activities, and those related with the transportation/logistics processes required to move the produce from the farm to the consumption point. Note that the first corresponds to the CO2 emissions that result from growing activities such as planting, cultivating, and harvesting at each location. This is highly dependent on the sources of energy used, how much energy is required by the technology available at each location. This location-dependent factors will result on crops with a base carbon footprint, which will be determined by the location where they are grown. To this initial footprint value, the emissions related to the logistics and transportation are added to account for the total carbon footprint at the point of consumption.

As explained in the methodology section of this article, the total emissions are penalized in the objective function with the use of a penalization parameter β. After running this scenario for different levels of penalization we can observe how it affects the competitiveness of each of the regions as depicted on Figure 4-12. As the penalization term starts to increase, or the consumer is more concerned about CO2 emissions, the expected revenues in each of the regions are directly affected. Some regions, such as Albuquerque, NM or Tucson, AZ may have more resilient positions and can keep a certain level of profitability as the penalization term increases, in this case around $300,000 and $200,000, respectively. But they do also experiment inflection points, such as a penalization change from 13 to 17, where the profitability is greatly diminished to near $150,000 for Albuquerque, and $80,000 for Tucson. Also is important to note, that as expected when the penalization is too high then there are just not enough incentives to articulate a production plan, as it can be observed in the right side of the Figure 4-12, where no location is selected to be part of the production and supply plan. It can also be observed that, with a penalization higher than 16 the only regions that are still profitable to produce are Tucson and Phoenix in AZ, and Albuquerque in NM. When the penalization term exceeds 44 there is no profitability for any of the regions considered, suggesting that the expected emissions are "too high" to be producing and shipping the products from any of these locations to the targeted market. The results of this experiment also show that the use of carbon emissions penalization provides more predictable results vis-a-vis a distance-based definition of local food. Each producing region has a different baseline emissions level (i.e.: carbon emissions related to growing and harvesting) depending on the resources available, the production practices, and productive potential that will position it differently to supply different markets. This can be interpreted as a producer's inherent value that can be considered when deciding how to match supply and demand match for a certain market.

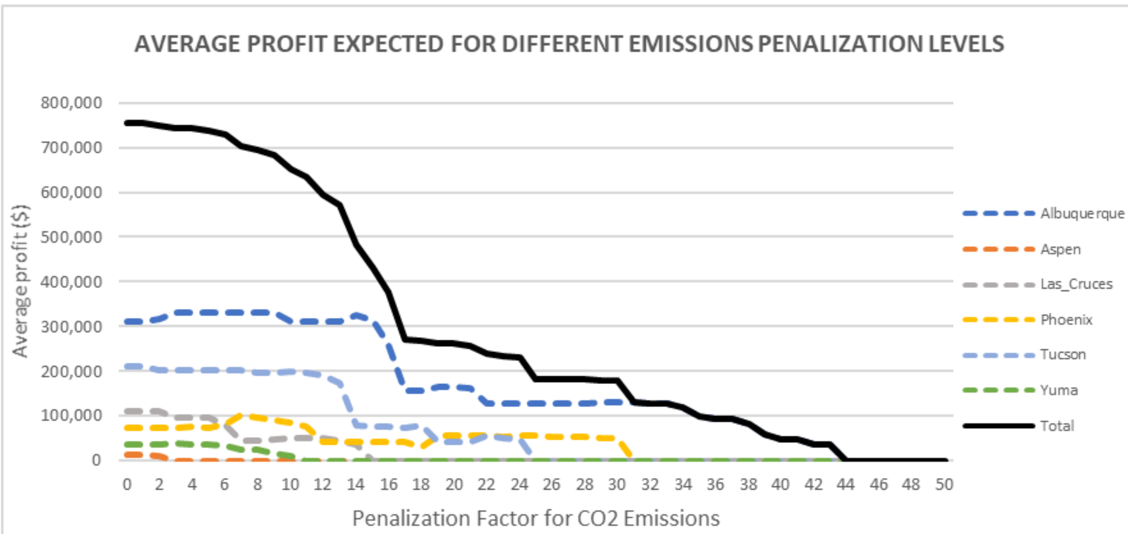


Figure 4-12: Effect of the CO2 Penalization Parameter (Beta) on the Expected Profits (Experiment 7).

4.4 Discussion of the Incorporation of Denomination Labels on Agricultural Supply Chain Planning

The results show how different non-monetary incentives or consumer preferences can be included in the planning models, either in the constraints or in the objective function. Depending on the incentive and the way it is included the solutions may vary, but an initial approach was obtained throughout the executed experiments. The results also show the benefits of coordinating multiple producing regions with complementary weather conditions, resulting in complementary producing seasons (Experiment 4). We were capable to include and assess the effect of a preference for local produce from both perspectives: as a hard requirement from the buyer/market (Experiment 5), and as a penalization factor in the objective function term (Experiment 6). Lastly, we presented a simple approach to start including the carbon footprint of different products as another consideration when deciding the supply chain configuration and allocating demand to producing regions (Experiment 7).

In summary, the work presented allows the inclusion of consumer preferences, such as denomination label, into the planning models to get insights regarding how the definition of these preferences can affect the competitiveness of different producing regions, the additional cost and the diversity of offerings that a buyer will have in a given market. With the base model, the Supply Chain Coordinator can take advantage of complementary producing regions to fill the market needs. The proposed tools can be used to accommodate the consumer preferences in the most efficient manner and evaluate how and when different regions become competitive or lose their advantages.

Something that the proposed models aim to achieve is the assessment of indirect consequences of the use of special denomination labels such as restricting some regions from supplying a market. This is a direct consequence of how the consumer preferences in that market are translated into the definition of denomination labels. For instance, when consumer preferences are introduced, the competitiveness of some producing regions will be affected, as shown in the results presented. That is, in some cases, under certain definitions of local produce, some regions may not be considered as local suppliers anymore, resulting in those regions being left at a disadvantage to supply some specific markets. The reverse may happen when a region is geographically well positioned, when falling under the definition of local production will receive the benefits of supplying a restricted market. A similar analysis can be applied to multiple non-monetary incentives or consumer preferences using the presented methodology and tools. These results highlight the need of well-defined labels such as "local-produce", as these definitions will directly impact the supply chain composition and operation; and more importantly, the choices of the consumers.

Thus, the use of labels as "Local Produce" affect the efficient allocation of market opportunities to potential producing regions. If some of these regions are located beyond what is considered "Local Produce", this may result in a loss of competitiveness of their products. The definition of "Local" produce plays a critical role in the competitiveness of producing regions despite other advantages that they may have given their geographical location and climate. Even if there is no consensus on what this label exactly means, the implications of this definition should consider additional factors before enacting policies around it. One of these factors is the economic development of the potential supplying regions, as this can be directly affected by the definition: if too restrictive, growers and land developers will be competing over land close to urban areas, resulting in increment in costs which will be transferred to the consumer in the form of higher prices. The latter is of critical importance while considering the accessibility to healthy fresh produce in a world of growing population. Also, by competing to be "close" to the market in urban areas, some farther locations with better resources availability (i.e.: weather, land, and water) will become less attractive as suppliers for urban areas, resulting in the loss of competitiveness in distant urban centers.

Furthermore, if the preference for local produce comes from a sustainable perspective, then there is a need to rely on alternative metrics such as carbon footprint. We believe that this measure better captures the environmental impact of a product, because a produce grown locally doesn't necessarily have a lower carbon footprint compared with a product being shipped from a farther location. However, the definition of carbon footprint needs to be well defined. For instance, the use of a carbon footprint measures that just captures transportation and logistics activities is not enough because leaves the very important carbon-related primary activities. In some cases, growing local will require higher emissions related with the production itself, even if the transportation and logistics emissions are reduced (Onozaka and McFadden, 2011). Thus, there is also a need for the standardization of these metrics to provide the right information to the consumers to make decisions about products to purchase, such as the use of carbon footprint to inform consumers concerned with the environmental impact of the products consumed.

Using carbon footprint can replace the definition of local as a measure of how sustainable the produce being purchased by the consumer is. This metric provides a quantitative value that can be used to account for the actual environmental impact behind the produce. This type of metric accounts not only for the environmental impact related with transportation, but also should include production practices, storage, supply chain waste, etc. A metric such as carbon footprint is easier to measure and can provide the consumers with more accurate information about the produce they are purchasing, which is not the case of the "local produce" label that may have a different definition depending on the market.

Chapter 5

PART II: TACTICAL OPPORTUNITY ALLOCATION CONSIDERING REVENUE DISTRIBUTION MECHANISMS

When looking to buy fresh produce, very often consumers expect year-round availability at the supermarket shelves. Consumers assume they should be able to find the same mix of produce regardless of the time of the year, and the retailers must be able to keep up with these expectations. Keeping the shelves stocked year-round is a difficult task, particularly considering that each produce's growing season is limited by weather seasonality in the supplying regions. For fresh produce, this task becomes even more complex given its high perishability and the long periods between planting and harvesting times. If inventory of fresh produce along the supply chain is at low level, there will be probably not enough time to react with a production plan to meet short-term demand, increasing the prices of the little available inventory. Thus, creating the proper timely connections between markets and growers becomes a critical task that, if done correctly, will result in planning the production season in such a way that that demand matches the supply in the best way, considering the variability observed at both ends of the supply chain.

In the context of agricultural supply chain planning, there are different levels of planning activities required to articulate a production plan to meet the demand associated with a new opportunity. From a grower's perspective, the demand associated with the market opportunity often comes in the form of a supply contract whose fulfilment has a value (intrinsic and extrinsic). Usually, these contracts call for supplying crops for an extended production season, beyond that observed by a single farmer or a single region, thus the need to include different growers and potentially different regions to meet the demand underlying these contracts. As identified by Villalobos et al. (2022) there is a set of steps required to articulate a supply chain as a response to a market opportunity, particularly with respect to the planning and coordination activities.

Under the scope of this paper, we assume a centralization of the planning and coordination activities performed by a coordination agent, the Supply Chain Articulator (SCA), as suggested by Villalobos et al. (2022). This agent acts as a representative of a group of growers and is responsible of converting the contracts resulting from the market opportunities identified into efficient implementable plans. Thus, the SCA aggregates market needs and requirements and translate them to a supply contract with the buyer(s). The value of this contract is determined by the overall maximum profit that can be extracted by the farmers participating in the opportunity. Once an initial theoretical value of the contract is determined, by using a centralized allocation strategy under the assumption that all the potential growers will accept the results of this allocation, the next step is to build a specific coalition of farmers capable of capturing the identified opportunity. This involves the determination of volumes, planting/harvesting times and corresponding prices for one or more crops to be allocated to the different growers, usually in the form of contracts. This generation of contracts involves agreements of production between the farmers and the buyers and are agreed by both sides before planting the contracted crops. We assume that the SCA, acting as a representative of a coalition of farmers, yet to be formed, negotiates a contract with the buyer in terms of volumes, timing and delivery prices having as objective the maximization of the value of the contract

The general process of contract definition and allocation is depicted in Figure 5-1 where each stage of the process is identified. The focus of this work is on stages V, VI, and VII, which are directly related with how the contract's value is distributed among the supply chain participants (growers).

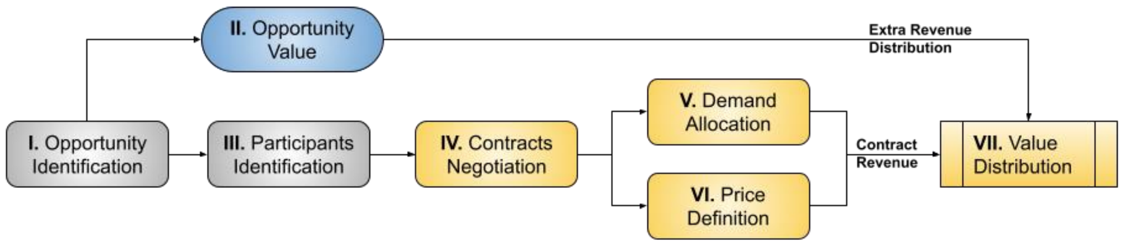


Figure 5-1: Flow Chart to Capture a Market Opportunity's Value.

The result of the negotiation stages is a production contract with each of the growers participating in the coalition. These contracts are defined by supply volumes, corresponding to part of the buyer's demanded volume, and a *transfer price*, which corresponds to the price offered to the grower at the time of the delivery of the contracted produce. Note that, the transfer price doesn't necessarily correspond to the full price accorded with the buyers, as the SCA may leave some funds aside to be used to achieve an efficient coordination. The purpose of the production contracts is to ensure that each party will fulfil his production commitments in addition to specify volumes, timing, and prices for the produced delivered, there are other terms included in the contract. The last stage of the process (stage VII in Figure 5-1) corresponds to the opportunity value distribution via a production contract offered to the growers, which consists mainly in required volumes and prices for the crops. Note that in total there are two payments that the growers will receive for being part of the coalition. The first payment is directly tied to the production contract with each grower and the crops supplied by them, and the second payment corresponds to the extra revenue allocated after the crops are delivered by the season. The coordination mechanism developed in this work considers these two payments as part of the production contract, and accounts for the growers' perception of both the coordination process and the benefits of engaging in the collaboration. Particularly, the SCA will specify some conditions that are desired and required to ensure an effective coordination; while the growers will include some other conditions related to their participation and expectations when accepting the contract. Thus, under the scope of this work, an efficient contract is such that, when presented together with a revenue distribution mechanism, entices all the growers to form a coalition satisfying both the SCA and the growers' needs.

From the SCA's perspective, besides allocating demand to growers, this agent is looking for specific characteristics in the resulting contracts, as these will enable an effective coordination. Some of these conditions include *Efficiency*, which is defined as a coordinated solution that increases the overall utility for all the involved parties, *Individual Rationality*, defined as the perception of the participants to benefit from participating in the collaborative solution, and the willingness of the growers to participate without obligation (Sandholm, 1999). Another required condition is *Budget Balance* property, which requires a mechanism to be implemented without the need of external capital or subsidies (Chu and Chen, 2006), in other words the benefits of the collaboration are enough to cover any coordination cost required to implement the solution.

From the growers' perspective, there are specific conditions that will influence their decisions of being part of the coalition, among them the expected profits, and risk levels associated to the proposed plan. In terms of expected profits, a grower will engage in a collaborative plan if the profitability from participation is higher than not participating in the coalition (*Individual Rationality*). With respect to risk perception, growers look for production plans that are within their risk tolerance. If being part of a coalition represents a compromise in their operations risk level, then some growers may be reluctant to participate. As identified by Komarek et. al. (2020) the two major types of risk perceived by the growers are production risk and market risk. The first one corresponding to the inherent risk associated with the yields that can be obtained from growing a crop, for instance the temperatures observed during the growing of the crop, while market risk is associated with fluctuations in both prices and demand at the time of selling the crop. In presence of a collaboration opportunity the perception of the risk from the perspective of the growers must be considered a priori to increase the probability of their involvement in the coalition.

The coordination problem is complex since there are many conditions and restrictions involved, such as: agronomic conditions, access to capital, cost structures, growers' preferences, etc. The problem becomes even more complex when the inherent variability of agriculture is considered, such as uncertainty in crops' yields, volatility of prices. Therefore, there is a need of practical decision support tools that can efficiently implement coordination mechanisms to form growers' coalitions to capture a market opportunity.

In this work, a coordination mechanism is developed to align incentives of a coalition of growers to maximize the expected profits obtained from a market opportunity, while considering the stochasticity inherent to the agricultural industry. The stochastic components of the problem are modeled using random scenarios chosen to capture the variability of both market prices and expected yields, as explained in the case study section of this document. The inclusion of these sources of variability allows to model the uncertainty faced by the agricultural supply chain during the decision-making process. In addition, this allows the use of coordination mechanisms while accounting for different growers' preferences and risk profiles, and to focus on increasing the expected profits received by them and likelihood to participate in the proposed coalition. One of the key elements of this mechanism is the exploration of different revenue-sharing mechanisms to create contracts that can, in some cases, result attractive to the participant growers.

5.1 Methodology

To address the coordination problem previously defined, we propose a mechanism that prescribes volume and time allocation for the growers depending on their agronomic profile and other resources as well as their overall contribution to the forming coalition. As it can be expected, different growers are willing to take different levels of risk depending on their own means, experiences, and preferences; and thus, they will expect different profits in return. In this section we expand on how the coordination within an agricultural supply chain can be achieved, while keeping in mind some of the characteristics that are important for any mechanism to achieve an effective coordination.

The elements of the supply chain considered in this work consist mainly of a coordination agent called the Supply Chain Articulator (SCA), and a group of growers who can produce the different crops required by the market. The market needs are captured in a demand contract, which may result in a new opportunity for the growers if properly addressed. The Supply Chain Articulator's main role is to represent a group of growers and their interests, and to assist the formation of a coalition as a response to a market signal or demand. The interactions between these participants are depicted in Figure 5-2. The different demand needs of the markets are aggregated by the SCA into a demand contract (top of the figure) and transformed into production contracts (bottom of the figure) that will be allocated to the potential growers participating in a coalition. The SCA will transform the demand contract into a production plan captured in contracts or agreements that will be offered to those growers that best meet the needs of the contract. This allocation will be done considering the production potential (i.e.: yields seasonality) of each region to best match the aggregated demand needs. The production contract that will be offered to the growers consists of a supply schedule and the corresponding prices to be received at the time of the delivery of the product or products in the contract. Each grower will be subject to profitability and risk levels corresponding to her/his conditions. Note that as part of the allocation, the SCA can offer a lower price to the growers than that it what was agreed upon with the buyers, resulting in surplus revenue that may be set aside and used later as a variable second revenue stream for the growers to attain effective coordination for the forming coalition. This extra revenue can be used in cases where the contract being offered to the growers, which will consider the whole SC benefit, is not attractive to some of the growers and extra incentives are needed to entice their participation in the coalition, if this participation results in a benefit to the coalition. As we explain later in this document, the mechanism on how this extra revenue is allocated may be critical to construct attractive contracts to the growers. With respect to the SCA's compensation, it will directly depend on the surplus from the opportunity being captured and will depend on the added value the SCA generates by creating a coalition capable of capturing the new opportunity. Under the scope of this work, we assumed the SCA's compensation corresponds to a percentage of the opportunity value and does not affect the value that is being offered to the growers. Another consideration is that logistics service providers are not consider in the decision-making process, as these services are usually outsourced and do not significantly influence the problem of allocating demand to growing regions.

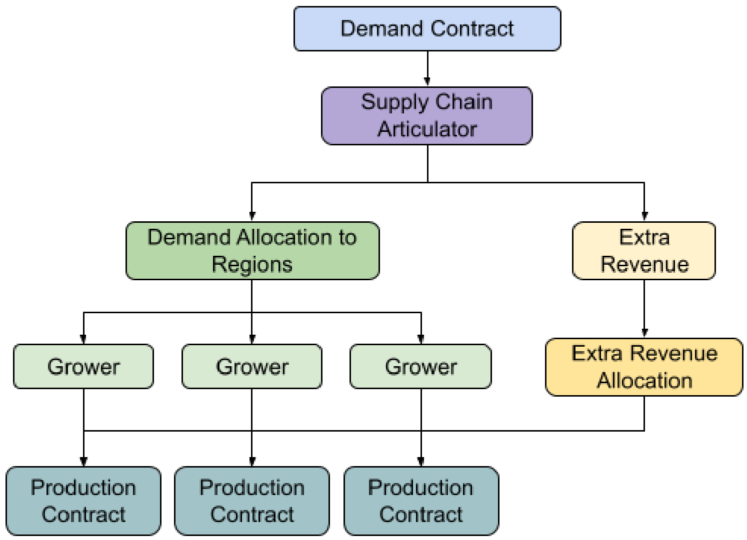


Figure 5-2: General Scheme of the Negotiation Process.

The extra profit that will be available to be allocated among the Supply Chain participants can be estimated as the difference of the prices for each crop *j* agreed in the demand contract with the buyers, denoted by $p_{0,j}$, and the transfer price that is initially offered to each of the growers *g* in the production contracts, denoted by p_g. Note that the demand in the contract is defined as the volume to be delivered for each crop *(j)* over each one of the weeks (*t*) considered in the contract (or planning horizon). Thus, for a given demand contract the total surplus revenue (ΔΠ) over what will be paid to the growers can be obtained by:

$$\Delta\Pi = \sum_{g,j,t} Demand_{j,t} * (p_{0j} - p_{g,j}) \qquad \text{Eq. 5.1}$$

This can be interpreted as income that the SCA is temporarily being set aside to be used as coordination budget, to be allocated in a way that can help achieve the best coalition of growers. The mechanism to allocate the extra benefit does not directly impact the SCA, as we assume that all the extra profits will be distributed among the growers regardless of the allocation method used. This means that for the SCA there is no difference on giving all the extra profits to a single grower, distribute it equally among all the producers, or use any another revenue distribution method. But this is not completely true, as his objective is to achieve the coordination of the supply chain, a bad profits allocation can make the building of the coalition unfeasible. The negotiation process with the growers to define the production contracts will be indirectly affected by the way the SCA distributes the profit among its participants. For instance, if the distribution method is perceived as not fair by the participants, then some of the growers may balk during the coalition formation.

As described in the literature, there are certain desirable characteristics that are required from the coordination mechanism to effectively coordinate the SC participants namely. *Budget Balance*, *Efficiency*, *Incentive Compatibility*, etc. The SCA's objective is not only to allocate production, but to ensure the growers collaboration required to supply the demand contract. This will require to offer a production contract to each of the growers such that they can expect to obtain at least a minimum additional benefit from the participation. We assume that a grower g will collaborate or commit to collaborate if the expected profit for being part of the coalition (Π_{g}^{*}), is at least what it could be obtain without being part of the coordinated solution (Π_{g}^{0}). Thus, for a grower g we can assume he will engage in the coordinated solution if:

$$\Pi_{\mathrm{g}}^{*} \geq \Pi_{\mathrm{g}}^{0} \qquad \forall g \qquad \mathrm{Eq.\,5.2}$$

Given the inherent uncertainty associated with agricultural operations, we also consider the risk exposure into the growers' decision process, as this will affect the decision of whether or not to engage in an opportunity and accept a production contract. To assess the risk perceived by the growers in different production plans, we propose the use a Risk Adjusted Profit (*RAP*) metric. A similar metric was used by Ahumada et. al. (2012), to determine a production plan for a single grower while considering the expected profits and the grower's risk-aversion level. The main advantage of using the *RAP* metric is that it considers both the expected profits received by the grower, and the risk associated to the corresponding production plan. The latter will depend on the growers' risk profile, which we represent by a parameter λ_g to quantify the risk aversion level of a grower. A value of λ_g equal to zero corresponding to risk-neutral growers, and as the value of λ_g increases, the higher the level of risk aversion. The formula used to estimate *RAP* is the following:

$$RAP(plan) = \ E_s[Profit^{g,s}] - \lambda_g * Risk \qquad \forall g \qquad \text{Eq. } 5.3$$

Note that for the same expected profits and risk level, two different growers may perceive different benefits from the same opportunity: a risk-averse grower will be more reluctant to engage in the opportunity than a risk neutral grower. Furthermore, when a production contract is offered to a grower, the contract will be appealing to him/her if the expected *RAP* for accepting the contract is higher than the case of not engaging in the collaborative opportunity. In other words, we can assume that a grower will be willing to accept the contract and for part of the coalition if:

$$RAP(contract) \geq RAP(no\ contract) \qquad \text{Eq. } 5.4$$

Another critical component on building a coalition of growers is the design and implementation of a policy for the distribution of the surplus profit of the supply chain among the participants. This policy will have a direct impact on the grower's behavior throughout the negotiation, and therefore must be carefully analyzed with respect to how different methods can achieve coordination and enable the implementation of the solution. In this work we analyze a profit distribution scheme based on the risk taken by the participating growers. As previously highlighted in the literature review, there is no consensus on how the risk is measured and allocated in agricultural supply chains, thus we consider two complementary metrics that are used to quantify the risk perceived by the growers. These two metrics are the following:

1. **Deviations from a Target**: This metric, originally used by Ahumada et. a. (2012) to account for growers' risk preferences when planning under uncertainty, is based on the deviations of the profits received for each with growers for different scenarios with respect to their targets ($Target_g$). It considers the probability of each scenario ($prob_s$) and penalizes the case where the profits fall below each grower's target value.

   This is modeled as

$$E[TargetDeviations]_g = \sum_s prob_s * \left(Target_g - Profit^{g,s}\right)_+ \qquad \text{Eq. 5.5}$$

2. **Profits Variability (Variance)**: This corresponds to measure the uncertainty of the expected profits under the different scenarios, as pointed out by Schieffer and Vassalos (2015), one of the major benefits that growers are looking from a contract is certainty of the outcomes of the season. Thus, we use the variance as a metric that represents the variability of the possible outcomes.

$$Risk_g = Variance(Profits^{g,s}) = \frac{\sum_s \left(Profit^{g,s} - \overline{Profit^{g,s}}\right)^2}{|S|} \qquad \text{Eq. 5.6}$$

where |S| represents the number of scenarios considered. The use of these two metrics allows to incorporate the two main sources of risk perceived from the growers into the decision-making process. These metrics present different numerical magnitudes (based on how they are calculated) and are included in the optimization problem defined in the next section by a penalization in objective function using the penalization terms λ_1^g and λ_2^g. These two penalization terms attempt to capture the growers' risk aversion level with respect to each of the metrics: λ_1^g represents how much a grower is concerned about deviations from a certain target, and λ_2^g represents a grower's concern with respect to the profits variability (Variance). Note that values of λ_1^g and λ_2^g close to zero represents risk-neutral growers, and higher values represent more risk averse growers with respect to each of the risk metrics defined in equations (5) and (6).

Having defined how the risk taken by the growers can be measured and accounted for during the planning stages, the next step is to define how the extra revenue resulting from engaging in the contractual opportunity is allocated to the participant growers. A basic property that must be satisfied by any coordination mechanism is the *Budget Balance* constraint:

$$\Pi_{total} = \sum_g \Pi_g + \Delta\Pi^c \qquad \text{Eq. 5.7}$$

Where Π_{total} corresponds to the total profit achieved by the coalition of growers, and Π_g to the profit that grower *g* will initially receive based on the contract offered by the SCA. The term $\Delta\Pi^c$ corresponds to the extra profit distributed among the participants coming from the extra budget set aside by the SCA, which will only be available if the coordination is achieved.

The general model defined in this section assists the SCA in the decision-making process of allocating the aggregated market demand to a set of potential growers located in different producing regions. Each grower and region have a set of characteristics that determines how they can participate in the coalition, such as: available land and resources that will limit how much can be planted per week, and different climate conditions that affects the expected yields for each of the crops throughout the season. In addition, the local markets in each of the regions are subject to prices uncertainty which are also considered by the model. Both prices uncertainty and yields variability are incorporated in the form of scenarios s constructed by a realization of both prices and yields. The model assists the determination of optimal planning decisions for the growers in each region (planting, harvesting, and shipping), with the option of considering a contract that must be satisfied. The inclusion of a contract results in commitments that must be fulfilled by the coalition either from production from different growers or purchases from the spot market. With this model, the SCA will assess how the growers in each of the candidate regions will position themselves as part of a coalition that can capture an identified market opportunity. Furthermore, the SCA will be able to find the best configuration of this coalition to try to maximize the value of the new market opportunity being captured by the emerging supply chain. The mathematical formulation of the model consists of a Quadratic Mathematical Program, which is explained in this section.

To explain the overall model, the nomenclature use in the model formulation is presented next.

Indices and Sets:

$g \in G$	: Set of growers *g*
$j \in J$	: Set of crops *j*
$t \in T$	: Set of feasible planning weeks *t*
$p \subset T$	: Set of planting weeks *p*
$s \in S$	: Set of scenarios *s*

Variables:

$Plant_{g,j,p}$	: Acres of crop *j* planted by grower *g* during week *p*
$Harvest_{j,t}^{g,s}$	: Pounds of crop *j* available to harvest by grower *g* in week *t*, under scenario *s*
$Ship_{j,t}^{g,s}$	: Pounds of crop *j* shipped by grower *g* from own production during week *t*, under scenario *s*
$Spot_{j,t}^{g,s}$	: Pounds of crop *j* purchased by grower *g* from the spot market during week *t* to satisfy the contract requirements, under scenario *s*
$SellCon_{j,t}^{g,s}$	: Pounds of crop *j* sold by grower *g* as part of the contract during week *t*, under scenario *s*
$SellSpot_{j,t}^{g,s}$	: Pounds of crop *j* sold by grower *g* to the open market during week *t*, under scenario *s*
$ContractAlloc_{g,j,t}$	: Demand of crop *j*, in pounds, allocated to grower *g* for week *t*
$BinPlant_{g,j,p}$	: Binary variable indicating if grower *g* is planting crop *j* during week *p*

Parameters:

$target_g$	: Minimum target profit expected by grower *g* from the collaboration
λ_1^g	: Parameter representing the risk preference with respect to downside deviations for grower *g*
λ_2^g	: Parameter representing the risk preference with respect to profits variability (Variance) for grower *g*

$priceCon_{g,j,t}$	: Price for crop *j* to be sold under the contract for grower *g* during week *t*
$priceSpot_{g,j,t}$	: Price for crop *j* to be sold in the spot market for grower *g* during week *t*
$costTrans_{g}$	: Transportation cost per pound of product for grower *g*
$costSpot_{j,t}$	: Cost for crop *j* to be purchased from the spot market during week *t*
$costHarvest_{j}$	: Cost to harvest a pound of produce *j*
$landAv_{g}$	: Land available, in acres, to grower *g*
$minPlant_{g,j}$	: Minimum weekly acreage to plant of crop *j* for grower *g*
$maxPlant_{g,j}$	: Maximum weekly acreage to plant of crop *j* for grower *g*
$contractDemand_{j,t}$	: Demand, in pounds, of crop *j* required from the buyer during week *t*
$yield_{j,p,t}^{g,s}$	: Expected yields for crop *j*, in pounds, during week *t* for grower *g*, which was planted during week *p*, for scenario *s*
$expectedYields_{g,j,p,t}$	: Expected yields for crop *j*, in pounds, during week *t* for grower *g*, which was planted during week *p*, across the scenarios
$minDemand_{j}$	: Minimum demand, in pounds, of crop *j* that can be allocated to a grower in a single week
$maxDemand_{j}$	: Maximum demand, in pounds, of crop *j* that can be allocated to a grower in a single week
$marketDemand_{g,j,t}$	: Maximum demand for crop *j* during week *t* at the local market for grower *g*
$prob_{s}$	: Probability of scenario *s*

<u>Objective Function</u>:

The objective function consists of maximizing the expected profits for all the participant growers, considering the planting costs and both risk metrics defined in equations 5.5 and 5.6:

$maximize$:

$$\sum_{g} E_s^g[Profit^{g,s}] - \sum_{g,j,p} Plant_{g,j,p} * costPlant_{g,j}$$

$$- \sum_{g} \lambda_1^g * E_s\left[\left(target_g - Profit^{g,s}\right)_+\right] - \sum_{g} \lambda_2^g * Variance(Profit^{g,s}) \quad \text{Eq. 5.8}$$

Where the terms corresponding to the grower's profits ($Profit^{g,s}$) and the risk taken by the grower ($Risk_g$) are modeled as:

$$\begin{aligned} Profit^{g,s} = &\sum_{j,t} SellCon_{j,t}^{g,s} * priceCon_{g,j,t} \\ &+ \sum_{j,t} SellSpot_{j,t}^{g,s} * priceSpot_{g,j,t} \\ &- \sum_{j,t} \left(Ship_{j,t}^{g,s} + Spot_{j,t}^{g,s}\right) * costTrans_g \\ &- \sum_{j,t} Spot_{j,t}^{g,s} * costSpot_{j,t} \\ &- \sum_{j,t} Harvest_{j,t}^{g,s} * costHarvest_j \end{aligned} \quad \text{Eq. 5.9}$$

$$Variance(Profit^{g,s}) = \frac{\sum_s \left(Profit^{g,s} - \overline{Profit^{g,s}}\right)^2}{|S|} \quad \text{Eq. 5.10}$$

<u>Constraints</u>:

$$\sum_{j,t} Plant_{g,j,t} \leq landAv_g \qquad \forall g \qquad \text{Eq. 5.11}$$

$$Plant_{g,j,p} \geq minPlant_{g,j} * binPlant_{g,j,p} \qquad \forall g,j,p \qquad \text{Eq. 5.12}$$

$$Plant_{g,j,p} \leq maxPlant_{g,j} * binPlant_{g,j,p} \qquad \forall g,j,p \qquad \text{Eq. 5.13}$$

$$\sum_{g} ContractAlloc_{g,j,t} = contractDemand_{j,t} \qquad \forall j,t\text{: } \textbf{with contract} \qquad \text{Eq. 5.14}$$

$$Plant_{g,j,p} \leq M * \sum_{t} ContractAlloc_{g,j,t} * expectedYields_{g,j,p,t} \quad \forall g,j,p: \textbf{ with contract} \quad \text{Eq. 5.15}$$

$$ContractAlloc_{g,j,t} \geq minDemand_j \quad \forall g,j,t: \textbf{ with contract} \quad \text{Eq. 5.16}$$

$$ContractAlloc_{g,j,t} \leq maxDemand_j \quad \forall g,j,t: \textbf{ with contract} \quad \text{Eq. 5.17}$$

$$\sum_{g,j,t} ContractAlloc_{g,j,t} = 0 \quad \textbf{without contract} \quad \text{Eq. 5.18}$$

$$Harvest_{j,t}^{g,s} \leq \sum_{p} Plant_{g,j,p} * yield_{j,p,t}^{g,s} \quad \forall g,j,s,t \quad \text{Eq. 5.19}$$

$$SellCon_{j,t}^{g,s} = ContractAlloc_{g,j,t} \quad \forall g,j,s,t \quad \text{Eq. 5.20}$$

$$Ship_{j,t}^{g,s} \leq Harvest_{j,t}^{g,s} \quad \forall g,j,s,t \quad \text{Eq. 5.21}$$

$$Ship_{j,t}^{g,s} + Spot_{j,t}^{g,s} = SellCon_{j,t}^{g,s} + SellSpot_{j,t}^{g,s} \quad \forall g,j,s,t \quad \text{Eq. 5.22}$$

$$SellSpot_{j,t}^{g,s} \leq marketDemand_{g,j,t} \quad \forall g,j,s,t \quad \text{Eq. 5.23}$$

Where equation 5.11 ensures that only the land available can be planted by each grower. Equations 5.12 and 5.13 limits the minimum and maximum weekly land to plant for each crop given the growers constraints and resources. Equations 5.14, 5.15, 6.16), and 5.17 are only used by the model under the presence of a contract from the SCA. Equation 5.14 allocates all the buyers demand to the potential producing regions, equation 5.15 aligns the allocated demand to a region based on its production potential, and equations 5.16 and 5.17 define the minimum and maximum volumes that can be weekly allocated to a single grower, depending on the crop. Equation 5.18 is only used if there is no contract offered by the SCA and ensures that no demand is required from a grower. Equation 5.19 relates the planting decisions with the expected weekly yields for each grower. Equation 5.20 forces that what the growers sell to the contract matches the demand allocated to them. Equation 5.21 limits shipping volumes to what is available to be harvested from the fields. Equation 5.22 corresponds to volume balance between what is supplied from either own production or the spot market, to what is being sold to the contract or the open market. Finally, Equation 5.23 limits the spot sales for each grower to their own market demand.

Given the nature of the optimization problem presented in this section, the size of the model grows exponentially with the number of scenarios computed and the number of growers/regions considered in the model. In fact, the presented problem can be seen as a variation of the job scheduling problem, where in our case the jobs correspond to planting and growing the different crops, and the machines to the land available at each location, making this problem NP-Hard. To deal with this problem, a decomposition method based on the stochastic version of Bender's decomposition, which works well for moderated-size NP-Hard problems, is used to separate the problem in a single master-problem, and a set of sub-problems. This method is similar to the algorithm developed by Ahumada et. al. (2012), but in this work the algorithm is modified to take into consideration our specific problem structure in such a way that each sub-problem corresponds to a single scenario for each of the growers. This allows to obtain small sub-problems that can be easily solved by the solver and their solutions, via Bender's optimality cuts, are compiled in a single master-problem. The problem decomposition into the master-problem and sub-problem is detailed below.

<u>Master-problem objective function</u>:

$maximize$:

$$\sum_{g,s} prob_s * \theta^{g,s} - \sum_{g,j,p} Plant_{g,j,p} * costPlant_{g,j}$$

$$- \sum_{g,s} \lambda_1^g * E_s\left[\left(target_g - \theta^{g,s}\right)_+\right] - \sum_{g} \lambda_2^g * Variance(Profit^{g,s}) \quad \text{Eq. 5.24}$$

<u>**Sub-problem objective function:**</u>

$maximize$:

$$\theta^{g,s}(x) = \sum_{j,t} SellCon_{j,t}^{g,s} * priceCon_{g,j,t}$$

$$+ \sum_{j,t} SellSpot_{j,t}^{g,s} * priceSpot_{g,j,t}$$

$$- \sum_{j,t} \left(Ship_{j,t}^{g,s} + Spot_{j,t}^{g,s}\right) * costTrans_g \quad \text{Eq. 5.25}$$

$$- \sum_{j,t} Spot_{j,t}^{g,s} * costSpot_{j,t}$$

$$- \sum_{j,t} Harvest_{j,t}^{g,s} * costHarvest_j$$

In the next section we present a case study used to analyze the behavior of the model. The results obtained are used to assess the impact of the different revenue allocation mechanisms on coalition formation. We focus on how each of the analyzed mechanisms can be perceived for the growers when deciding whether or not to accept the production contracts offered by the SCA.

5.2 Case Study

The case study considers four regions of production: Albuquerque, NM; Aspen, CO; Las Cruces, NM; and Phoenix, AZ. These regions were selected as they are geographically contiguous, yet they present different environmental conditions, resulting in complementary producing seasons. This case study considers two crops: tomatoes and bell peppers. It is assumed that the demand for these products has been captured in a contract negotiated by the SCA with one or more buyers. This contract includes the weekly volumes for each product that needs to be delivered to the buyers for the duration of the contract. Figure 5-4 presents an example of the contract, corresponding to the total volume required by the buyers during for each period (week) for each of the crops. For this case study, we assumed that the buyers are in Las Vegas, NV, and that the SCA has already aggregated their needs into a demand contract which will be allocated to the growers. Note that the value of the opportunity, and the actual benefit it may present to the growers, will directly depend on how the contract is allocated to the producing regions and if the coordination is achieved.

To model the market and prices variability, which are both independent to the acceptance of the contract, we used historical terminal market prices data to create price scenarios, each corresponding to a vector of weekly prices for each crop. Figure 5-3 below shows the average weekly price for both crops using historical terminal market prices data between 2008 and 2018. With respect to the available markets, we assume that the growers, without being part of the forming coalition, will have only access to the local market in their respective region. The local markets for each grower are defined such that the prices that growers can access for each crop correspond to just 75% of the terminal market price estimation. In addition, if the produce is purchased from the spot market, we assumed an extra cost of 20% over the terminal market price.

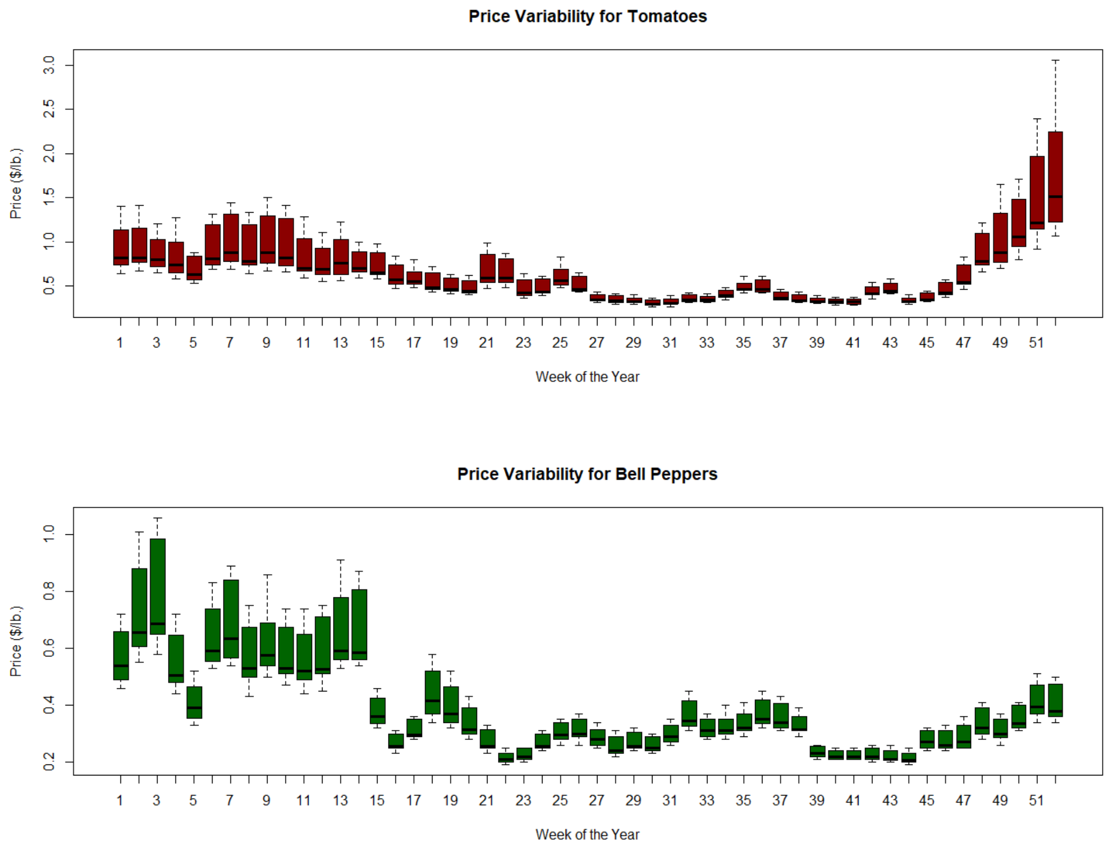


Figure 5-3: Terminal Market Prices for the Considered Crops, in $/lb.

The first part of the analysis corresponds to determining the grower's situation without participating in the coalition. The objective is to obtain a baseline to what the growers may expect before the opportunity of participating in the coalition is presented by the SCA. Under the uncoordinated case, it is assumed that each grower has access to the local markets in the regions where they are located, and the production plans are mostly based on the best match between their expected yields and their market demand. In this base case, no interaction occurs between the growers, and each of their decision-making processes is perform independently for each of the regions. With the use of the planning model presented in the previous section, and using the constraints determined by equation (8), we obtained the optimal planning decisions for the growers in each region and estimated the expected profits considering the different scenarios, the variability of the profits, and the expected deviations from the target. Table 5-1 summarizes these results including the calculated *RAP* for each of the growers without being part of the coalition, considering risk aversion levels of $\lambda_1^g = 0.1$ and $\lambda_2^g = 0.0001$, which are estimates considering the order of magnitude of the risk terms in the objective function. These results are considered as a baseline to what the grower may expect before the new opportunity is presented by the SCA. In other words, the growers will require at least these expected results, in terms of expected profits and risk level, to engage in any alternative plan that requires their participation.

Table 5-1: Summary Results for the Base Case, with No Contract Offered to the Growers.

Region	λ_1^g	λ_2^g	E[Profit]	Variance	Target Deviations	RAP
Albuquerque, NM	0.1	0.00001	$ 97,533	$ 359,550,217	$ 27,539	$ 91,184
Aspen, CO	0.1	0.00001	$ 46,407	$ 68,059,922	$ 6,232	$ 45,103
Las Cruces, NM	0.1	0.00001	$ 129,267	$ 1,153,420,952	$ 12,212	$ 116,511
Phoenix, AZ	0.1	0.00001	$ 78,101	$ 319,037,197	$ 10,021	$ 73,909

Under a coordinated solution, when a contract is offered to the growers, they can decide either to accept the contract or to stay out of it depending on how they perceive the benefits of engaging in the coalition with respect to their baseline *RAP*. The calculation of the *RAP* under the coordinated solution depends on the optimal decisions for each of the different contracts offered, and the revenue distribution mechanism used by the SCA.

For our analysis we modeled different production contracts being offered to the growers. Each of these contracts is defined by a different transfer price (p_s) being offered to the growers, using a *price factor (ϕ)* that correlates to a different percentage of the total price (p_0) agreed between the SCA and the buyers. For a given contract *c*, the transfer price (p_s^c) is estimated as follows:

$$p_s^c = \phi^c * p_0 \qquad \forall c \qquad \text{Eq. 5.26}$$

Thus, we have a range of contracts where the price offered to the growers goes from 5% of the price agreed with the buyer, all the way to contracts where the full price (100%) is transferred to the growers. This difference in prices is used to estimate the total value kept by the SCA as surplus, or coordination budget. For each of the price factor levels, the optimal allocation of the buyers' demand volumes is obtained using the planning model described on the previous section, including equations 5.14, 5.15, 5.16, and 5.17. An example of the contract breakdown is show on Figure 5-4 below with the volumes required by the buyers during each week of the year. On top of the figure, we have the demand contract that the SCA needs to be fulfill (a), and below it we present an example of how this contract can be "optimally" allocated to the growers in Albuquerque, NM (b), Aspen, CO (c), Las Cruces, NM (d), and Phoenix, AZ (e).

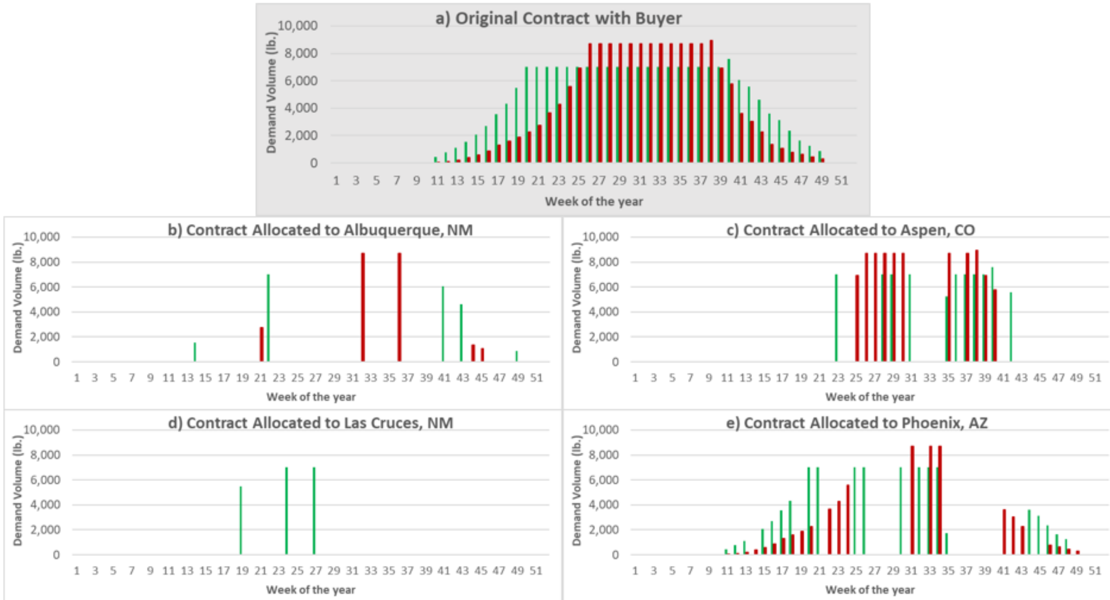


Figure 5-4: Original Contract with the Buyer (a), and Sample Contract Allocation to Each of the Producing Regions (b), (c), (d), and (e).

The results for different contracts, defined by different price factors (ϕ^c), are summarized in Table 5-2. For each region we present the Revenue Adjusted Profit (*RAP*), and the difference between the coordinated case and the base case (no coordination from Table 5-1) is presented as ΔRAP. Note that ΔRAP can be directly interpreted as the perceived benefit by the growers in each region of engaging in the coalition as a response to each of the contracts. The results from our case study shows that, just considering the offered contract, the transfer price has great impact on the benefits that growers can obtain from the collaboration. For instance, when the transfer price is low (top part of Table 5-1) none of the regions perceive benefits from the contract, as all the values of ΔRAP are negative. When the transfer price is increased, there are breaking points for each of the regions: for the growers in Albuquerque, NM, they only perceive minor benefits from the collaboration when the transfer price is 100% (Contract #20); growers in Aspen, CO start perceiving benefits from the contract when the transfer price reaches 75% (Contract #15); and for the growers in Phoenix, AZ this happens when production contract considers a transfer price of at least 70% (Contract #14). We can note that in the case of Las Cruces, NM the growers in this region do not perceive benefits for engaging in the collaboration under any offered contract, suggesting that just a production contract alone may not be enough to incentivize the growers in this region to participate in the coalition. These results highlight the importance of considering extra incentives that will be needed to entice them to collaborate. The last two columns of Table 5-2 show how much capital is set aside for the Supply Chain Articulator and is available to be used as coordination budget and align incentives with the growers in the form of a second payment. The total balance is estimated as the difference between the extra revenue available and the minimum required to compensate all the growers who are perceiving loses if they engage in the collaboration. These results are also graphically shown in Figure 5-5, where we can observe the total extra revenue generated for each contract offered, and the minimum capital required to compensate those growers who would incur in a loss if the only revenue received would come from the production contract. As the transfer price increases there is a piecewise linear reduction on the capital required to coordinate the growers, with slope changes at transfer price levels for which a new grower start perceiving benefits directly from the production contract (ΔRAP), without the need of extra incentives or compensation. For example, at a transfer price of 70% (Contract #14) the growers in Phoenix, AZ obtain positive values of ΔRAP and may not need additional compensation to participate in the coalition. The same occurs, in a smaller magnitude, at transfer prices of 75% (Contract #15) and 100% (Contract #20) for which the growers in Aspen, CO and Albuquerque, NM obtain positive values of ΔRAP

respectively. We can also relate the results in Figure 5-5 with the *Budget Balance* requirement for an effective coordination mechanism, and we can observe that when the transfer price is kept below 95% (Contract #19) there is not enough budget to distribute and entice all the growers to participate. When the price factor is higher than this value the total extra revenue kept aside is not enough to compensate the perceived loses, thus offering these contracts will require extra capital, violating the *Budget Balance* characteristic required for a coordination mechanism.

Table 5-2: Summary of the Benefits Perceived by the Growers for Each of the Offered Contracts.

Contract #	Price Factor (ϕ)	Albuquerque, NM		Aspen, CO		Las Cruces, NM		Phoenix, AZ		Budget Balance	
		RAP	ΔRAP	RAP	ΔRAP	RAP	ΔRAP	RAP	ΔRAP	Extra Rev.	Balance
1	5%	$ 77,305	$ (17,596)	$ 9,260	$ (36,321)	$ 111,966	$ (13,788)	$ 38,186	$ (37,885)	$ 134,755	$ 29,164
2	10%	$ 78,234	$ (16,668)	$ 12,012	$ (33,569)	$ 112,404	$ (13,350)	$ 41,160	$ (34,911)	$ 127,662	$ 29,164
3	15%	$ 79,162	$ (15,740)	$ 14,764	$ (30,817)	$ 112,842	$ (12,911)	$ 44,134	$ (31,937)	$ 120,570	$ 29,164
4	20%	$ 80,090	$ (14,812)	$ 17,516	$ (28,065)	$ 113,281	$ (12,473)	$ 47,108	$ (28,963)	$ 113,478	$ 29,164
5	25%	$ 81,018	$ (13,884)	$ 20,268	$ (25,313)	$ 113,719	$ (12,035)	$ 50,082	$ (25,989)	$ 106,385	$ 29,164
6	30%	$ 81,946	$ (12,955)	$ 23,020	$ (22,561)	$ 114,157	$ (11,597)	$ 53,056	$ (23,015)	$ 99,293	$ 29,164
7	35%	$ 82,874	$ (12,027)	$ 25,772	$ (19,809)	$ 114,595	$ (11,158)	$ 56,030	$ (20,041)	$ 92,201	$ 29,164
8	40%	$ 83,802	$ (11,099)	$ 28,524	$ (17,057)	$ 115,034	$ (10,720)	$ 59,004	$ (17,067)	$ 85,108	$ 29,164
9	45%	$ 84,730	$ (10,171)	$ 31,276	$ (14,306)	$ 115,472	$ (10,282)	$ 61,978	$ (14,093)	$ 78,016	$ 29,164
10	50%	$ 85,658	$ (9,243)	$ 34,028	$ (11,554)	$ 115,910	$ (9,843)	$ 64,952	$ (11,119)	$ 70,924	$ 29,164
11	55%	$ 86,586	$ (8,315)	$ 36,780	$ (8,802)	$ 116,349	$ (9,405)	$ 67,926	$ (8,145)	$ 63,831	$ 29,164
12	60%	$ 87,514	$ (7,387)	$ 39,532	$ (6,050)	$ 116,787	$ (8,967)	$ 70,900	$ (5,171)	$ 56,739	$ 29,164
13	65%	$ 88,442	$ (6,459)	$ 42,284	$ (3,298)	$ 117,225	$ (8,528)	$ 73,874	$ (2,197)	$ 49,647	$ 29,164
14	70%	$ 89,371	$ (5,531)	$ 45,036	$ (546)	$ 117,664	$ (8,090)	$ 76,848	$ 777	$ 42,554	$ 28,388
15	75%	$ 90,299	$ (4,603)	$ 47,788	$ 2,206	$ 118,102	$ (7,652)	$ 79,822	$ 3,751	$ 35,462	$ 23,207
16	80%	$ 91,227	$ (3,675)	$ 50,540	$ 4,958	$ 118,540	$ (7,213)	$ 82,796	$ 6,725	$ 28,369	$ 17,481
17	85%	$ 92,155	$ (2,747)	$ 53,292	$ 7,710	$ 118,979	$ (6,775)	$ 85,770	$ 9,699	$ 21,277	$ 11,755
18	90%	$ 93,083	$ (1,818)	$ 56,044	$ 10,462	$ 119,417	$ (6,337)	$ 88,744	$ 12,673	$ 14,185	$ 6,029
19	95%	$ 94,011	$ (890)	$ 58,796	$ 13,214	$ 119,855	$ (5,898)	$ 91,718	$ 15,647	$ 7,092	$ 304
20	100%	$ 94,939	$ 38	$ 61,548	$ 15,966	$ 120,294	$ (5,460)	$ 94,692	$ 18,621	$ -	$ (5,460)

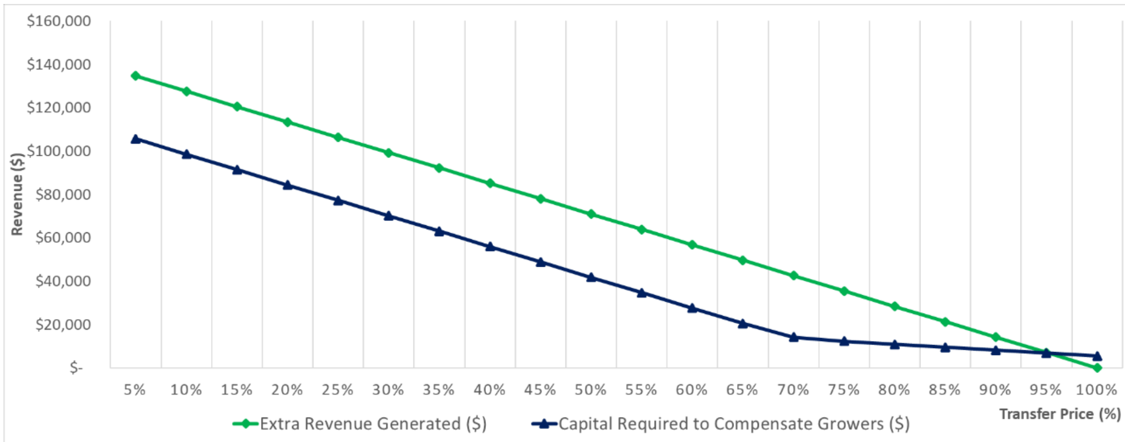


Figure 5-5: Budget Balance for the Different Contracts Considering the Capital Required to Form the Coalition.

One can observe that even if the total profits increase with the market opportunity, this does not imply that every grower will perceive an increment to his own profit. This situation is highly dependent on the contract structure being offered to the growers as observed in Table 5-2. Furthermore, depending on how the contract offered to the growers is defined there might be the case where there is not even enough capital to compensate the growers for engaging in the coordinated solution (Figure 5-5). Thus, the remaining of this section focuses on analyzing how the extra revenue generated from each of the offered contracts can be allocated. The results of the allocation are compared for different revenue distribution mechanisms, with an emphasis on how the total benefits from the contract, including the extra revenue allocation, are perceived by the growers. As the growers' risk tolerance highly impacts how the contract can be allocated, we provide a sensitivity analysis of the balance remaining after considering the capital required to compensate the growers for their participation in the coalition. Negative balance values for a contract indicate that there is not enough capital available to compensate all the growers and the *Budget Balance* condition can't be met for those contracts. The summary of the sensitivity analysis is shown in Figure 5-6 for different levels of risk aversion (λ_1^g), where we can observe that as the risk aversion level increases (values of λ_1^g increases) the amount of revenue available to be distributed decreases. We can also note the changes of direction in each of the curves, corresponding to the transfer prices at which at least one additional grower starts perceiving benefits (positive ΔRAP) from the offered contract.

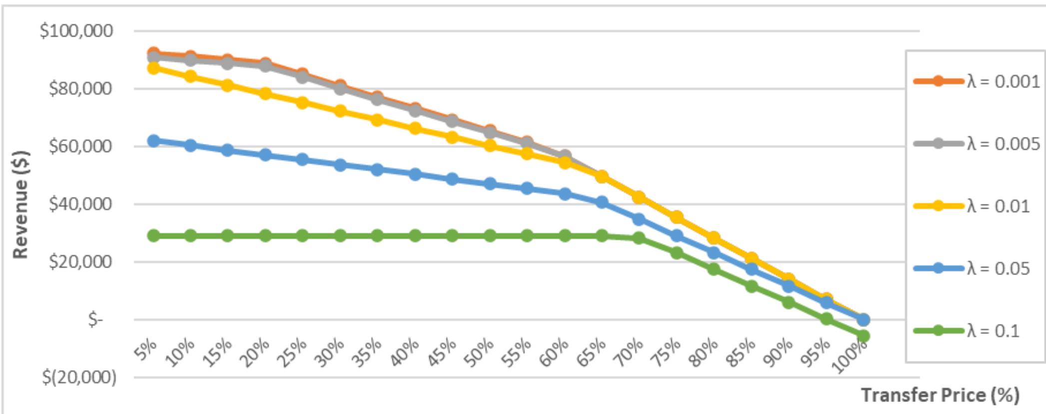


Figure 5-6: Results of Sensitivity Analysis to Risk Aversion.

To further expand this analysis and get closer to an effective contract, we explore how different revenue allocation mechanisms can result in different coordinated conditions for the growers. The method used to distribute the excess of revenue affects the coordination process as it may result in favorable conditions for the growers, if done correctly, or in unfavorable conditions dissuading them from collaborating. When considering the extra revenue allocated from the coordination, the different approaches considered and compared are:

a) **No revenue distribution**: The entire extra revenue is kept by the Supply Chain Articulator, and the growers only receive what corresponds to them based on the offered contract (volume and prices)

b) **Equally distributed**: The extra revenue is equally distributed among the participants, resulting in the same incentive value to each grower. This could be considered fair under a myopic perspective as it is providing everyone the same amount; but it does not consider each growers contribution, risk, or value provided to the opportunity.

c) **Volume-based distribution**: The extra revenue is allocated proportional to the volume supplied from each grower to satisfy the contract with the buyer. This method can be seen as a fair distribution, but it does not account for the value generated by the volume provided nor the risk taken by each grower.

d) **Value-based distribution**: In this case the extra revenue is allocated proportional to the value of the contract with the buyer captured by the produce each grower is supplying. This can be seen as a fair distribution but does not account for the risk taken by each grower nor their contribution to the whole captured value.

e) **Risk-based distribution**: In this case the extra revenue is allocated proportional to the risk taken by each grower, measured by the expected deviations from the target and the variability of the outcomes using the Revenue Adjusted Profit (RAP). This can be seen as a fair measure as it considers what is supplied from each grower and the risk exposure that each grower is taking, but it does not consider their contribution to the opportunity or their perceived benefit (profit or loss).

It can be expected that those growers who take higher risks (market and production) will receive a higher percentage of the additional profits compared with conservative growers who are taking lower risks. As suggested by Xu et. al. (2018), this can be modeled as having a constant relationship, defined by the parameter k, between the perceived profits and the risk taken as follow:

$$\Pi_g = k * risk_g \qquad \text{Eq. } 5.27$$

f) **Maximize the minimum benefit**: In this case the revenues are distributed in such a way that the minimum benefits perceived by any of the growers is maximized. This mechanism could be considered fair as it tries to maximize all participants individual benefits, but it may result in growers not receiving anything from the allocation if the contract is initially favorable (i.e.: the case of Albuquerque, NM in Table 5-2). A detailed explanation of this mechanism is provided with an example in the next section of this document.

g) **Shapley Value Distribution**: This mechanism uses the marginal contribution of each grower to the aggregated solution and distributes the extra revenue according to it. It averages the contribution of each grower to all possible groups of participants, and estates the marginal contribution to the whole opportunity for each grower. It has been proven to be fair (Pan et. al., 2009; Xu et. al., 2018), but it may result in a mechanism more complex to explain to the growers when presented in addition to the production contract.

To illustrate how these mechanisms work and how the solution is perceived by the growers, we analyze the case of distributing the extra revenue using each mechanism for each of the contracts presented in Table 5-2. The results obtained from the Case Study are explained in the next section

5.3 Results Analysis

The first results correspond to the case where there is no revenue being distributed among the participant growers. This means that all the benefits the growers perceive corresponds to the profits from the contract offered by the SCA in volumes and prices. These results are shown in Figure 5-7 for the growers in each of the regions, where the x-axis corresponds to each of the contracts in terms of the price factor, or transfer price, offered by the SCA to the growers; and the y-axis represents the ΔRAP perceived by the growers for each contract. Note that these values correspond to the results depicted on Table 5-2 in the previous section before the allocation takes place. Here, only the growers in Albuquerque, NM, Aspen, CO, and Phoenix, AZ start receiving benefits as the transfer prices increases to 100%, 75%, and 70% respectively. This means that without an extra incentive, or extra revenue allocated distributed to these growers, they will only accept a contract that is offering a transfer price above these values. In the case of the growers in Las Cruces, NM they won't be willing to accept the offered contracts under any of the possible transfer prices, as these solutions violate the required condition of *Incentive Compatibility* for the coordinated solution.

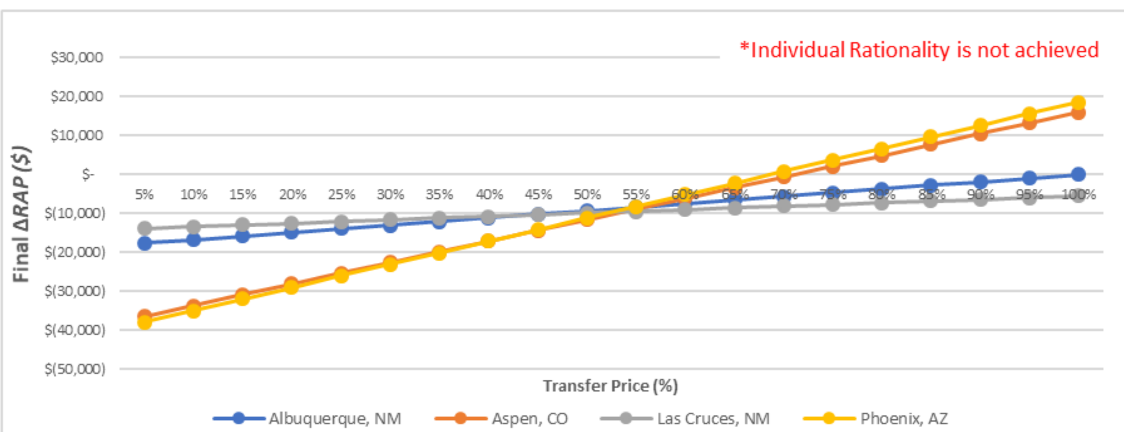


Figure 5-7: Perceived Benefits with No Revenue Distributed among the Participants.

In the remaining of this section, we describe and analyze how different revenue allocation mechanism can contribute to achieve a coordinated solution that may, under certain circumstances, entice the collaboration of all the growers required to capture the value of the new market opportunity.

The first mechanism analyzed is an even distribution of the extra revenue between the regions. The results show how the growers perceive the benefits of being in the coalition using this mechanism and are summarized in Figure 5-8. In this case, the only range of contracts that provide benefits for the growers in all the regions are those in which the transfer price is between 25% and 75%. For values below this range, smaller than 25%, only two of the regions get benefits from the coordinated solution: Albuquerque, NM and Las Cruces, NM. For transfer prices above 75%, the growers in Las Cruces, NM do not receive benefits from the coalition, even after the extra revenue is distributed. It is important to note that an equal revenue distribution mechanism between the regions does not consider any type of contribution to the (i.e.: Albuquerque, NM contributes with less volume to the contract than Aspen, CO, as depicted in Figure 5-4). This results on lower transfer prices representing higher benefits for the less-contributing regions, as they are subsidized by the high-contributing regions. For those regions that are contributing with higher value or volume to the coalition, having lower transfer prices implies negative effect on their profits. This effect can be observed in Figure 5-8 as the values of $Final\ \Delta RAP$ with respect to increments in the transfer price are increasing for Aspen, CO and Phoenix, AZ; and decreasing for Albuquerque, NM and Las Cruces, NM. Under this mechanism, all the growers perceive benefits from the coalition when the transfer prices are between 25% and

75%, which satisfy the *Individual Rationality* requirement for them to engage in the coordinated plan. The use of any transfer price outside this range violates the *Individual Rationality* requirement for at least one of the regions, and an effective coordination won't be possible without additional considerations.

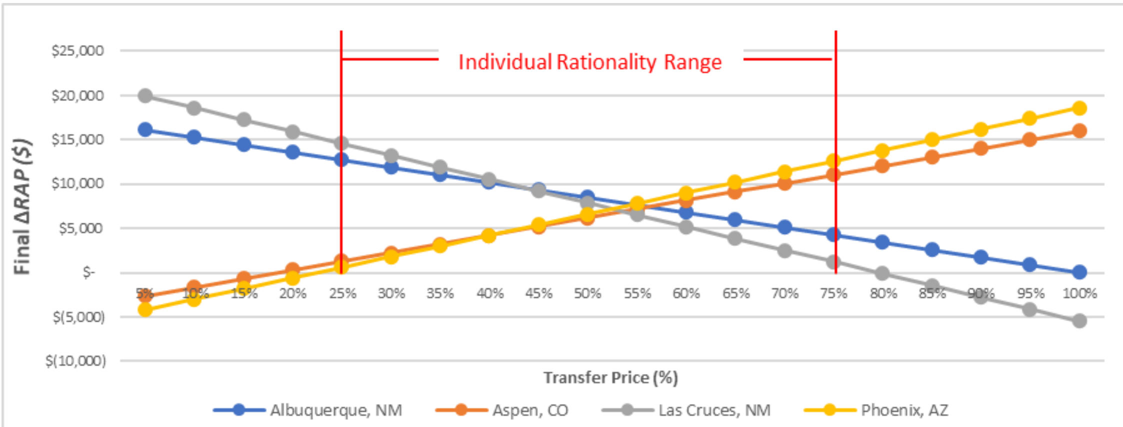


Figure 5-8: Perceived Benefits Using the Equal Revenue Distribution Mechanism.

In the case of using a volume-based distribution of the extra revenue, the values of ΔRAP for all the growers present minor variations to different transfer prices as shown in Figure 5-9. As the extra revenue kept aside depends on the transfer price for each of the contracts, the total available revenue to be distributed will diminish as the transfer prices increases (see Table 5-2). At the same time the profits from the production contracts initially perceived by the growers (before the revenue allocation) will increase. The effect that higher transfer prices have in increasing the initial profit almost compensates the reduction in the surplus available for distribution, resulting in a total final benefit (ΔRAP) very similar across the different contracts. There are some variations in the values of ΔRAP given that the revenue allocation is based in the total volume supplied, without considering the actual value provided by each grower. In the case of the growers in Albuquerque, NM, they only perceive benefits when the transfer prices are above 85%, while the growers in Las Cruces, NM do not perceive benefits for engaging in the coalition under any of the offered contracts. Thus, this mechanism does not satisfy the *Individual Rationality* for all the participants, suggesting that for this case study an effective coordination won't be achieved using a volume-based revenue distribution mechanism.

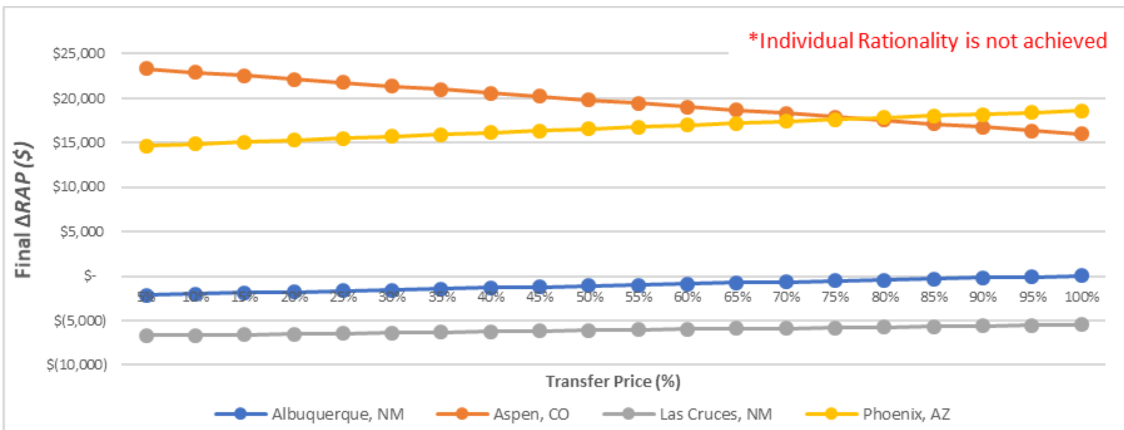


Figure 5-9: Perceived Benefits Using a Volume-based Revenue Distribution Mechanism.

The effect of not considering the value provided by each grower to the opportunity is in some way corrected under a value-based revenue distribution, as shown in Figure 5-10.As this mechanism is accounts for the different value provided by each crop during each period. The results are still similar to the case of a volume-based distribution, as the growers in Las Cruces, NM do not receive benefits from any of the offered contracts. The difference between this mechanism and the previous (volume-based distribution) is that under this mechanism the total perceived benefit by each grower is the same for any offered contract. This is expected as this mechanism is the same as a case where part of the value is being offered ahead (as a transfer price in the production contract), and the rest of the value provided after the coordination is achieved. At the end, the solution is the same as if the transfer price offered by the SCA corresponds to the price agreed in the demand contract with the buyers, or to have a transfer price of 100%. Similar to the case of a volume-based distribution, this mechanism does not fulfil the *Individual Rationality* requirement for all the growers to take part in a coordinated solution.

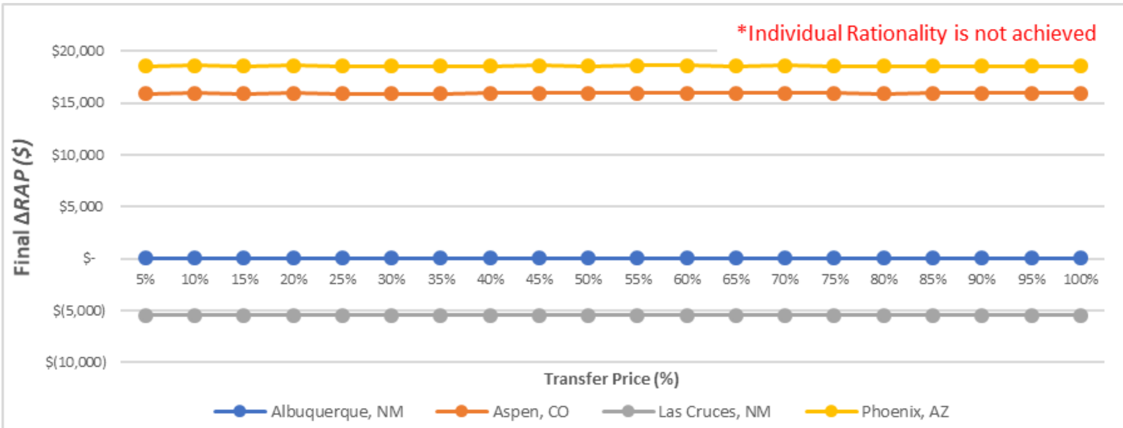


Figure 5-10: Perceived Benefits Using a Value-based Revenue Distribution Mechanism.

Different is the case of using a risk-based allocation mechanism. In this case the metric being used to account for the risk directly affects how the revenues are allocated, influencing also how different growers perceive the benefits from the contracts offered by the SCA. For our case study we considered the effect of risk as presented in equation 5.3 to perform our analysis, and the results of using this mechanism to distribute the revenues for each contract are summarized in Figure 5-11. We can observe that growers in Aspen, CO and Phoenix, AZ receive increased benefits as the transfer price increases, while growers in the rest of the regions perceive lower benefits as the transfer price increases. Particularly, when the transfer price is between 70% and 90% the growers in all the regions perceive benefits from engaging in the coalition. For any transfer price outside that range there is at least one grower that won't be willing to participate, as the solution violates the

Individual Rationality requirement of a coordinated solution. Note that this mechanism presents a narrower range where Individual Rationality is met compared with the mechanism that distributes the surplus revenue equally among all the regions (Figure 5-8). But the range of transfer prices that makes feasible the coordination using the risk-based distribution are higher, which may result in a more appealing initial contract to the growers and in a "cheaper" coordination process for the SCA, as less resources are needed to be distributed. The drawback of this mechanism is on the calculation of risk itself, which can be difficult considering a heterogeneous group of growers or regions.

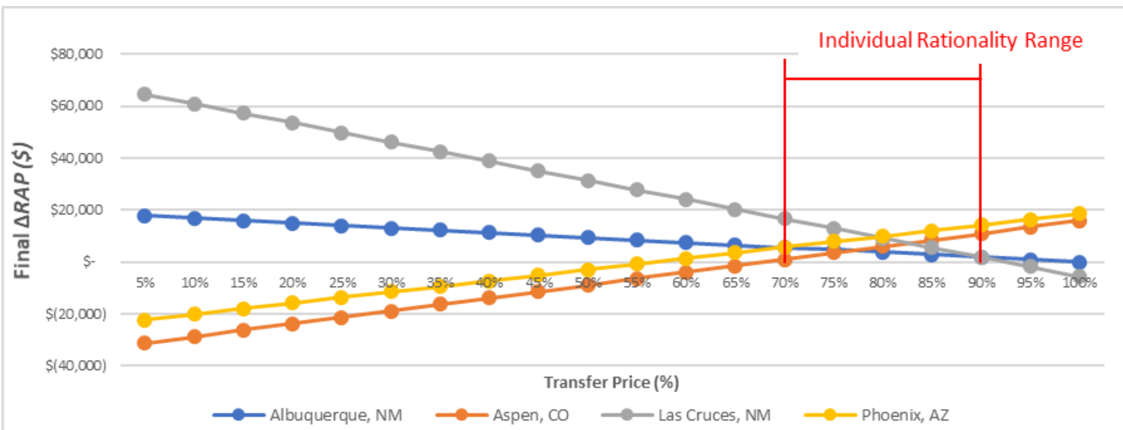


Figure 5-11: Perceived Benefits Using a Risk-based Revenue Distribution Mechanism.

A detailed example of the implementation of this mechanism is show in Table 5-3 below using Contract #10, which corresponds to a transfer price of 50%. On that table we present the Base *RAP*, which is used as a baseline to compare how the contract is perceived for the growers. In this case, we can see that the values of ΔRAP are all negative when consider just the revenue coming from the contract, indicating that for the growers in all four regions there is no benefit of engaging in the contract and some extra incentives might be needed to entice their participation. On the right side of Table 5-3 we can observe the equivalent risk estimated using equations 5.5 and 5.6, and the distribution factor that is used to allocate the extra revenue. For this example, the extra profit is allocated proportionally to each grower's equivalent risk, following the relationship given by equation 5.27 for each of the growers, and the total revenue that can be allocated resulting in the following set of equations:

$$\Pi_{Albuquerque} = k * \$5{,}548 \qquad \text{Eq. 5.28}$$

$$\Pi_{Aspen} = k * \$805 \qquad \text{Eq. 5.29}$$

$$\Pi_{Las\ Cruces} = k * \$12{,}273 \qquad \text{Eq. 5.30}$$

$$\Pi_{Phoenix} = k * \$2{,}451 \qquad \text{Eq. 5.31}$$

$$\Pi_{Albuquerque} + \Pi_{Aspen} + \Pi_{Las\ Cruces} + \Pi_{Phoenix} = Extra\ Revenue = \$70{,}924 \qquad \text{Eq. 5.32}$$

After solving the system of equations given by equations 5.28, 5.29, 5.30, 5.31, and 5.32 the extra revenue allocated to each grower is obtained (see Table 5-3), with a resulting constant relationship parameter of k = 3.36. The final benefit for each grower after both compensations (the contract and the extra revenue allocation) is shown in the last column of Table 5-3. We can observe that even after the extra profits distribution there are some regions (Aspen, CO and Phoenix, AZ) that do not see enough benefits to become part of the coalition for this contract, which is consistent with what is presented in Figure 5-11 for a transfer price of 50%.

Table 5-3: Example of the Risk-based Allocation Mechanism using Contract #10

		Results from the Contract (#10)					Results From the Revenue Allocation			
Region	**Base RAP**	**E[Profit]**	**Variance**	**E[Loss]**	**RAP**	**ΔRAP**	**Equivalent Risk**	**Distribution Factor**	**Extra Profit Allocated**	**Final ΔRAP**
Albuquerque, NM	$ 94,901	$ 91,206	$ 297,150,488	$25,764	**$ 85,658**	$ (9,243)	5,548	26%	$ 18,668	$ 9,425
Aspen, CO	$ 45,581	$ 34,833	$ 18,184,407	$ 6,232	**$ 34,028**	$ (11,554)	805	4%	$ 2,709	$ (8,844)
Las Cruces, NM	$ 125,754	$ 128,184	$ 1,105,231,428	$12,212	**$115,910**	$ (9,843)	12,273	58%	$ 41,299	$ 31,456
Phoenix, AZ	$ 76,071	$ 67,403	$ 147,505,664	$ 9,758	**$ 64,952**	$ (11,119)	2,451	12%	$ 8,247	$ (2,872)

When the revenue allocation mechanism used seeks to maximize the minimum perceived benefits (ΔRAP) the results are completely different. A summary of the results obtained using this mechanism for each of the contract is shown in Figure 5-12. One can observe that for any contract up to a transfer price of 95%, there is enough budget to achieve *Individual Rationality*. This means that for these contracts the mechanism can provide a solution that increases the perceived benefits for all the growers participating in the coalition, without the need of external incentives. In other words, the extra revenue that can be kept aside by the SCA is enough to compensate and align those growers who may not perceive enough benefits from the production contract alone. When the transfer price is higher than 95%, then the extra revenue is not enough to compensate and at least one of the growers do not receive enough compensation to take part in the coordinated solution, violating the *Budget Balance* requirement for the mechanism. This is consistent with the results on Figure 5-5, which depicts how the *Budget Balance* characteristic of a mechanism can be achieved for each of the contracts when the transfer price is up to 95%. The advantage of this mechanism over the other two mechanisms where *Individual Rationality* could be achieved (equal distribution and risk-based distribution) is that the range for which this requirement is achieved is wider, resulting in more flexibility for the SCA when offering production contracts to the growers. A disadvantage is how the allocation could be perceived by the growers in some regions as some of the revenues obtained from the highly contributing regions are used to subsidize those in a less favorable position. Even if at the end every participant may receive the same benefit from the coalition formation, these will not necessarily be proportional to their contribution.

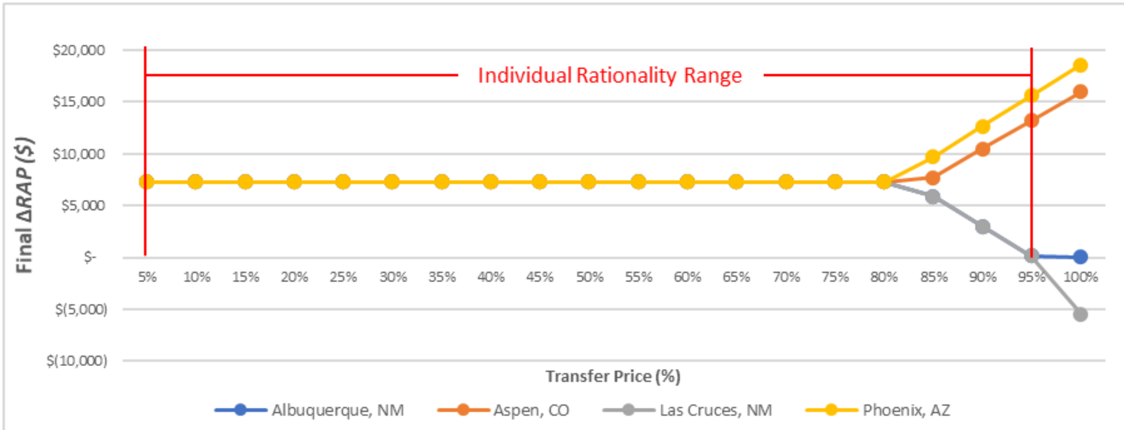


Figure 5-12: Perceived Benefits Maximizing the Minimum *ΔRAP* for Each Contract.

A detailed example of this allocation is show in Table 5-4 and Figure 5-13 using Contract #10 (which corresponds to a price factor of 50%). Initially, the growers in Albuquerque, NM, Aspen, CO, Las Cruces, NM and Phoenix, AZ perceive losses from the contract alone. The initial values of ΔRAP perceived solely form the offered contracts for these regions are -$9,243, -$11,554, -$9,843, and -$11,119 respectively. The allocation of the extra revenue starts with the region receiving the least benefit (or higher loss), which is Aspen, CO. The remaining extra revenue will then be allocated to maximize the minimum benefit expected for any of the participants. When applying this mechanism for Contract #10, the additional revenues allocated by the mechanism to Albuquerque, NM, Aspen, CO, Las Cruces, NM and Phoenix, AZ are $16,534, $18,845, $17,134, and 18,410 respectively, resulting in a final total benefit (*Final* ΔRAP) for each of the regions of $7,291 as shown on the right side of Table 5-4. After the revenue allocation using this mechanism, everyone will receive benefits from the coalition and, theoretically, a coordinated solution satisfying all the desired characteristics of the mechanism and the solution.

Table 5-4: Summary Results Comparing the Case of No Coordination (no contract), and an Example of the Allocation Using the Maximization of the Minimum Benefit for Contract #10.

		Results from the Contract (#10)					Result of Allocation	
Region	Base RAP	E[Profit]	Variance	E[Loss]	RAP	ΔRAP	Extra Profit Allocated	Final ΔRAP
Albuquerque, NM	$ 94,901	$ 91,206	$ 297,150,488	$25,764	$ 85,658	$ (9,243)	$ 16,534	$ 7,291
Aspen, CO	$ 45,581	$ 34,833	$ 18,184,407	$ 6,232	$ 34,028	$ (11,554)	$ 18,845	$ 7,291
Las Cruces, NM	$ 125,754	$ 128,184	$ 1,105,231,428	$12,212	$115,910	$ (9,843)	$ 17,134	$ 7,291
Phoenix, AZ	$ 76,071	$ 67,403	$ 147,505,664	$ 9,758	$ 64,952	$ (11,119)	$ 18,410	$ 7,291

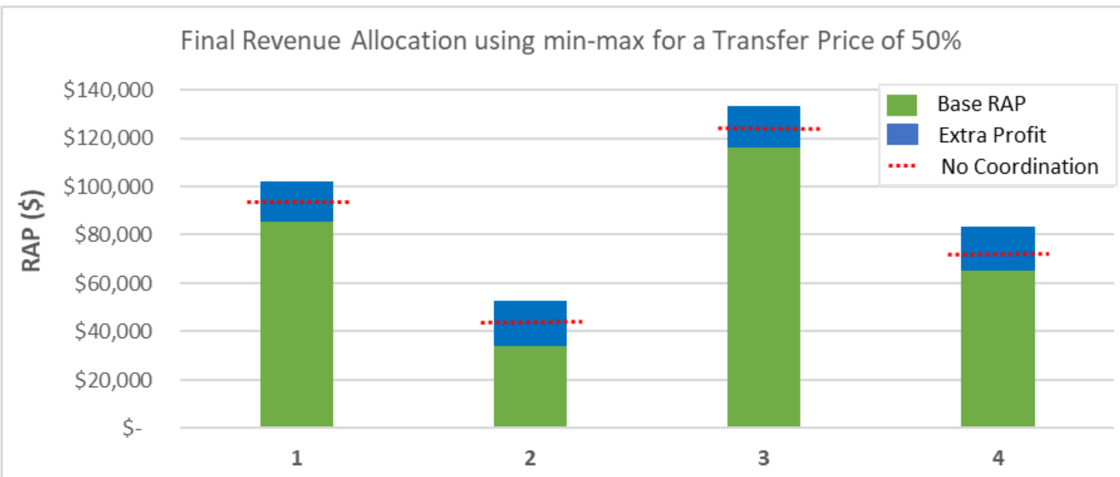


Figure 5-13: Comparison of the Expected RAP for Each Region in Presence of the Coordinated Solution and the Extra Revenue Allocation.

The last mechanism analyzed corresponds to a revenue allocation based on the marginal contribution of each grower, using the Shapley Value method. This method consists of evaluating all the possible combinations of supply chain participants, and to estimate the marginal contribution that each of the growers provide under any of these combinations (for a detail discussion of this method, the reader is referred to Winter 2002). Then the estimated marginal contributions are used to compute the percentage of the extra revenue that is allocated to each grower. The results from this mechanism are shown in Figure 5-14 below.

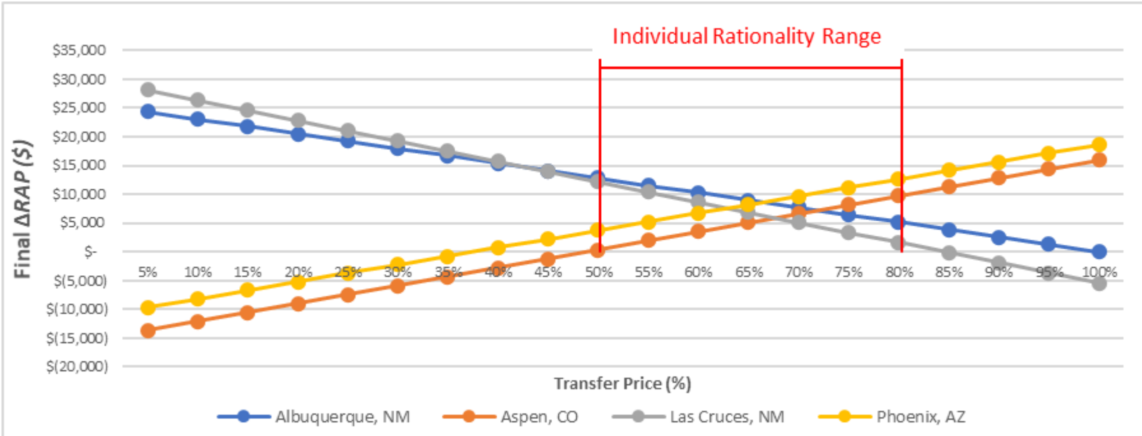


Figure 5-14: Perceived Benefits Using the Marginal Contribution Mechanism.

One can observe that when the marginal contribution is used to distribute the extra revenue, the range of transfer prices on which the *Individual Rationality* requirement is fulfilled for all the growers is between 50% and 80%. For any transfer price outside this range there is at least one grower who won't perceive enough incentives from the opportunity to participate in the coalition. Note that for the growers in Albuquerque, NM and Las Cruces, NM the perceived benefits of the opportunity decrease as the transfer price increases, while for those in Aspen, CO and Phoenix, AZ an increment in the transfer price is seen as beneficial. With respect to the previous mechanisms, the results of this mechanism provide a balanced range of transfer prices for which the coordination could be achieved: the width of the range is of about 30% (with transfer prices from 50% and 80%), and in the high-end of the range, which may offer a better response from the growers. A drawback of this mechanism is that the calculations behind the revenue distribution are more complex than the previous methods, and the process of how the marginal contributions are estimated may be hard to convey to the growers in such a way that they can trust the allocation solution, which makes the implementation of this mechanism harder than the rest.

The results analyzed above suggests that different mechanism may present different advantages and disadvantages. Some advantages of the equal distribution (b), volume-based (c), and value-based (d) distributions are that they are simple to explain and to calculate how the revenues are distributed. But the trade-off for the simplicity is that they may be perceived as unfair if no other considerations are made while allocating the extra revenues, such as the risk taken or how each grower contributes to the overall solution. On the other hand, mechanisms such as a risk-based (e), maximum minimum benefit (f), and marginal contribution (g) based methods may be perceived as more fair mechanisms as they consider more factors into the calculations, but the explanation and actual implementation may result difficult, with respect to the "alternative scenarios" that are considered within the calculation. An example of this is the case of the marginal contribution (g) mechanism, which requires to analyze very single combination of potential participants in the opportunity to evaluate their marginal contributions. Thus, there is not an overall "best mechanism" as some of the methods explored will not lead to a solution that will entice the participation of all growers in the coalition. Another drawback of these mechanisms is that they rely on complete information from the growers' side, such as cost's structure, risk profiles, etc. Also, there is the issue of growers not willing to share their information, or even worse, having incentives to provide false information to take advantage of the mechanism, topic that is outside of the scope of this work.

5.4 Determination of Production Contracts Using Auction Mechanisms within Each Producing Region

The previous results provided a general idea of how the demand contract could be allocated to potential producing regions and how the contract value could be distributed in such a way that each of the regions is enticed to collaborate. This baseline provides an estimated total value that could be allocated to the growers in each of the regions, which depending on their particular conditions and preferences, may require different contractual terms. Thus, we use of the results from the previous section as a total production contract and value that could be distributed among the growers in each of the regions. Using an adapted version of the tool developed by Mason (2015) we simulate a decentralized negotiation process between the SCA and the growers in each of the regions to obtain specific contractual terms for each grower that will coordinate the growers in each region. The model consists of an auction process on which an initial vector of prices is offered to the growers. With these prices published, the growers determine what is their best production alternative and submit a supply offer (volumes) for the season. Then, the SCA compiles the responses from all the growers and determines the difference between the supplied volume and his needs (portion of the demand contact allocated to that specific region). If there is a mismatch, then the SCA adjusts the price vector increasing the price when there is shortage and decreasing the price for those weeks where there is surplus of produce being supplied. With this new price vector, the growers re-evaluate their decisions and submit a new response to the SCA. This process goes on, until a convergence in the prices and solutions is achieved or the volume supplied by the growers matches the SCA requirements. This process is depicted in Figure 5-15 below.

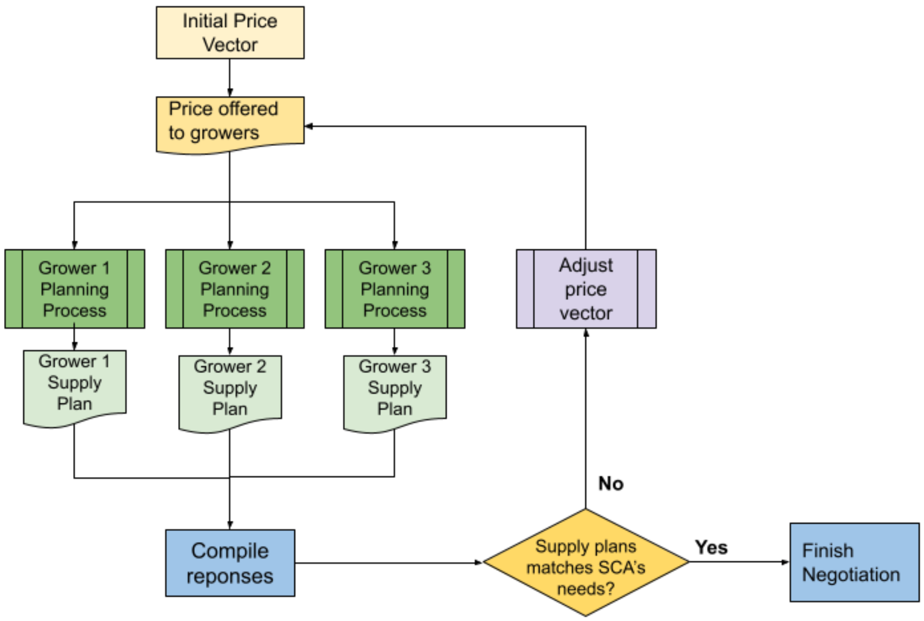


Figure 5-15: Price Negotiation Process in the Auction Mechanism Developed by Mason (2015).

To facilitate the interpretation of the rest of this section, we included the original model developed by Mason (2015) for his auction mechanism. The model is included below, and for a more detailed explanation of the model the reader is referred to his work found in Mason (2015).

<u>Indices and Sets</u>:

$t \in T$	: Set of planning periods *t* (weeks)
$p \in P \subset T$	: Set of planting weeks *p*
$h \in H \subset T$	: Set of harvesting weeks *h*
$j \in J$	: Set of crops *j*
$q \in Q$	: Set of quality states *q*
$l \in L$	: Set of locations (growers)

<u>Variables</u>:

$Vplant_{pjl}$	: Area to plant of crop *j* in period *p* at location *l*
$Vharv_{hjl}$	: Harvest quantity of crop *j* in period *h* at location *l*

$Vlab_{tl}$: Seasonal laborers employed at location *l* at time *t*

$VHire_{tl}$: Seasonal laborers hired for location *l* at time *t*

$VFire_{tl}$: Seasonal laborers dismissed from location *l* at time *t*

Y_{jpl} (Binary) : 1 If crop *j* is planted at period *p* at location *l* 0 otherwise

$Vtrans_{hjql}$: Amount to transport from location *l* of crop *j* with quality *q* at time *h*

$Vinv_{hjq}$: Amount to store of crop *j* with quality *q* at time *h*

$Vwaste_{hjq}$: Amount of crop *j* with quality *q* discarded at time *h*

$Vsell_{hjq}$: Amount of crop *j* to sell with quality *q* at time *h*

$Vover_{hj}$: Overage of crop *j* at time *h*

$Vunder_{hj}$: Underage of crop *j* at time *h*

Parameters:

$Land_l$: Land available at location *l* (in acres)

$LaborP_{ptj}$: Workers required at period *t* for cultivating crop *j* planted at period *p* (Men-week/ Acre)

$LaborH_j$: Workers required for harvesting crop *j* (Men-week/Acre)

$MaxLab_l$: Max number of workers that can be hired in location l

$Yield_{phj}$: Expected yield of crop *j* planted in location *l* at time *p* and harvested in week *h* (%)

$Total_{jl}$: Expected total production of crop *j* planted in location *l* at time *p* (Cartons/ Acre)

$MaxL_j$: Maximum allowed amount to plant of crop *j* during one week (in Acre)

$MinL_j$: Minimum allowed amount to plant of crop *j* during one week (in Acre)

$QualD_{jql}$: Quality distribution *q* for crop *j* for farmer *l*

Δtl_l : Travel time from location *l* to facility

Δql_{lj} : Change in quality for product *j* traveling from location *l* to facility

$MaxDem_{hj}$: Maximum demand of crop *j* at time *h* (Maximum open market)

$MinDem_{hj}$: Minimum demand of crop *j* at time *h* (Contracted demand)

$qmin_j$: Minimum quality accepted for crop *j*

$WHCap$: Total capacity of consolidation facility

Δq_j : Change in quality for product *j* stored one week at CF

$Cplant_{jl}$: Cost per acre of planting and cultivating for crop *j* (exclude labor)

$Charv_{jl}$: Cost per acre of harvesting for crop *j* (exclude labor)

$Chire_t$: Fixed cost to hire a seasonal worker at time *t*

$Clab_t$: Variable cost to hire a seasonal worker at time *t*

$Ctrans_{jl}$: Cost of transportation form location *l* to facility

$Cinv_j$: Inventory cost for crop *j*

$Cwaste_j$: Cost of disposing of product *j*

$Cover_j$: Cost of overage for product *j*

$Cunder_j$: Cost of underage for product *j*

$Price_{hj}$: Expected price for crop *j* at time *h*

Objective Function:

The objective function consists of maximizing the expected profits for all the participant growers, considering the planting costs and both risk metrics defined in equations 5.5 and 5.6:

$maximize$:

$$\sum_{hj,qmax_j \geq q \geq qmin_j} Vsell_{hjq} * Price_{hj} - \sum_{hjq} Vinv_{hjq} * Cinv_j - \sum_{hjq} Vover_{hj} * Cover_j - \sum_{hjq} Vunder_{hj} * Cunder_j - \sum_{ljqt} Vtrans_{hjql} * Ctrans_{jl} - \sum_{tl} (VHire_{tl} * Chire_t) - \sum_{tl} (Vlab_{tl} * Clab_t) - \sum_{pjl} \left(VPlant_{pjl} * Cplant_j\right) - \sum_{hjl} \left(Vharv_{hjl} * Charv_j\right) \qquad \text{Eq. 5.33}$$

Where the terms corresponding to the grower's profits ($Profit^{g,s}$) and the risk taken by the grower ($Risk_g$) are modeled as:

Constraints:

$$\sum_{j}\sum_{p} Vplant_{pjl} \leq Land_l \qquad \forall\, l \in L \qquad \text{Eq. 5.34}$$

$$Min_j * Y_{jpl} \leq Vplant_{pjl} \leq Max_j * Y_{jpl} \qquad \forall\, j \in J,\ p \in P, l \in L \qquad \text{Eq. 5.35}$$

$$Vharv_{hjl} \leq \sum_{p} Vplant_{pjl} * Yield_{phj} * Total_{jl} \qquad \forall\, h \in H,\ j \in J,\quad l \in L \qquad \text{Eq. 5.36}$$

$$Vlab_{tl} \geq \sum_{p}\sum_{j} Vplant_{pjl} * LaborP_{ptj} + \sum_{h=t}\sum_{j} Vharv_{hjl} * LaborH_j \qquad \forall\, t \in T, l \in L \qquad \text{Eq. 5.37}$$

$$VHire_{tl} - VFire_{tl} = Vlab_{tl} - Vlab_{(t-1)l} \qquad \forall\, t \in T,\ l \in L \qquad \text{Eq. 5.38}$$

$$\sum_{t} VHire_{tl} \leq MaxLab_l \qquad \forall\quad l \in L \qquad \text{Eq. 5.39}$$

$$Vharv_{hjl} * QualD_{hjql} = Vtrans_{lj(q-\Delta ql_{lj})(h+\Delta tl_l)} \qquad \forall\quad h, j, q, l \qquad \text{Eq. 5.40}$$

$$\sum_{l} Vtrans_{hljq} = PVarr_{h,j,q} \qquad \forall\quad \mathrm{j, q}, h \qquad \text{Eq. 5.41}$$

$$PVarr_{h,j,q} + Vinv_{h-1,jq+\Delta q_j} - Vsell_{hjq} - Vwaste_{hjq} = Vinv_{h,j,q} \qquad \forall\quad \mathrm{j, q}, h \qquad \text{Eq. 5.42}$$

$$MinDem_{hj} - Vunder_{hj} \leq \sum_{qmax_j \geq q \geq qmin_j} Vsell_{hjq} \leq MaxDem_{hj} + Vover_{hj} \qquad \forall j, h \forall\quad h \qquad \text{Eq. 5.43}$$

$$\sum_{jq} Vinv_{hjq} \leq WHCap \qquad \forall h \qquad \text{Eq. 5.44}$$

The changes to the model developed by Mason (2015) consist of the inclusion of the spot market in each of the growers decision-making problem. The inclusion of the spot market is to be consistent with the model developed in the first part of this chapter. A second change to the model consists of using different step-size for the gradient descent algorithm that adjusts the prices.

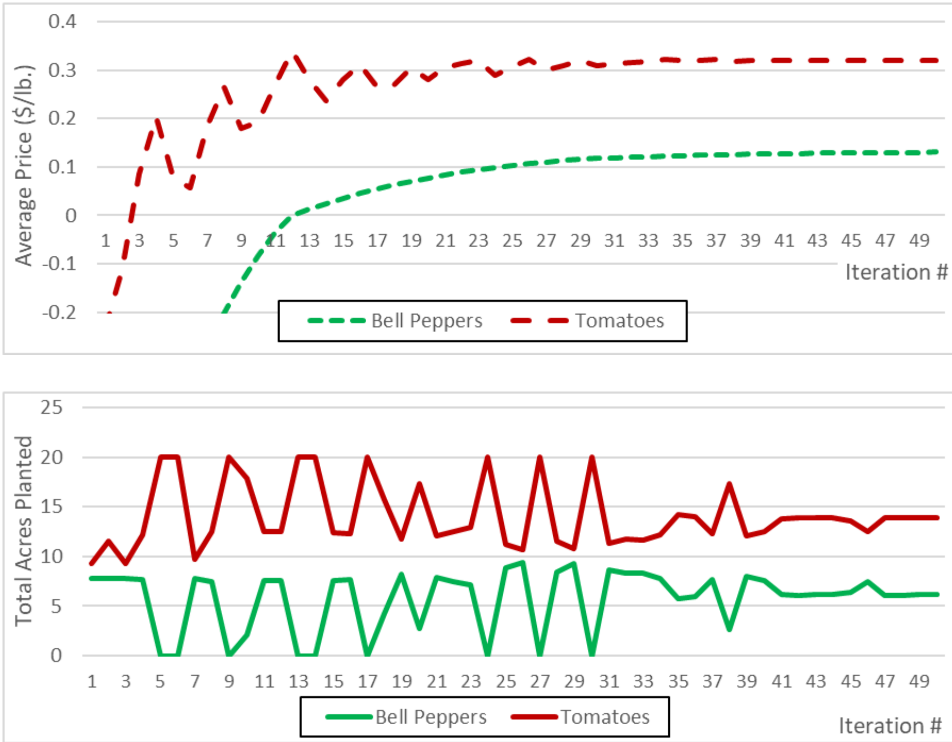
The original constraint used by Mason (2015), defined by equation 5.40, relates the harvested volumes ($Vharv_{h,j,l}$) and the quality distribution ($QualD_{j,q,l}$), with the shipments to the consolidation facility ($Vtrans_{h,j,q,l}$), which in our case corresponds to the produce that is being supplied to SCA. To adapt the constraint defined above to our framework, we modified it by including an additional term representing the sales to the spot market, $VsellSpot_{h,j,q,l}$. This allows the independent growers to determine if it is more convenient to sell their produce to the SCA (via the offered contract) or to their local spot market. The resulting modified constraint is as follows:

$$Vharv_{hjl} * QualD_{hjql} + VsellSpot_{h,j,q,l} = Vtrans_{lj(q-\Delta ql_{lj})(h+\Delta tl_l)} \qquad \forall h,j,q,l \qquad \text{Eq. 5.45}$$

The last modification to the model originally developed by Mason (2015) was the inclusion of a crop dependent step size for the gradient descent algorithm. In their original work, the authors considered a step-size that was the same for all crops, and for all weeks. This was modified in the research presented in this document by adding the crop index j to the gradient descent step size. This allowed us to have the prices for each crop to change at a different rate, enabling higher stability in the solutions.

With these modifications we were able to use the results from the centralized negotiation model (previous section) to obtain contractual terms that result from the decentralized negotiation between the SCA and the growers at a local scale in each of the regions. A summary of these results is shown below, with a focus on how this complements the revenue distribution mechanisms presented in the previous section. We consider the cases where the agreed price with the growers, after the negotiation takes place, coincides with the feasible/desirable range for transfer prices for the different proposed mechanisms; and if it does not, we provide insights on how the two models could be integrated to modify the results of the general coordination to influence the likelihood of acceptable contracts as an outcome for the negotiation.

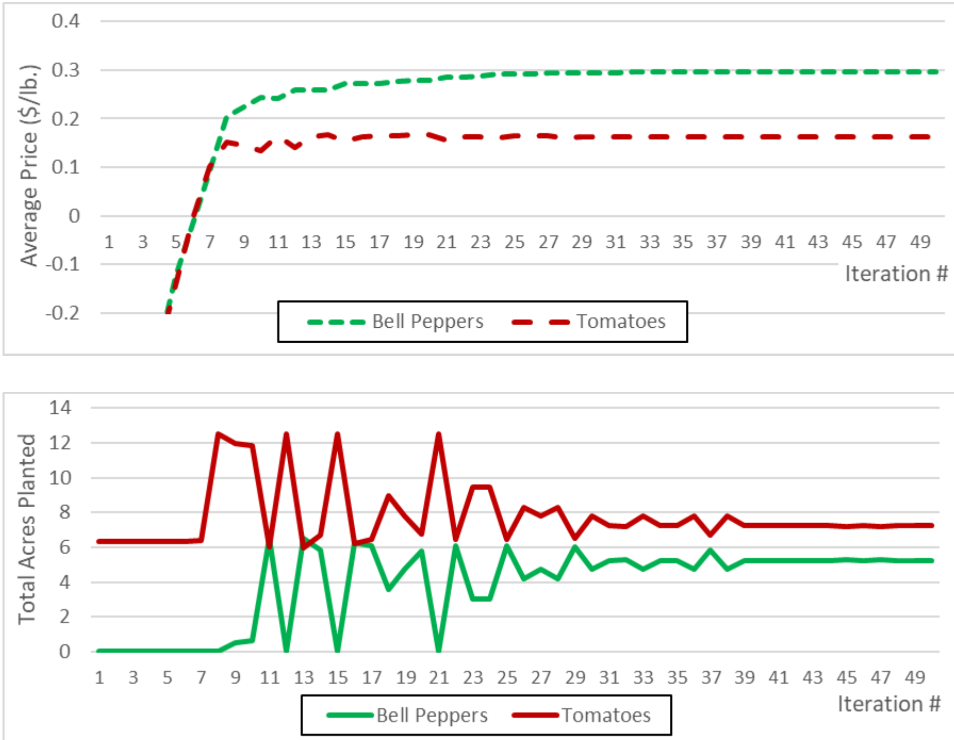
Using the modified version of the auction mechanism developed by Mason (2015) we were able to simulate the negotiation process between the SCA and the growers in each of the four regions presented in the previous section. This implementation was done using AMPL and running on a system equipped with an Intel Core i5-8500 @ 3.00 GHz processor, and 16GB of RAM. Each region was offered a different general contract, in terms of volumes and timings, and the price was negotiated with the growers to come up with the final contractual terms for each grower. In the case of the growers in Albuquerque, NM the results are shown in Figure 5-16, where one can observe that there is a convergence in the auction prices after around 40 iterations (which was achieved within 10.6 seconds of CPU time), where also the planting decisions for the growers stabilize. This contract price corresponds to an equivalent transfer price of 54%, generating a surplus of $120,178 available for the SCA to distribute as part of the second payment, as explained in the previous sections.



Contract Cost	Contract Revenue	Surplus	Equivalent Transfer Price (%)
$ 59,061	$ 120,178	$ 61,118	**54%**

Figure 5-16: Results of the Negotiation Process Between the SCA and the Growers in Albuquerque, NM.

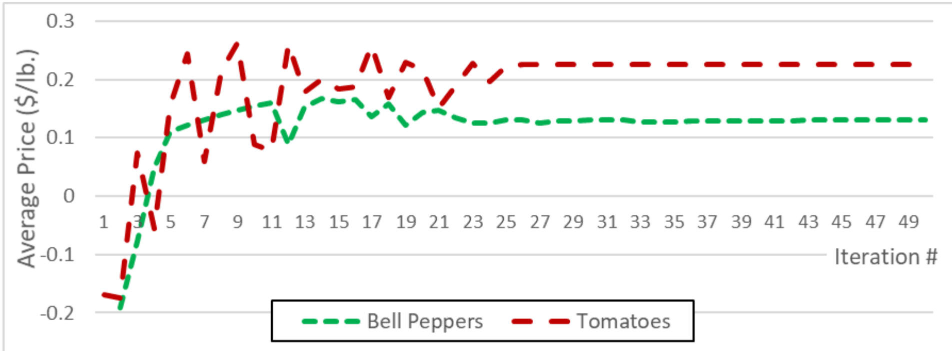
In the case of the negotiation between the SCA and the growers in Aspen, CO the mechanism converges slightly faster reaching stability in after 25 iterations in terms of prices (7.6 seconds of CPU time), and 40 interactions in terms of planting decisions (10.4 seconds of CPU time), as shown in Figure 5-17. With respect to the final agreement, the resulting equivalent transfer price corresponds to 69% of the price agreed between the SCA and the buyers. This generates a surplus profit of $75,000 available for the SCA to distribute as part of the second payment in the revenue distribution mechanism.

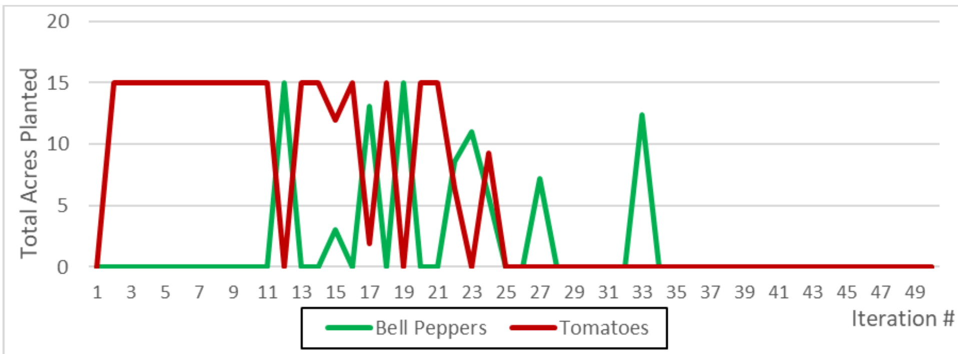


Contract Cost	Contract Benefit	Surplus	Equivalent Transfer Price (%)
$ 84,701	$ 159,761	$ 75,060	**69%**

Figure 5-17: Results of the Negotiation Process Between the SCA and the Growers in Aspen, CO.

In the case of the negotiation with the growers in Las Cruces, NM the auction mechanism reaches stability with respect to the prices after 25 iterations (8.2 seconds of CPU time), and 35 iterations (10.9 seconds of CPU time) with respect to the planning decisions for the growers. This solution generates a surplus profit of $2,278, with a transfer price of 60%. Note that the surplus level is much less than the one generated by the growers in both Albuquerque, NM and Aspen, CO. This occurs given that the volume allocated to Las Cruces is much less than what is being requested from other regions (see Figure 5-4 for an example).

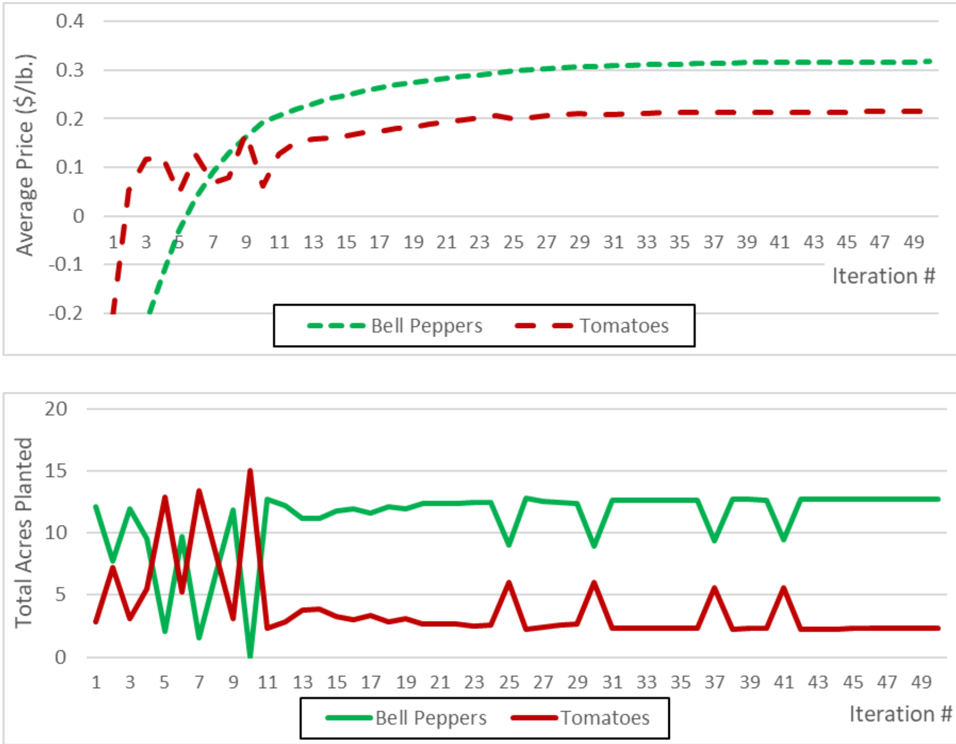




Contract Cost	Contract Benefit	Surplus	Equivalent Transfer Price (%)
$ 3,279	$ 5,557	$ 2,278	**60%**

Figure 5-18: Results of the Negotiation Process Between the SCA and the Growers in Las Cruces, NM.

The last simultaneous negotiation process is with between the SCA and the growers in Phoenix, AZ and the results are shown in Figure 5-19. We can observe convergence in both prices and planting decisions after 45 iterations (10.9 seconds of CPU time). This result corresponds to equivalent transfer prices of 62%, generating a surplus of $11,063 available for the SCA to distribute in the second payment.



Contract Cost	Contract Revenue	Surplus	Equivalent Transfer Price (%)
$ 148,697	$ 159,761	$ 11,063	**62%**

Figure 5-19: Results of the Negotiation Process Between the SCA and the Growers in Phoenix, AZ.

With these solutions obtained we can determine which of the proposed revenue distribution mechanism could be used for the coordination, based on the resulting equivalent transfer prices of the negotiation between the SCA and each of the regions. From the results we obtain that the range of transfer prices goes from 54% to 69%, obtained from the negotiations from Albuquerque, NM and Aspen, CO. The only revenue distribution mechanisms compatible with these range of transfer prices is when the extra revenue is distributed equally (Figure 5-8), the maximization of the minimum value of ΔRAP (Figure 5-12), and based on the marginal contribution (Figure 5-14). This suggests, that at least theoretically the SCA could use any of these three revenue distribution mechanisms with the contracts obtained after the individual negotiations and the coordination could be achieved in such a way that all the growers perceive benefits from engaging in the coordinated solution, even when considering their individual decision-making processes. As explained in previous section, the implementation of each of the mechanism will have its complexity with respect to how it is perceived by the growers, i.e.: in terms of fairness, and how complex it could be to explain the calculations behind the revenue distribution, particularly for a mechanism based on the marginal contribution of each grower.

After the negotiation with the growers in each of the regions is finalized, we can observe the resulting contracts structure in Figure 5-20 for Bell Peppers, and Figure 5-21 for Tomatoes. On these figures, the black continuous line represents the price offered by the buyers to the SCA and what will the SCA finally obtain for the crops. The dashed colored lines represent the price agreed with the growers in each region for that particular week of the year. A counter intuitive result is the fact that for some weeks the prices offered to the growers are higher than what the SCA will receive from the buyer, which will represent a loss for the SCA in that week for that specific crop. But we also observe that in many cases the offered prices are below the agreed price with the buyers, which represents profits that the SCA will obtain by procuring those crops at a cheaper price than what will receive from the buyers in that week.

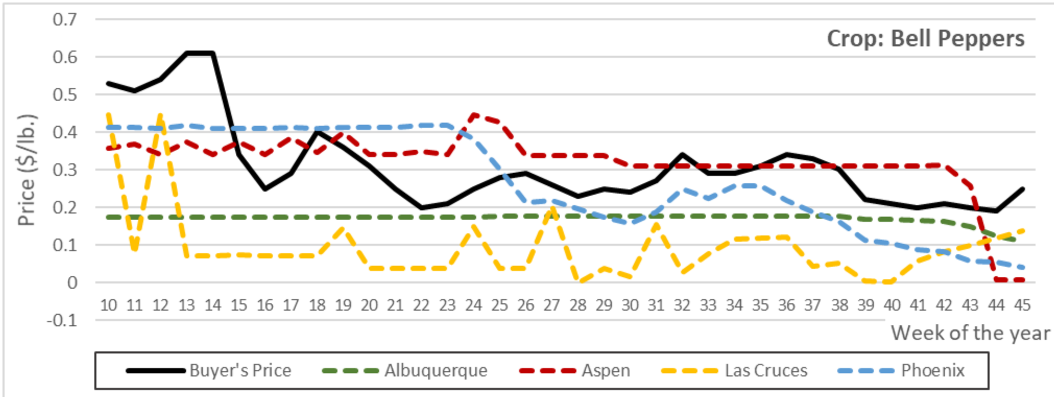


Figure 5-20: Contract Price for Bell Peppers after the Negotiation with the Growers in Each Region Reaches Stability.

For instance, in Figure 5-20 we can observe that between weeks 19 and 30 the prices for Bell Peppers offered to the growers in Aspen, CO (red dashed line) are higher than the price offered by the buyer (black continuous line); while for the growers in Albuquerque, NM (green dashed line) the price for bell peppers is always lower than the buyer's price. Similarly, we can see that in the case of tomatoes (Figure 5-21), the price offered to the growers in Las Cruces, NM (yellow dashed line) is higher than the price obtained from the buyer between weeks 30 and 35.

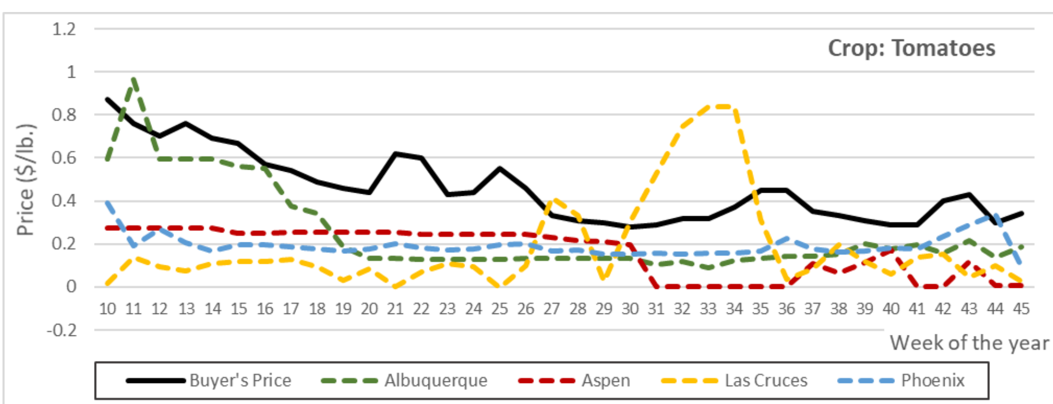


Figure 5-21: Contract Price for Tomatoes after the Negotiation with the Growers in Each Region Reaches Stability.

Allowing the SCA to simultaneously negotiate the price for both crops with each grower enables the flexibility to increase the price when there is a shortage of supply, even if this results in an offered price higher than what could be obtained from the buyer. This is compensated by allowing to reduce the price for those weeks on which there is an excess of supply. The combined effect of being able to negotiate individual prices for each planning week for each crop, allows to achieve a coordinated solution that in the overall enables the solution convergence, and to achieve the best match between supply from the growers and the buyers' demand.

5.5 Discussion of the Revenue Distribution Mechanisms on the Formation of Growers Coalition

With the tools and methodology presented in this document we were able to model both the demand allocation process, in the form of production contracts to a set of potential producing regions, and the effect of different revenue allocation mechanisms. With the use of the Revenue Adjusted Profit (RAP) metric we were able to analyze if the resulting contracts are appealing to the growers, and under which circumstances each grower will be willing to engage in the collaborative solution. The presented tool allowed to consider not only how the expected profits are received, but also to account for the risk preference of each participant and how it affects the perceived benefits of the coordinated solution.

We compared different revenue allocation mechanisms and how they can be perceived from the supply chain participants to accept or reject the proposed solution by the coordinating agent. The case study results show that for different contracts, the mechanism used to distribute the profits affects the growers' perception of the both the coordination and the revenue distribution processes. Depending on how the contract is designed and allocated, some growers may be enticed to participate even without allocating extra incentives. But when the extra revenue is used to entice the collaboration of the remaining growers, the mechanism used may not be enough to provide a solution that satisfy every participant's needs.

For the negotiation processes studied, when growers perceive a higher *RAP* estimation for the collaboration than the case without coordination, they can be initially enticed to engage in the coalition. But when the results of the process are published, some issues may arise as some growers may find the allocation process unfair to them. Knowing how the excess of revenue will be allocated a-priori may allow to overcome this issue as the participants will know ahead of time how it will be allocated, and the rules that the SCA will use to estimate and distribute the extra revenue.

We analyzed how the requirements for a coordination mechanism are affected by the way the contracts are created. In general, when setting some of the capital aside to be used to align incentives in a subsequent phase (revenue distribution), the coordination agent has to be careful to leave enough capital to compensate the perceived loses of some of the participants. If this is not considered, the *Budget Balance* condition will be violated, as the coordination could not be achieved without external sources of capital. On the other hand, depending on the mechanism used the *Individual Rationality* requirement may not be met, as some of the growers won't receive enough incentives to perceive the offered contract as a better option than staying out of the collaborative solution, even after the profit distribution is implemented.

With the integration between the models developed in this work with the model developed by Mason (2015), we were able to simulate the negotiation process between the SCA and the growers in each of the producing regions. Furthermore, specific contracts were obtained with each of the growers when considering their own decision-making process from a decentralized perspective. We were able to compare the resulting contract prices with the different possible transfer prices analyzed in Section 5.4 and determine which mechanisms could be used for this specific case study resulting in agreements that are likely to be accepted by the growers when also considering the values of ΔRAP from the participation in the coalition.

Chapter 6

PART III: NEGOTIATION WITH THE BUYER

The tools developed in previous sections take the perspective of coordinating the supply side of the supply chain, as the main SC agents involved in the process are the SCA, who acts as a coordinator, and the growers in each potential producing region. For the purpose of the development of these tools, we assume that a demand source was identified, and the volumes and prices required by the buyers were already known by the SCA when performing the identification and coordination of the growers. However, from a practical perspective the determination of volumes of the products to be supplied, and their corresponding prices, it is a key element in the overall process of making direct connections between the growers in the coalitions and the buyers of those products. Thus, in this section, a general coordination model is developed to facilitate the negotiation process between the potential buyers and the SCA. The basic set-up is comprised of a buyer seeking to give supply contracts, ahead of the realization of a future market demand. From the SCA's perspective the contract negotiation process involves finding and determining the contractual terms that will maximize the profits obtained by the growers he represents. Thus, the research presented in this section is takes the perspective of negotiating a supply contract between the buyer and the SCA. The result of this negotiation is a contractual agreement composed by prices and volumes over a period of multiple weeks, which are needed to build growers coalitions and provide transparency in the coordination process.

From the buyer's perspective he needs to procure produce to fulfill the expected demand for a given upcoming planning season. Under the scope of this work, we assume that the sourcing options are limited to either procure all the produce from the spot market once the demand is realized, or to enter into a procurement contract with the SCA (who is representing a group of growers) to secure part of the supply needed. From the perspective of the SCA, it is assumed that he represents growers from different regions, with different productions regions, whose production can be aggregated to satisfy the buyer's requirements. Thus, the SCA will represent the aggregated production capacity of the represented growers and will be perceived by the buyer as a single counterpart supplier in the preparation of the supply or production contract. The production contract can be seen as an agricultural forward contract in which a production schedule is prepared ahead of time growing season and the volume called for in the contract is delivered at the agreed date (Haydu et. al., 1992; Hasan et. al., 2018; Huh and Lall, 2013). However, to build more flexibility in the contract and to better accommodate risk, we assume that the production contract consists of a mix of fix commitments, and optional purchases (Barnes et. al., 2002; Wang et. al., 2015; Wang et. al., 2017). This type of contracts provides benefits to both the buyer(s) and the growers: the buyers have a secure supply for the produce that might be required by the market and have the option not to purchase excess of product if the demand is lower than expected, reducing his financial risk. On the other hand, the growers also gain certainty regarding the demand and receive an upfront payment, from the optional purchases, that will serve both as an initial capital to be used for the planting and growing activities, and as a lower bound on the incomes that could receive during the season. Note that as pointed out by Schieffer and Vassalos (2015), these are the two major reasons for growers to engage in a production contract. The fix commitments correspond to volume of a product that the buyer will have to purchase from the SCA regardless of the observed demand, with a specified price c_{fix}. The optional purchases correspond to a specified volume that the buyer has the right but not the obligation to purchase at the time window specified. Usually, the buyer exercises the options at his convenience given the observed demand occurrence. To offer this flexibility, the SCA charges a cost to reserve the optional purchase volumes, or cost of the option (c_{opt}). Once the demand is realized, and the buyer exercises the options, he will be paying an execution price c_{strike}. Note that in terms of the assumed relationship between these costs we have that $c_{opt} < c_{fix} < c_{opt} + c_{strike}$ to avoid getting trivial solutions. Thus, the negotiation process between these two parties corresponds to determining the number of fix commitments (F) and supply options (Q) the buyer will commit prior to the demand realization. There is a balance or trade-off between these two parameters for both the buyer and the SCA, as we explain below.

In terms of the buyer's problem, he must determine the quantity to purchase for both the fixed commitments and the supply options before the demand is realized. This will enable the buyer to develop a procurement plan for the expected demand. Therefore, the costs for the buyer before the season starts corresponds to the cost of the supply options. After the demand is realized he will incur in the cost of both the fix commitments and the cost of exercising some of the options at the cost c_{strike}. If the buyer does not procure enough volume in the production contract with the SCA, it is assumed that he will be forced to obtain the remaining produce from the spot market at a premium price c_{spot}, which is higher than $c_{opt} + c_{strike}$. In terms of the revenue for the buyer, we assume that the price received by the buyer from the market is estimated at a fixed value of p ($/lb.), and that the revenue received when the market demand is realized depends directly on that realization. The revenue and costs structure for the buyer is depicted at the top of the timeline presented in Figure 6-1.

From the SCA's perspective his decisions are tied to the buyer's choice of fix commitments and supply options quantities. In this work, we assume that the SCA will be able to supply all what is being requested by the buyer, regardless of the actual final number of options exercised. This means, that the SCA will procure the produce from either the growers' production, the spot market, or a combination of both. We assume that the production cost to the SCA is captured by a single price c_{prod}. In terms of the costs incurred by the SCA, the costs will correspond to the procurement cost of the whole volume purchased by the buyer as fix commitments and supply options. With respect to the revenues, it is assumed that revenues from options will be received at the time of signing the contract, and the payment from the fix commitments will be received when the products are received by the buyer. During the harvesting season the SCA may receive an extra revenue depending on the number of supply options exercised by the buyer at a price c_{strike}, and for the sale of the excess of produce in an alternative market at a salvage price of p_{salv}, for which it is assumed that $p_{salv} < c_{prod}$. The revenue and costs structure for the SCA is detailed at the bottom of the timeline presented in Figure 6-1.

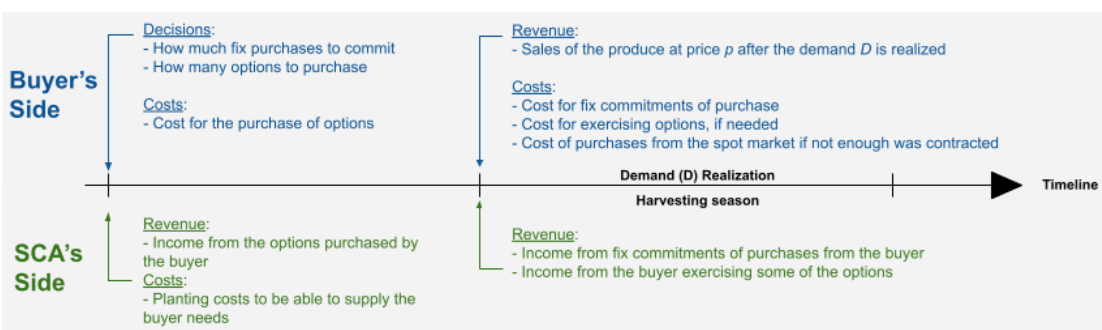


Figure 6-1: Timeline of Decisions, Costs, and Revenue for Each Participant of the Negotiation Process.

In the following section, we detail the mathematical formulation of the problem from the perspective of the buyer and the SCA as individual agents. To assess the need of a negotiation process that can enable the coordination and maximize the total value for both parties together, we model their profitability as a supply chain.

6.1 Mathematical Formulation and Derivations

Having defined the costs and revenue sources for both parties involved in the negotiation process, the next step is to determine the mathematical formulation that allows us to properly model and solve the problem of finding the optimal quantities for the buyer to purchase before the market demand is realized. In this context, the optimal quantity of options purchases corresponds to the number of option purchases that maximizes the expected profit for each participant when negotiating the contract. For this we used a modified version of the newsvendor problem which has been extensively studied for these type of problems (Brown & Lee, 1998; Wang et. al., 2017; Zhou et. al., 2019). In our case we consider a supply chain composed of a single supplier (the SCA) and a single retailer (the buyer), and we assume a two-period planning and execution processes on which the contractual terms are agreed at the first period ($t = 0$), and the remaining decisions (options exercised by the buyer) are made once the demand is realized at $t = T$. For our model, we assume that the value of the revenues or cost incurred by the parties each time period is not affected by the time value of money through interest rate, or alternatively that the interest rate is so small that is negligible, which is another common assumption under a newsvendor formulation (Wang et. al., 2017; Zhou et. al., 2019). On Table 6-1 below we detail the mathematical expression that corresponds to the revenue and cost received or incurred by each party at each of the time periods. We also include in the third row the aggregated values, which would be the case when both the buyer and the SCA are part of a vertically integrated company and both of them seek the maximization of the benefits of the two-stage supply chain without considering the split of the benefits between the two echelons of the supply chain.

Agent	Income (t=0)	Cost (t=0)	Income (t=T)	Cost (t=T)
Buyer	0	$Q * c_{opt}$	$price * D$	$F * c_{fix}$ $+(\min(D, F+Q) - \min(D,F)) * c_{strike}$ $+ \max(D-Q-F, 0) * C_{spot}$
SCA	$Q * c_{opt}$	$(F+Q) * c_{prod}$	$F * c_{fix} + (\min(D, F+Q) - \min(D,F)) * c_{strike}$ $+(Q - \min(D, F+Q) + \min(D,F)) * p_{salv}$	0
SC	0	$(F+Q) * c_{prod}$	$price * D$ $+(Q - \min(D, F+Q) + \min(D,F)) * p_{salv}$	$\max(D-Q-F, 0) * C_{spot}$

Table 6-1: Summary of the Revenue and Costs for the Buyer, SCA, and SC at Different Times Periods.

As explained before, in the negotiation process each of the participants will be seeking his own benefit and attempt to find the contract terms that will maximize his own profit. Thus, the models developed in this section seek to identify each participant's preferences and find an equilibrium that can result in a maximization of the total benefits achieved by the supply chain. In the next paragraphs we explain the problem from the perspective of the buyer and the SCA independently, and then we expand to consider both agents as a whole SC. Furthermore, by analyzing their profit functions we are capable of determine the conditions that will allow the coordination of both parties in such a way that the overall benefit is maximized.

From the buyer's perspective his profit will depend on the expectation of the costs and revenue detailed in the first row of Table 6-1 once the demand is exercised. Thus, without loss of generality we assume that the overall demand can be modeled as a random variable with probability density function $g(y)$ and cumulative probability function $G(y)$, which is common in the literature (Brown & Lee, 1998; Wang et. al., 2017; Zhou et. al., 2019; Polanco et. al., 2012). Thus, the profit function for the buyer based on the assumptions of our adaptation of the newsvendor problem described above in Table 6-1, is obtained as

$$\Pi^B(F,Q) = E[D] * price - Q * c_{opt} - F * c_{fix} + E[\min(D, F+Q) - \min(D,F)] * c_{strike} + E[\max(D-Q-F, 0)] * c_{spot} \qquad \text{Eq. 6.1}$$

And after some algebraic manipulation we get

$$\Pi^B(F,Q) = E[D] * \left(price - c_{spot}\right) - F * \left(c_{fix} - c_{spot}\right) - Q * (c_{opt} - c_{spot} + c_{strike}) + \left(c_{strike} - c_{spot}\right) * \int_0^{F+Q} G(y)dy - c_{strike} * \int_0^{F} G(y)dy \qquad \text{Eq. 6.2}$$

By considering the structure of the profit function for the buyer, we can derive the optimal quantity of supply options to procure as defined in Lemma 1 below.

Lemma 1*: The buyer's revenue function on the decision variable* Q *is concave, since it is a maximization problem composed by the sum of concave (maximization) functions. Furthermore, as the function is concave on* $Q \geq 0$, *then any point satisfying the first order optimality conditions is guaranteed to be a global optimum.*

<u>Proof</u>:

By taking the derivative of the profit function defined by equation 6.2 with respect to the quantity of options purchase Q, we can obtain

$$\frac{\partial \Pi^B(F,Q)}{\partial Q} = c_{spot} - c_{opt} - c_{strike} + \left(c_{strike} - c_{spot}\right) * G(F+Q)$$

And by taking the second derivative we attain

$$\frac{\partial^2 \Pi^B(F,Q)}{\partial Q^2} = \left(c_{strike} - c_{spot}\right) * g(F+Q)$$

For which we know that as $c_{spot} < c_{strike}$, and that $g(F+Q) > 0$, then we can state that $\frac{\partial^2 \Pi^B(F,Q)}{\partial Q^2} < 0$ indicating that the function defined by $\Pi^B(F,Q)$ is concave over its domain. This satisfies the second order optimality condition for a function to have a global maximum. Thus, any optimal solution will be a global optimal.

The optimal quantity of the number of supply options for the buyer to procure can be obtained by the first order optimality condition denoted by

$$\frac{\partial \Pi^B(F,Q)}{\partial Q} = 0$$

Which results in the optimal options purchase quantity of:

$$Q_B^* = G^{-1}\left(\frac{c_{opt} + c_{strike} - c_{spot}}{c_{strike} - c_{spot}}\right) - F \qquad \text{Eq. 6.3}$$

□

This result suggests that the optimal options quantity will directly depend on the number of fix commitments (*F*) and on the cumulative probability function of the future demand, *G(y)*. As denoted by equation 6.3 the optimal quantity of supply options from the buyer will depend on how much produce might be needed above the fix commitments quantity. This result is also graphically shown in Figure 6-2, where we have the profit function for the buyer as a function of the number of supply options. We can observe that, for the buyer the optimal number of supply options corresponds to $Q_B^* = 3{,}549$, with a corresponding expected profit of $2,142.

Note that the values inside the inverse cumulative probability function in equation 6.3 are between 0 and 1, for all the domain. The proof of this statement is included in the appendix section of this document.

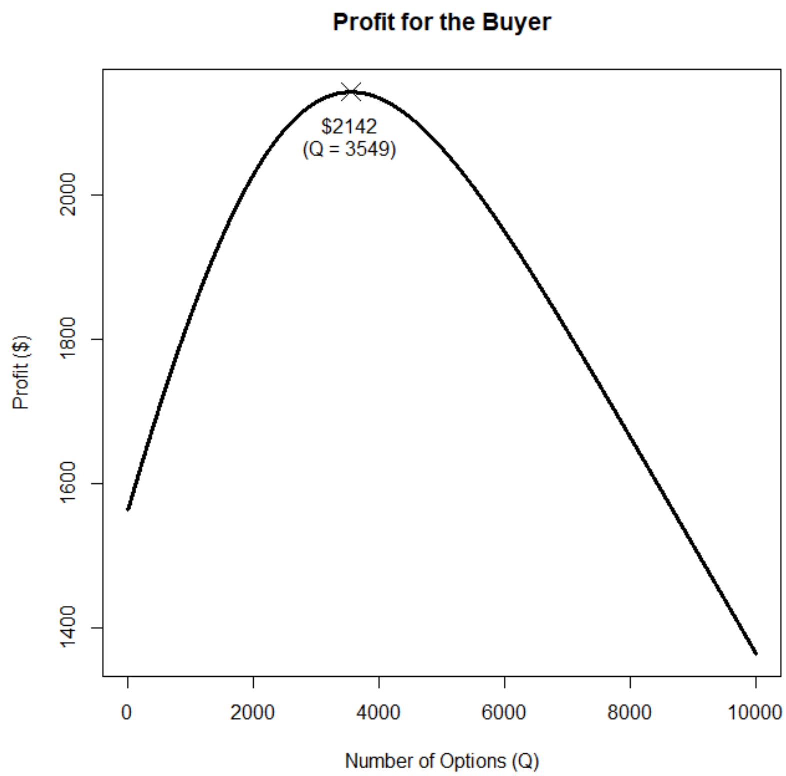


Figure 6-2: Effect of the Number of Supply Options (Q) in the Expected Profit for the Buyer.

Having determined the optimal decision for the buyer, we need to look at the problem from the SCA's perspective. In this case, the SCA's profit function will be defined by the revenue and costs detailed in the second row of Table 6-1. Then, the profit function for the SCA is defined as

$$\Pi^{SCA}(F,Q) = Q * c_{opt} - (F+Q) * c_{prod} + F * c_{fix} + E[\min(D,F+Q) - \min(D,F)] * c_{strike} + E[Q - \min(D,F+Q) + \min(D,F)] * p_{salv} \quad \text{Eq. 6.4}$$

And after some algebraic manipulation we get

$$\Pi^{SCA}(F,Q) = F * \left(c_{fix} - c_{prod}\right) + Q * \left(C_{opt} + c_{strike} - c_{prod}\right) + (p_{salv} - c_{strike}) * \int_0^{F+Q} G(y)dy - (p_{salv} - c_{strike}) * \int_0^{F} G(y)dy \quad \text{Eq. 6.5}$$

By considering the structure of the profit function for the SCA, we can derive the optimal quantity of supply options to procure as defined in Lemma 2 below.

Lemma 2*: The SCA's revenue function on the decision variable Q is concave, since it is a maximization problem composed by the sum of concave (maximization) functions. Furthermore, as the function is concave on $Q \geq 0$, then any point satisfying the first order optimality conditions is guaranteed to be a global optimum.*

Proof:

Similar to the proof of Lemma 1, we can take the derivative of the profit function defined by equation 6.5 with respect to the quantity of supply purchase *Q*, we can obtain

$$\frac{\partial \Pi^{SCA}(F,Q)}{\partial Q} = c_{opt} + c_{strike} - c_{prod} + (p_{salv} - c_{strike}) * G(F+Q)$$

And by taking the second derivative we attain

$$\frac{\partial^2 \Pi^{SCA}(F,Q)}{\partial Q^2} = (p_{salv} - c_{strike}) * g(F+Q)$$

Now, as we know that $c_{strike} < p_{salv}$ and that $g(F+Q) < 0$, then we can claim that $\frac{\partial^2 \Pi^{SCA}(F,Q)}{\partial Q^2} < 0$ indicating that the function defined by $\Pi^{SCA}(F,Q)$ is concave over its domain. This satisfies the second order optimality condition for a function to have a global maximum. Thus, any optimal solution will be a global optimal.

The optimal quantity of the number of supply options for the buyer to procure that maximizes the profit for the SCA can be obtained by the first order optimality condition denoted by

$$\frac{\partial \Pi^{SCA}(F,Q)}{\partial Q} = 0$$

Which results in the optimal options purchase quantity of:

$$Q^*_{SCA} = G^{-1}\left(\frac{c_{opt} + c_{strike} - c_{prod}}{c_{strike} - p_{salv}}\right) - F \qquad \text{Eq. 6.6}$$

□

Similarly, the optimal quantity for the buyer (Q^*_B), this quantity depends on the number of fix commitments and the distribution function for the future demand. This result is also graphically shown in Figure 6-3, where we have the profit function for the SCA as a function of the number of supply options. We can observe that, for the SCA the optimal number of supply options corresponds to $Q^*_{SCA} = 4{,}710$, with a corresponding expected profit of $1,477.

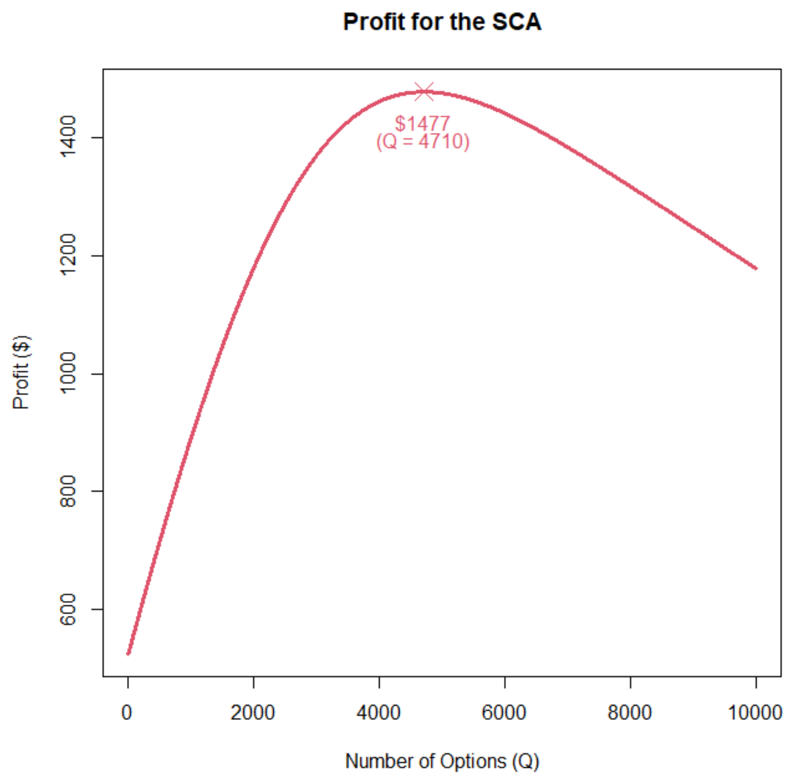


Figure 6-3: Effect of the Number of Supply Options (Q) in the Expected Profit for the SCA.

Having determined the optimal quantity of supply options that maximizes the revenue for both the buyer and the SCA independently, we then can compare the optimal quantities and observe that the values do not coincide. Thus, at least initially, the two parties will have a different optimal quantity of supply options desired to maximize each one's profit. This suggests the need of a coordination mechanism that will ensure to come to an agreement for both parties and achieve the maximum benefit for both simultaneously. To address this issue, we look at the problem by considering both parties together as part of the whole supply chain. Then the profit function for the supply chain can be obtained by considering the revenue and cost terms from the third row of Table 6-1 as follows:

$$\Pi^{sc}(F,Q) = E[D] * price - (F+Q) * c_{prod}$$
$$+ E[Q - \min(D, F+Q) + \min(D,F)] * p_{salv} \qquad \text{Eq. 6.7}$$
$$- E[\max(D - Q - F, 0)] * c_{spot}$$

And after some algebraic manipulation we get

$$\Pi^{sc}(F,Q) = E[D] * \left(price - c_{spot}\right) + (F+Q) * \left(c_{spot} - c_{prod}\right)$$
$$+ \left(p_{salv} - c_{spot}\right) * \int_0^{F+Q} G(y)dy - p_{salv} * \int_0^{F} G(y)dy \qquad \text{Eq. 6.8}$$

Following a similar procedure than the one used to determine the optimal purchase quantity for the buyer and the SCA in Lemma 1 and 2, respectively, we can determine the optimal number of supply options that maximizes the profit for both parties when considered together.

Lemma 3*: When considering the buyer and the SCA together as a Supply Chain, the resulting SC's revenue function on the decision variable Q is concave, since it is a maximization problem composed by the sum of concave (maximization) functions. Furthermore, as the function is concave on* $Q \geq 0$*, then any point satisfying the first order optimality conditions is guaranteed to be a global optimum.*

<u>Proof</u>:

Similar to the proof of Lemmas 1 and 2, we can take the derivative of the profit function defined by equation 6.8 with respect to the quantity of supply options Q, we can obtain

$$\frac{\partial \Pi^{SC}(F,Q)}{\partial Q} = c_{spot} - c_{prod} + \left(p_{salv} - c_{spot}\right) * G(F+Q)$$

And by taking the second derivative we attain

$$\frac{\partial^2 \Pi^{SC}(F,Q)}{\partial Q^2} = \left(p_{salv} - c_{spot}\right) * g(F+Q)$$

Now, as we know that $p_{salv} < c_{spot}$ and that $g(F+Q) < 0$, then we can claim that $\frac{\partial^2 \Pi^{SC}(F,Q)}{\partial Q^2} < 0$ indicating that the function defined by $\Pi^{SC}(F,Q)$ is concave over its domain. This satisfies the second order optimality condition for a function to have a global maximum. Thus, any optimal solution will be a global optimal.

The optimal quantity of the number of supply options for the buyer to procure from the SC's perspective can be obtained by the first order optimality condition denoted by

$$\frac{\partial \Pi^{SC}(F,Q)}{\partial Q} = 0$$

Which results in the optimal options purchase quantity of:

$$Q_{SC}^{*} = G^{-1}\left(\frac{c_{spot} - c_{prod}}{c_{spot} - p_{salv}}\right) - F \qquad \text{Eq. 6.9}$$

□

This result is also graphically shown in Figure 6-3, where we have the profit function for the supply chain as a function of the number of supply options. We can observe that, in the case of the integrated SC the optimal number of supply options corresponds to $Q_{SC}^{*} = 4{,}074$, with a corresponding expected profit of $3,596.

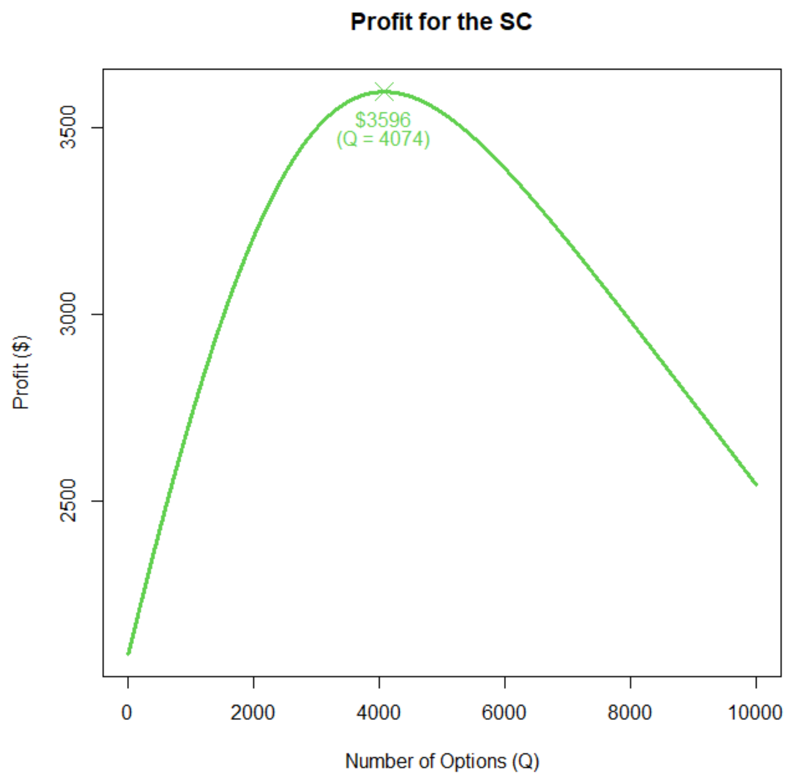


Figure 6-4: Effect of the Number of Supply Options (Q) in the Expected Profit for the Integrated SC.

From the lemmas presented above we can infer that there is an optimal quantity of supply options that will maximize each of the participants profitability. Furthermore, from Lemma 1 we can obtain a closed expression that can be used to determine the quantity of supply options that the buyer will be seeking to purchase at the beginning of the negotiation. Similarly, from Lemma 2 we can obtain the closed expression that represents the optimal quantity of supply options that the SCA prefers for the buyer to purchase. As we observed that both quantities are different, thus a coordination or negotiation scheme is required to align both parties to come into an agreement.

When considering both agents together as part of the same supply chain, the optimal quantity of supply options can be derived as shown in Lemma 3. This quantity indicates that the maximum profitability for the system (buyer and SCA) can be achieved if the number of options purchased by the buyer at the beginning of the negotiation corresponds to Q_{SC}^{*}. Again, the outcome of an efficient negotiation process will be such that the decision is as close as possible to the overall optimal decision, meaning that the highest profitability will be achieved. By having their decision-making processes independently, both agents have incentives to negotiate towards a different quantity of Q, thus in the next section we analyze some of the mechanisms that may ensure an alignment of incentives in such a way that both parties are leaning towards the quantity Q_{SC}^{*}.

Note that the profit functions for the buyer, the SCA, and the integrated supply chain are a function of both the amount of fix commitment purchases (F), and the amount of option purchases by the buyer (Q). Both quantities are relevant to the negotiation process as the final contract between the buyer(s) and the SCA will be defined by the purchase of both the fix commitments and the supply options. Under the scope of this work, we focus primarily on the effect of the amount of supply options (Q) to seek the coordination, as the execution these options provides flexibility to the buyer and will be more directly related with the variability of the random variable corresponding to the future demand, and its realization. The effect of the fix commitments (F) on the negotiation scheme is left for a future expansion of this work, but as a preliminary analysis we offer the following: we can obtain the Hessian Matrix for the buyer's profit function as shown below. By looking at the rows composing the Hessian Matrix we can determine that is positive semidefinite, suggesting that the function is concave for both Q and F. In Figure 6-5 below we can numerically observe the impact of the number of fix commitments purchased in the expected profit for the buyer.

$$H\left(\Pi^B(F,Q)\right) = \begin{Bmatrix} \dfrac{\partial^2\Pi^B(F,Q)}{\partial F^2} & \dfrac{\partial^2\Pi^B(F,Q)}{\partial Q \partial F} \\ \dfrac{\partial^2\Pi^B(F,Q)}{\partial F \partial Q} & \dfrac{\partial^2\Pi^B(F,Q)}{\partial Q^2} \end{Bmatrix}$$

$$H\left(\Pi^B(F,Q)\right) = \begin{Bmatrix} \left(c_{strike} - c_{spot}\right) * g(F+Q) - c_{strike} * g(F) & \left(c_{strike} - c_{spot}\right) * g(F+Q) \\ \left(c_{strike} - c_{spot}\right) * g(F+Q) & \left(c_{strike} - c_{spot}\right) * g(F+Q) \end{Bmatrix}$$

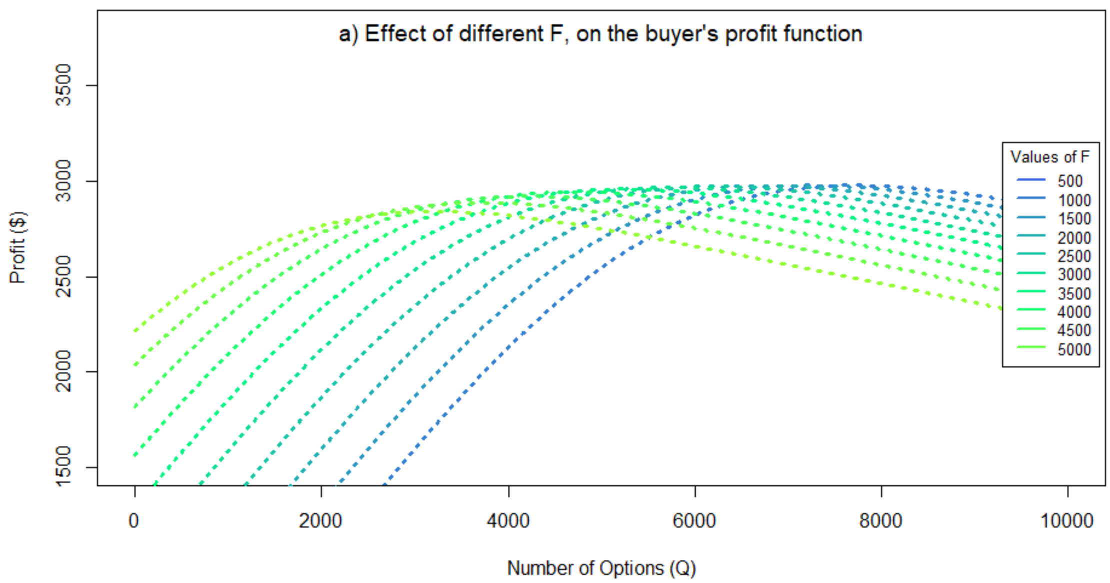


Figure 6-5: Sensitivity Analysis of the Number of Fix Commitment Purchases (F) on the Optimal Number of Supply Options (Q) for the Buyer.

We explore next how the coordination between the SC participants could be achieved, particularly from the perspective of aligning both parties' incentives in such a way that the overall profitability could be maximized. To illustrate these results, we introduce the following case study for a supply chain composed by a single buyer and the Supply Chain Articulator. In this case we assume the following parameters shown in Table 6-2.

Table 6-2: Parameters Used in the Case Study

Parameter	Value
Price (p)	\$1.0
Salvage price (p_{salv})	\$0.08
Mean demand (μ_D)	6,000
Demand Standard Deviation (σ_D)	2.000
Production cost per unit (c_{prod})	\$0.30
Fix commitment purchase price (c_{fix})	\$0.45
Option purchase price (c_{opt})	\$0.15
Option exercise price (c_{strike})	\$0.60

6.2 Coordination and Negotiation Approach

As we can observe from lemmas 1 and 2, we can note that the optimal quantity of supply options to be purchased by the buyer is directly dependent on the costs of purchasing and exercising the option. Thus, to align both parties' interest we can find the relationship between these costs that will allow the coordination of both participants making the optimal quantity for the SC (Q^*_{SC}) coincide with the individual optimal quantities.

By following the approach suggested by Brown & Lee (1998) we can find the option purchase cost that coordinates the SC by making the individual expressions for the optimal quantity for both parties, defined by equations 6.3 and 6.6, equal. This is done below:

$$Q^*_B = G^{-1}\left(\frac{c_{opt} + c_{strike} - c_{spot}}{c_{strike} - c_{spot}}\right) - F = G^{-1}\left(\frac{c_{opt} + c_{strike} - c_{prod}}{c_{strike} - p_{salv}}\right) - F \ = Q^*_{SCA}$$

Then, by rearranging some of the terms we can find the optimal option cost (c^*_{opt}) that will allow to make coordinate the interests of both parties as follows:

$$c^*_{opt} = \frac{\left(c_{strike} - c_{spot}\right) * \left(p_{salv} - c_{prod}\right)}{\left(c_{spot} - p_{salv}\right)} \qquad \text{Eq. 6.10}$$

By using the expression from equation 6.10 we can obtain the value of the coordinating option costs (c^*_{opt}) that will coordinate the SC participants, which for our case study corresponds to $0.16. The effect of this change in each participant's profitability is graphically shown in Figure 6-6 below. One can observe that the solid lines represent the original profit functions for the buyer (black line), the SCA (red line), and the SC as a whole (green line). The dotted lines correspond to the new profit functions once the options purchase price is set following the coordination option cost (c^*_{opt}). In the original setting, the optimal decision from the buyer's perspective was to purchase 3,548 options achieving an expected profit of $2,142; for the SCA, the optimal number of options to be purchased by the buyer was 4,709, giving him an expected profit of $1,477. Under the new conditions (defined by c^*_{opt}), the optimal decision for both parties, in terms of the number of options to be purchased by the buyer, is aligned with the optimal quantity for the SC obtaining $Q^*_B = Q^*_{SCA} = Q^*_{SC} = 4{,}073$. Furthermore, even if the total SC's profit is maximized, the effect of the new option purchase price is different for each participant as shown in Figure 6-6. From the buyer's perspective the new cost represents an increment in profitability (black dotted line) from $2,142 to $2,303, while for the SCA it represents a loss in the expected profits (red dotted line) from $1,477 to $1,293.

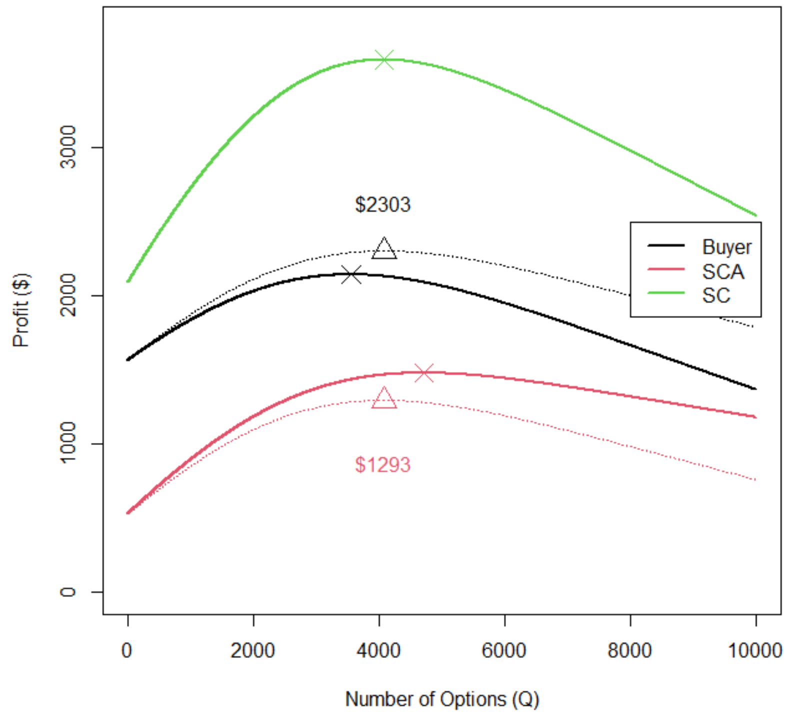


Figure 6-6: Effect of the Coordinating Option Cost in Each Participant Optimal Decision.

Furthermore, the expression defined by equation 6.10 allows us to find the relationship between the option purchase cost (c_{opt}) and the rest of the parameters that affects both parties' decision-making process. We can identify that some of these values are given by fixed or external factors (i.e.: the market) such as c_{prod}, c_{spot}, and p_{salv}. But there the costs related with the option purchase and execution, c_{opt} and c_{strike}, will directly depend on the SCA as he is offering the option to the buyer. This suggests that unlike previous attempts to coordinate that only focused on one of these costs, there might be a combination of values of c_{opt} and c_{strike} that will enable the SC coordination and align both parties' optimal quantity. For instance, the work by Brown & Lee (1998) assumed a fixed exercise cost (c_{strike}) and suggested a corresponding option purchase cost (c_{opt}) that aligns both agents optimal option purchases quantity to the one that maximizes the overall SC profits. In our work, we expand these findings by arranging the terms from equation 6.7 to find that there is a set of combinations c_{opt} and c_{opt} that will coordinate the SC, as defined in Lemma 4 below.

Lemma 4*: In presence of an options contract agreement between the supplier (SCA) and a buyer, there is a set of combinations between the option purchase price and the strike price that will coordinate the agents, matching each of the participants individual optimal options quantity to the optimal for the SC.*

Proof:

By rearranging the terms in equation 6.10 we can obtain

$$c_{opt} = (c_{strike} - c_{spot}) * \frac{(p_{salv} - c_{prod})}{(c_{spot} - p_{salv})}$$

And by separating the right-hand side with respect to the terms multiplying c_{strike} and what is external constant terms we obtain

$$c_{opt} = c_{strike} * \frac{(p_{salv} - c_{prod})}{(c_{spot} - p_{salv})} - \frac{c_{spot} * (p_{salv} - c_{prod})}{(c_{spot} - p_{salv})} \qquad \text{Eq. 6.11}$$

Which corresponds to a linear relationship between c_{opt} and c_{strike} that will suffice the conditions required to align both agents' interests in such a way that each participant's optimal corresponds to the SC optimal quantity of options to be purchased by the buyer.

□

Thus, as far as the option cost and strike price follow the relationship defined by equation 6.11, then the optimal number of supply options to be purchased by the buyer will be aligned with the optimal quantity to be sold by the SCA. Furthermore, this new optimal set of quantities will coincide with the optimal quantity for both parties considered together as a SC. Thus, any of the possible combinations will result in an efficient solution that aligns the decision-making process and increases the total profit for both parties when considering as a whole SC. The linear relationship, and possible combinations between these two costs is depicted in Figure 6-7 below.

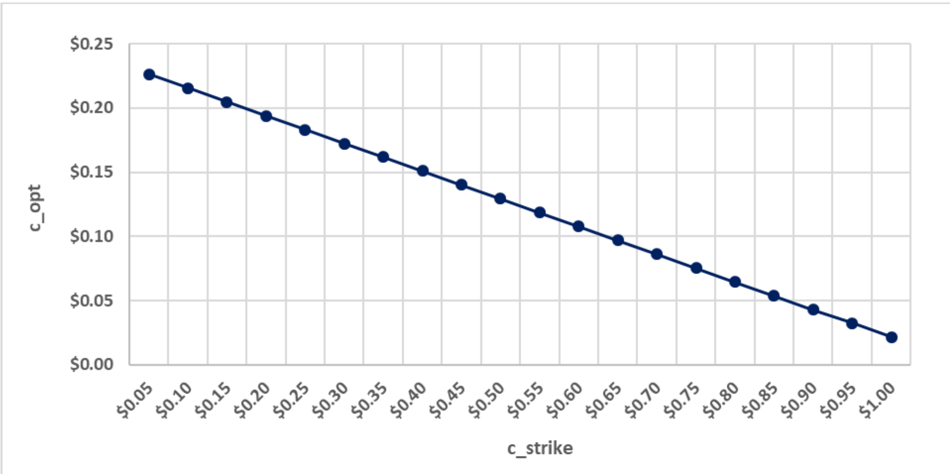


Figure 6-7: Option Cost and Strike Price Negotiation to Achieve SC's Maximum

In particular, each of the points that can be obtained from equation 6.11 (and shown in Figure 6-7) corresponds to a different solution in terms of how the revenues are allocated between both parties. Furthermore, each combination will denote a different profit curve for both the buyer and the SCA, as depicted in Figure 6-8. Thus both parties will have different incentives: the buyer (Figure 6-8a) will prefer higher values of c_{opt}, with the corresponding lower costs for c_{strike}; while the SCA (Figure 6-8b) will prefer offering a lower option purchase price, but with a higher exercise value. Thus, the linear relationship defined by equation 6.11 represents a trade-off between the profits that each of the involved agents can obtain, and an extra analysis is required to achieve a solution that can coordinate both parties.

Therefore, there is a need of an extra analysis to determine which of the possible combinations of c_{opt} and c_{strike} will result in convenient terms for both agents. This will require the inclusion of an external consideration or constraint, such as the minimum profit expected from the negotiation. We can assume then that both the buyer and the SCA will have a minimum expected profit that will be required to come to an agreement. For the buyer, he will be expecting to obtain a minimum profit of $Target^{B}$ from the resulting contract to commit to it, similarly, the SCA will have a minimum profit of $Target^{SCA}$ that will result in an attractive coordination.

The inclusion of an additional constraint such as a minimum profitability level will affect the set of feasible solution defined by equation 6.11 (Figure 6-7). Furthermore, an analysis of these considerations will assist to set limits to the selection of c_{opt} and c_{strike} in such a way that the final combination is desirable by both agents.

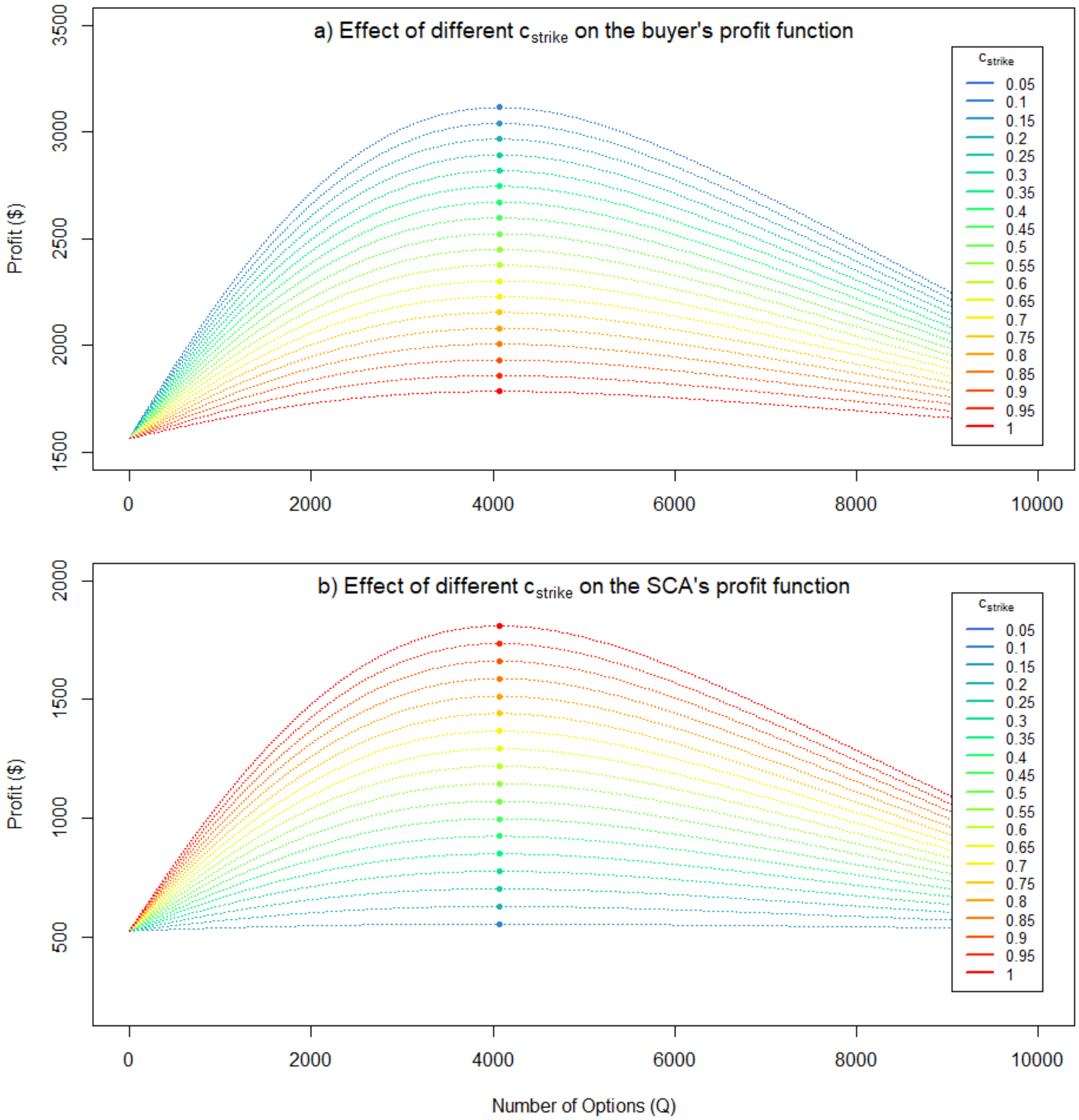


Figure 6-8: Effect of Different Coordinating Combinations of c_{opt} and c_{strike} in the Profits for the Buyer (a) and SCA (b).

Theorem 1*: When the buyer is requiring a minimum expected profit from engaging in an options contract agreement defined by an option purchase price (c_{opt}) and an option exercise price (c_{strike}), then there is a critical combination of c_{opt} and c_{strike} that will* *determine the feasible set of combinations for the contract to be acceptable for the buyer in such a way that the whole SC's profit is maximized.*

Proof:

To find the critical point for c_{strike} (and the corresponding c_{opt}), we can find the configuration that makes the expected profit function for the buyer, defined by equation 6.3, equal to the target profit for the buyer as below:

$$\Pi^B = Target^B$$

which corresponds to

$$E[D] * (price - c_{spot}) - F * (c_f - c_{spot}) - Q * (c_{opt} - c_{spot} + c_{strike}) + (c_{strike} - c_{spot}) * \int_0^{F+Q} G(y)dy - c_{strike} * \int_0^F G(y)dy = Target^B$$

By re-arranging some of the terms we obtain

$$-Q * c_{opt} + c_{strike} * \left(\int_0^{F+Q} G(y)dy - \int_0^F G(y)dy - Q\right) = \alpha^B$$

with

$$\alpha^B = Target^B - Q * c_{spot} - E[D] * (price - c_{spot}) + F * (c_f - c_{spot}) + c_{spot} * \int_0^{F+Q} G(y)dy \qquad \text{Eq. 6.12}$$

Now, replacing the expression for c_{opt} obtained from equation 6.10 in the equation we obtain:

$$-Q * \left(c_{strike} * \frac{(p_{salv} - c_{prod})}{(c_{spot} - p_{salv})} - \frac{c_{spot} * (p_{salv} - c_{prod})}{(c_{spot} - p_{salv})}\right) + c_{strike} * \left(\int_0^{F+Q} G(y)dy - \int_0^F G(y)dy - Q\right) = \alpha^B$$

Simplifying, and rearranging the terms we obtain

$$-c_{strike} * Q * \frac{(p_{salv} - c_{prod})}{(c_{spot} - p_{salv})} + c_{strike} * \left(\int_0^{F+Q} G(y)dy - \int_0^{F} G(y)dy - Q \right)$$

$$= \alpha^B - \frac{c_{spot} * Q * (p_{salv} - c_{prod})}{(c_{spot} - p_{salv})}$$

Which is equivalent to

$$c_{strike} * \left(\int_0^{F+Q} G(y)dy - \int_0^{F} G(y)dy - Q \left(1 + \frac{(p_{salv} - c_{prod})}{(c_{spot} - p_{salv})} \right) \right)$$

$$= \alpha^B - \frac{c_{spot} * Q * (p_{salv} - c_{prod})}{(c_{spot} - p_{salv})}$$

And finally obtain the critical value of c_{strike} that will determine the minimum profitability for the buyer:

$$c_{strike} = \frac{\alpha^B - Q * \frac{c_{spot} * (p_{salv} - c_{prod})}{(c_{spot} - p_{salv})}}{\beta^B} \qquad \text{Eq. } 6.13$$

with

$$\beta^B = \int_0^{F+Q} G(y)dy - \int_0^{F} G(y)dy - Q \left(1 + \frac{(p_{salv} - c_{prod})}{(c_{spot} - p_{salv})} \right) \qquad \text{Eq. } 6.14$$

Thus, from equations 12, 13, and 14 we obtained a closed form that could be used to calculate the critical value of c_{strike} that will allow the buyer to attain his target profit. Note that by using equation 6.8 one can also obtain the corresponding value of c_{opt} that enables the buyer to attain his target profit.

□

By using the result from Theorem 1 in our case study with a minimum profitability for the buyer as $Target^B = \$2{,}000$ we obtain that the resulting values of c_{strike} and c_{opt} are \$0.54 and \$0.12, respectively. The resulting feasible set of combinations that will result in profit levels above the minimum target for the buyer is depicted in Figure 6-9 below. In this case, the set of possible combinations of c_{opt} and c_{strike} that allows the SC to obtain its maximum profitability is reduced by the buyer's minimum profit requirement. Similarly, when the SCA is expecting and requiring a minimum profitability level, the resulting set of possible combinations is also reduced, as defined in Theorem 2 below.

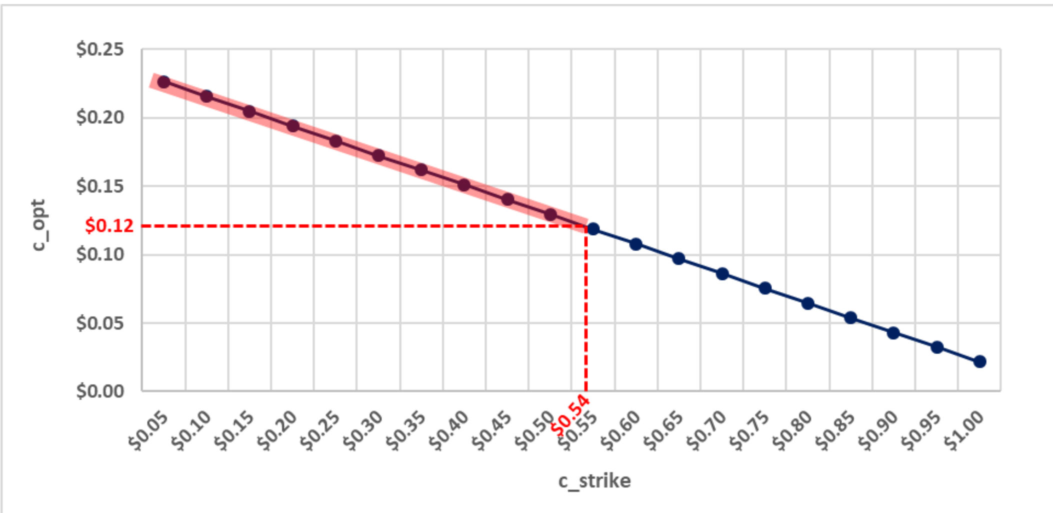


Figure 6-9: Feasible Coordination Range (in red) of Values of c_{opt} and c_{strike} for the Buyer.

Theorem 2: *When the SCA is requiring a minimum expected profit from engaging in an options contract agreement defined by an option purchase price (c_{opt}) and an option exercise price (c_{strike}), then there is a critical combination of c_{opt} and c_{strike} that will* *determine the feasible set of combinations for the contract to be acceptable for the SCA in such a way that the whole SC's profit is maximized.*

<u>Proof</u>:

To find the critical point for c_{strike} (and the corresponding c_{opt}), we can find the configuration that makes the expected profit for the SCA, defined by equation 6.6, equal to the target profit for the buyer as below:

$$\Pi^{SCA} = Target^{SCA}$$

which corresponds to

$$F * \left(c_{fix} - c_{prod}\right) + Q * \left(C_{opt} + c_{strike} - c_{prod}\right) + \left(p_{salv} - c_{strike}\right) * \int_0^{F+Q} G(y)dy - \left(p_{salv} - c_{strike}\right) * \int_0^{F} G(y)dy = Target^{SCA}$$

By re-arranging some of the terms we obtain

$$Q * C_{opt} + Q * c_{strike} - Q * c_{prod} + p_{salv} * \int_0^{F+Q} G(y)dy - c_{strike} * \int_0^{F+Q} G(y)dy - p_{salv} * \int_0^{F} G(y)dy + c_{strike} * \int_0^{F} G(y)dy = Target^{SCA} - F * \left(c_{fix} - c_{prod}\right)$$

$$Q * C_{opt} + c_{strike}\left(Q - \int_0^{F} G(y)dy + \int_0^{F+Q} G(y)dy\right) = \alpha^{SCA}$$

with

$$\alpha^{SCA} = Target^{SCA} - F * (c_{fix} - c_{prod}) + Q * c_{prod} - p_{salv} * \int_0^{F+Q} G(y)dy + -p_{salv} * \int_0^{F} G(y)dy \qquad \text{Eq. 6.15}$$

Now, replacing the expression for c_{opt} obtained from equation 6.10 in the equation we obtain:

$$Q * \left(c_{strike} * \frac{(p_{salv} - c_{prod})}{(c_{spot} - p_{salv})} - \frac{c_{spot} * (p_{salv} - c_{prod})}{(c_{spot} - p_{salv})} \right) + c_{strike} \left(Q - \int_0^{F} G(y)dy + \int_0^{F+Q} G(y)dy \right) = \alpha^{SCA}$$

Simplifying, and rearranging the terms we obtain

$$c_{strike} * \left(Q - \int_0^{F} G(y)dy + \int_0^{F+Q} G(y)dy + Q * \frac{(p_{salv} - c_{prod})}{(c_{spot} - p_{salv})} \right) = \alpha^{SCA} + Q * \frac{c_{spot} * (p_{salv} - c_{prod})}{(c_{spot} - p_{salv})}$$

Which is equivalent to

$$c_{strike} = \frac{\alpha^{SCA} + Q * \frac{c_{spot} * (p_{salv} - c_{prod})}{(c_{spot} - p_{salv})}}{\beta^{SCA}} \qquad \text{Eq. 6.16}$$

with

$$\beta^{SCA} = \int_0^{F+Q} G(y)dy - \int_0^{F} G(y)dy + Q * \left(1 + \frac{(p_{salv} - c_{prod})}{(c_{spot} - p_{salv})} \right) \qquad \text{Eq. 6.17}$$

Thus, from equations 15, 14, and 16 we obtained a closed form that could be used to calculate the critical value of c_{strike} that will allow the SCA to attain his target profit. Note that by using equation 6.8 one can also obtain the corresponding value of c_{opt} that enables the SCA to attain his target profit.

□

By using the result from Theorem 1 in our case study with a minimum profitability for the buyer as $Target^{SCA} = \$1{,}000$ we obtain that the resulting values of c_{strike} and c_{opt} are $0.45 and $0.14, respectively. The resulting feasible set of combinations that will result in profit levels above the minimum target for the buyer is depicted in Figure 6-10 below.

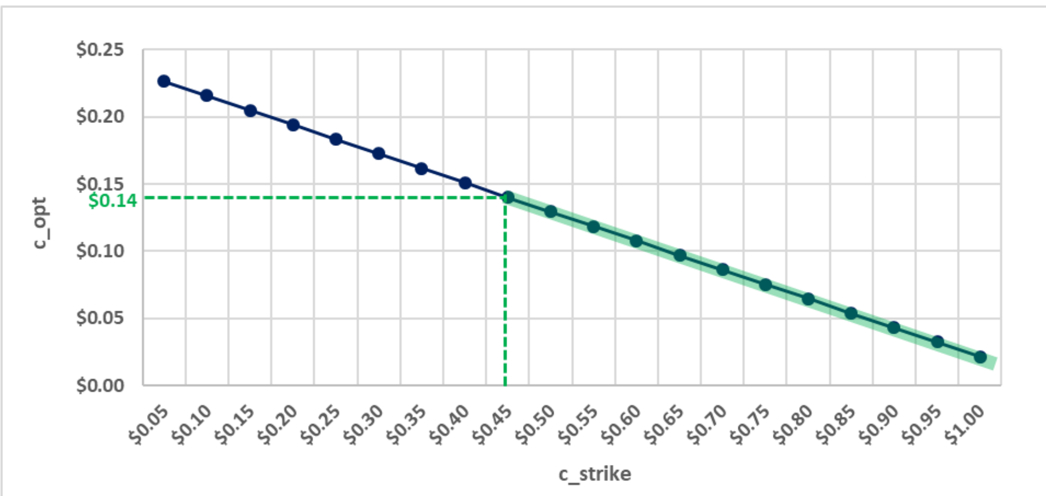


Figure 6-10: Feasible Coordination Range of Values of c_{opt} and c_{strike} for the SCA.

Note that from theorems 1 and 2, we could find the specific range of combinations that will result in an acceptable contact for the buyer and the SCA separately. Thus, an agent seeking to maximize the overall SC' profit could use these results to attain a reduced set of combinations that will satisfy both parties interest and could result in acceptable contract terms for everyone. Using the results from our case study, we present the resulting feasible range for the combinations of c_{opt} and c_{strike} in Figure 6-11 below.

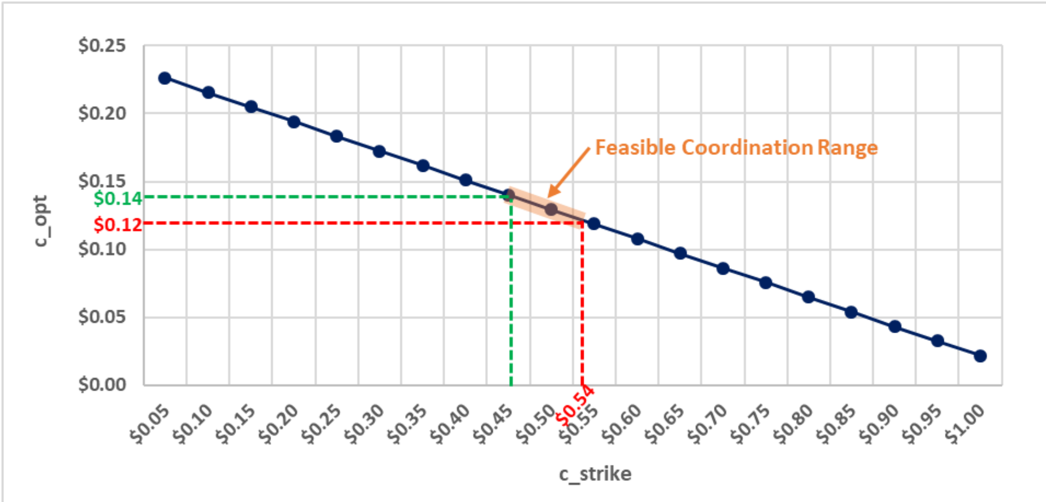


Figure 6-11: Feasible Coordination Range of Values of c_{opt} and c_{strike} for Both Agents.

Another consideration is that from an integrated SC's perspective the definition of c_{opt} and c_{strike} does not affect the SC's profit level. As far as the relationship is given by the optimal relationship from Lemma 4 (equation 6.11) all the resulting solutions will maximize the overall SC's profit. The only difference is in the distribution of the profits between the buyer and the SCA, as discussed in the paragraphs before (see Figure 6-8).

The methodology presented above can also be expanded to assist the definition of a demand contract between the buyer and the SCA, in terms of weekly volume and prices required by the buyer. For instance, it could be used to identify the feasible coordination conditions for a longer season (i.e.: a set of weeks), that will provide a negotiation baseline for the demand contract between the buyer and the SCA. For our case study, we used of the methodology presented above to determine the feasible range of solutions that will result in a contract acceptable for both the buyer and the SCA over a set of weeks. By assuming that the demand experienced by the buyer follows the same pattern as the demand contract as the contract for tomatoes with the buyer from Chapter 6 (see Figure 5-4), we were able to apply this methodology for each of the weeks to find the range of values for c_{strike} and c_{opt} that will coordinate the ordered volumes for each of the weeks. This result is shown in Figure 6-12 below for the feasible range of values of c_{strike}. As we can observe at the beginning and the end of the contract, where the demand is lower, the feasible range is very restrictive compared with the middle section where there is more flexibility for the values of c_{strike}. Furthermore, by analyzing the figure we can identify that there is a value of c_{strike} that is acceptable across the weeks, which corresponds to \$0.486 (dashed line in Figure 6-12).

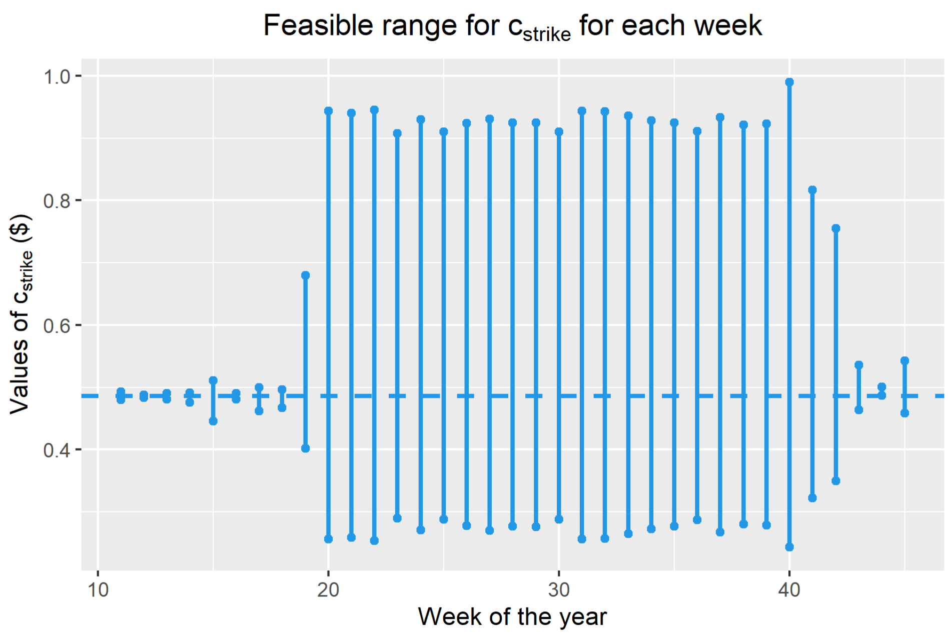


Figure 6-12: Feasible Coordination Range of Values of c_{strike} for Both Agents Over an Extended Contract.

Similarly, when looking at the feasible range of values of c_{opt} presented in Figure 6-13 one can observe the same behavior. This is expected, as by shown in Lemma 4 there is a one-to-one relationship between the values of c_{opt} and c_{strike}. Furthermore, by analyzing the possible values of c_{opt} that will coordinate the decision for both parties, we can find that for an option purchase cost of $0.132 the optimal value is achieved across all the weeks (dashed line in Figure 6-13).

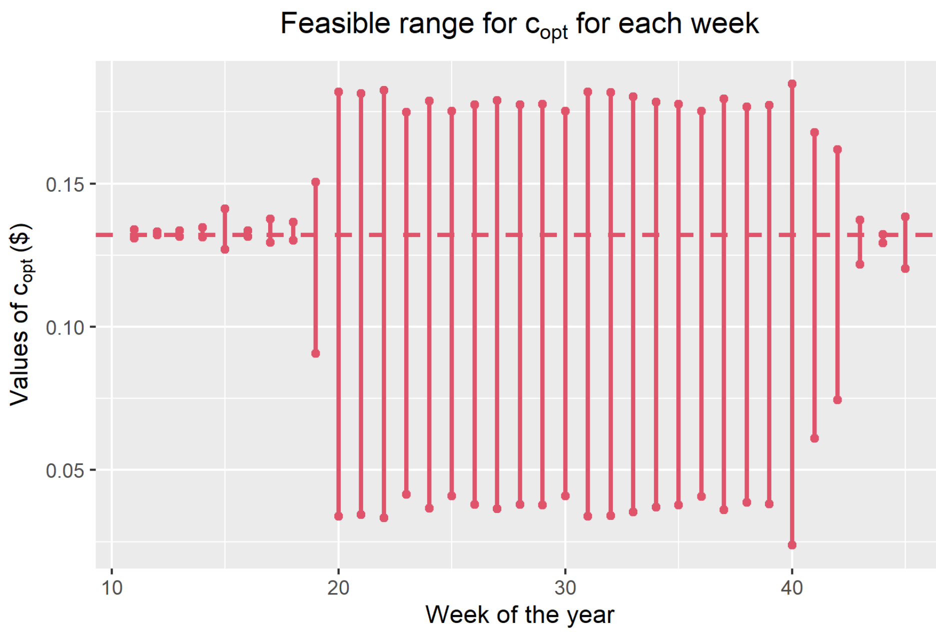


Figure 6-13: Feasible Coordination Range of Values of c_{opt} for Both Agents Over an Extended Contract.

By combining these two results, both parties can agree into contractual terms that are both efficient (maximizes the SC's profit) and desirable for both parties (each agent's minimum profit is achieved). Particularly in this case, the values of c_{strike} and c_{opt} that result in the coordination are the same for each of the weeks when produce is required by the buyer. This means, that a contractual agreement for the whole contract could be achieved by setting an option purchase price of $0.132, with an option exercising cost of $0.486. Having an agreement like this, where the option purchase and execution prices are the same all through the duration of the contract, would simplify the implementation of the agreement as there is a fix value for the buyer for exercising the supply options.

Note that this may not be always the case, and in some circumstances the resulting range of values for c_{opt} and c_{strike} for each week may not allow to define a single set of values for the entire contract duration. Under these circumstances, the contractual agreement may consider the definition of multiple values of c_{opt} and c_{strike}, depending on each of the weeks. In the worst case, there will be a unique combination of c_{opt} and c_{strike} for each of the weeks where produce is needed.

6.3 Discussion on Contract Negotiation Between the SCA and the Buyer

With the methodology presented above we were able to model the expected profit function for both counterparts involved in a negotiation process for a procurement contract that considers supply options as part of the alternatives offered to the buyer. We found that given an option purchase and execution costs, there is an optimal quantity of options for the buyer to purchase before the demand is realized. Furthermore, from the perspective of the supplier (SCA) there is also an optimal quantity of options that maximizes his expected profit.

With the profit functions we were able to find that even if the optimal quantities of options to be purchased by the buyer may differ for the buyer and the SCA, there is an optimal quantity that maximizes the profitability of both agents considered together as a SC. Moreover, this quantity can be achieved and be desirable also for both involved agents by using a coordinated options price as depicted by equation 6.7. In fact, we expanded these findings to identify that there is not a unique solution that could align the buyer and the SCA's optimal decision. There is, in fact, a set of combinations of c_{opt} and c_{strike} that will entice both parties to agree on the optimal quantity of options that maximizes the SC's profit, as defined by equation 6.11 in Lemma 4.

Even when the SC's profit is maximized by selecting the option purchase price and exercise cost as those which maximizes the SC's expected profits, each of the involved players will have different preferences regarding the options pricing scheme. Depending on the selection of these two parameters each of the parties will perceive a different effect in their own profit function (Figure 6-8), and in the maximum expected profit attainable by each.

We were able to address this issue by incorporating another constraint from each participant, which is a minimum expected profit level. By doing so, we were able to obtain the critical contractual terms (c_{opt} and c_{strike}) at which each party will attain his minimum profit. This was analytically obtained in theorems 1 and 2 and allowed to restrict the set of feasible coordinating combinations of c_{opt} and c_{strike} to those that will ensure each party a minimum profit level.

When the results for a single period are expanded to multiple periods, we could find the range of combinations of c_{opt} and c_{strike} for each week. We were able to find a single combination that is feasible for the whole contract considering each week's independent range of feasible values for these parameters. Furthermore, having a range of feasible combinations of these two costs allows a coordination process to take place and sets the basis for a negotiation that will result in a solution that maximizes the overall profit for all the involved agents. By using this methodology, a demand contract could be determined in such a way that the minimal requirements from both the buyer and the SCA are met.

Chapter 7

DISCUSSION AND FUTURE WORK

It is important to highlight the significance of policies and programs related to land use such as those that seek to subsidize the use of land for agriculture in urban areas, to support local food production. Continuous urban encroachment into agricultural areas creates competition over the use of land, resulting on increasing costs for the growers closer to the main demand centers, which will also result in increasing the price of the crops they produce, even after subsidies are applied. An option for the urban growers would be to relocate, however, this may result in difficulties to meet the requirements for "Local Produce" in their old market. Under certain conditions it may be counterproductive to incentivize the consumption of local produce, as this may force growers and cities to compete for land that is more and more scarce in urban areas and may result in a vicious circle.

The tools presented in this work allow the decision-maker, i.e.: The Supply Chain Articulator, to transform demand signals or market needs into implementable supply plans. These tools addressed the issues of identifying the best combination of producing regions that are capable of supply produce over extended seasons, given their complementary production seasons, and considering the market needs and preferences. Moreover, another issue addressed by this work is the coordination of multiple regions that can conform a coalition needed to supply a market opportunity, particularly considering each region's characteristics and the resources and constrictions from the growers within each of the regions. The inclusion of a revenue distribution methodology allowed the decision-maker to account for how the value generated by the opportunity could be allocated to the potential SC participants, when there is a need of extra incentives to align their interests and entice them to collaborate. The last part of this work explored the negotiation process that takes place in the demand side of the SC, between the buyers and the SCA. This tool allowed the determination of potential contractual terms that will result in a demand contract desirable for both the buyers and the SCA. Furthermore, the integration of tools that address different problems within the SC planning and implementation stages enables to attain coherent solutions at different levels of the planning stages, which are critical to the proper deployment of a responsive SC.

From the perspective of the role of the Supply Chain Articulator, the is the issue of determining his compensation in such a way that the services provided to the buyers and the growers are still profitable to them and everyone receives a “fair” share of the captured opportunity. There is also a possible extension of this work consisting of integrating this negotiation processes with the process of defining the demand contract with the buyers. In this case the SCA will be participating in a two-sided negotiation on which each side will have its own characteristics and restrictions given what could be achieved with the other side. For example, as shown on this work the negotiation and coordination with the growers is limited by the demand contract that was agreed with the buyers. And we observed that under certain circumstances the SCA cannot articulate a production plan to respond to that contract. With the integration of both negotiation processes the SCA could take advantage of the obtained solution and use it to re-negotiate with the buyers and reach new terms that may result in a more favorable solution, which ultimately will also benefit the buyers who are seeking suppliers for the markets they represent.

In terms of potential expansion of the presented work, there are several areas directly related to the food supply chain planning problem, and some areas indirectly related to it. A natural expansion of this work, within the context of supply chain planning methodologies, is the introduction of variability in the markets (i.e.: prices) and the production in the different potential producing regions (i.e.: yields) to obtain a more robust solution and assess the potential risks that will affect the supply chain configuration. In this work we only accounted for a single demand point (Las Vegas), but we know that each region, even the producing regions, have their own local market. Thus, from a logistics perspective there is the opportunity to develop and research the use of a logistic network to allow shipments between producing regions and markets to obtain a better match of supply and demand, considering each region's market preferences. This line of research, as it expands, should also consider the interaction of different regions to get an overall strategy to procure fresh produce for a country. Our vision is that this high-level plan should be used to identify potential gaps and ways to bridge them, rather than taking a central planning perspective. Another expansion to this work is the incorporation of multiple incentives or consumer preferences simultaneously and address their joint effect into the planning decisions and regions competitiveness. This work also highlights the importance of a well-defined carbon footprint metric, further research can be done with respect to defining a methodology to identify the appropriate measures of carbon footprint at different stages of the supply chain and to use this metrics in continuous monitoring and improvement systems.

Regarding the coordination mechanism and the revenue distribution methods, there are also additional areas that could be explored. For instance, external investment could be considered with the inclusion of an external agent who can contribute with capital to coordinate the growers. This contribution could take the form of additional capital that can be allocated to coordinate the participants, cost-subsidies to manage the growers' risk, or other forms of allocation. Having this type of investment-oriented agent can provide extra flexibility to the coordinator (SCA) to enable a solution that may not be easily achieved with purely supply chain participants. Another expansion of the mechanism presented on this document could be the inclusion of the revenue sharing mechanism within the growers' decision-making process, from a decentralized perspective. This tool provides a starting point for the local negotiations with the growers within each of the producing regions, which in practicality takes the form of a decentralized coordination process where each grower is an independent decision-making agent. An expansion will be to tie the methodology developed in this work to a coordination mechanism similar to the one presented by Mason (2015) to achieve specific contractual terms with each grower within a region, while considering the potential revenue distribution mechanisms. As the growers will learn how the profits could be distributed, this may affect how they negotiate the contracts with the coordination agent, thus a more complex, and potentially more realistic, solution could be achieved.

With respect to the last part of the work presented in this document, there are potential expansion opportunities regarding, for instance, the consideration of multiple crops. This increases the complexity of the problem but could also result in more flexibility regarding the potential decisions. As each crop will provide different ideal solutions for each party, the flexibility of having a trade-off between crops can be used as a negotiation tool to determine the final commitments that will compose the demand contract. Moreover, the inclusion of an initial budget could limit the number of options that can be initially purchased by the buyer, and in presence of multiple crops finding the optimal quantity of each crop to commit to purchase becomes a cumbersome problem. Another expansion could be regarding the risk assessment related with the negotiation process: as each party will also have a different risk level, this can also limit and affect the set of feasible solutions that could be achieved.

REFERENCES

Ahumada, O. (2008). Models for Planning the Supply Chain of Agricultural Perishable Products (Arizona State University). Retrieved from http://books.google.cl/books?id=Z0ahApnAFPUC

Ahumada, O., & Villalobos, J. R. (2009). Application of planning models in the agri-food supply chain: A review. European Journal of Operational Research, 196(1), 1–20. https://doi.org/10.1016/j.ejor.2008.02.014

Ahumada, O., & Villalobos, J. R. (2011a). Operational model for planning the harvest and distribution of perishable agricultural products. International Journal of Production Economics, 133(2), 677–687. https://doi.org/10.1016/j.ijpe.2011.05.015

Ahumada, O., & Villalobos, J. R. (2011b). A tactical model for planning the production and distribution of fresh produce. Annals of Operations Research, 190(1), 339–358. https://doi.org/10.1007/s10479-009-0614-4

Ahumada, O., Rene Villalobos, J., & Nicholas Mason, A. (2012). Tactical planning of the production and distribution of fresh agricultural products under uncertainty. Agricultural Systems, 112, 17–26. https://doi.org/10.1016/j.agsy.2012.06.002

Ahumada, O, Xaimarie Hernández-Cruz, Francisca Quijada, Rodrigo Ulloa and J. Rene Villalobos, “A Tactical Planning Model for Fresh Produce Production Considering Productive Potential and Changing Weather Patterns”, Journal of Agricultural Systems, Under Review, 2021

Akkerman, R., Farahani, P., & Grunow, M. (2010). Quality, safety and sustainability in food distribution: a review of quantitative operations management approaches and challenges. Or Spectrum, 32(4), 863-904.

Albrecht, M. (2010). Supply chain coordination mechanisms: New approaches for collaborative planning (Lecture notes in economics and mathematical systems; 628). Berlin; London; New York: Springer.

Albrecht, S. V., & Stone, P. (2018). Autonomous agents modelling other agents: A comprehensive survey and open problems. Artificial Intelligence, 258, 66–95. https://doi.org/10.1016/j.artint.2018.01.002

Amorim, P., Günther, H. O., & Almada-Lobo, B. (2012). Multi-objective integrated production and distribution planning of perishable products. International Journal of Production Economics, 138(1), 89–101. https://doi.org/10.1016/j.ijpe.2012.03.005

Ausubel, L. M., & Cramton, P. (2004). Auctioning many divisible goods. Journal of the European Economic Association, 2(2–3), 480–493. https://doi.org/10.1162/154247604323068168

Babaioff, M., & Walsh, W. E. (2005). Incentive-compatible, Budget-balanced, Yet Highly Efficient Auctions for Supply Chain Formation. Decis. Support Syst., 39(1), 123–149. http://doi.org/10.1016/j.dss.2004.08.008

Backus, G. B. C., Eidman, V. R., & Dijkhuizen, A. A. (1997). Farm decision making under risk and uncertainty. In Netherlands Journal of Agricultural Science (Vol. 45, Issue 2, pp. 307–328). https://doi.org/10.18174/njas.v45i2.520

Banasik, A., Kanellopoulos, A., Claassen, G. D. H., Bloemhof-Ruwaard, J. M., & Van Der Vorst, J. G. A. J. (2016). Closing loops in agricultural supply chains using multi-objective optimization: A case study of an industrial mushroom supply chain. Intern. Journal of Production Economics, 183, 409–420. https://doi.org/10.1016/j.ijpe.2016.08.012

Barnes-Schuster, D., Bassok, Y., & Anupindi, R. (2002). Coordination and flexibility in supply contracts with options. Manufacturing & Service Operations Management, 4(3), 171-207.

Behzadi, G., O'Sullivan, M. J., Olsen, T. L., & Zhang, A. (2018). Agribusiness supply chain risk management: A review of quantitative decision models. Omega (United Kingdom), 79, 21–42. https://doi.org/10.1016/j.omega.2017.07.005

Birthal, P. S., & Hazrana, J. (2019). Crop diversification and resilience of agriculture to climatic shocks: Evidence from India. Agricultural Systems, 173(October 2018), 345–354. https://doi.org/10.1016/j.agsy.2019.03.005

Bond, C. A., Thilmany, D. D., & Bond, J. K. (2008a). What to choose? The value of label claims to fresh produce consumers. Journal of Agricultural and Resource Economics, 33(3), 402–427. https://doi.org/10.2307/41220601

Bond, C. A., Thilmany, D., & Keeling Bond, J. (2008b). Understanding consumer interest in product and process-based attributes for fresh produce. Agribusiness: An International Journal, 24(2), 231-252.

Borodin, V., Bourtembourg, J., Hnaien, F., & Labadie, N. (2016). Handling uncertainty in agricultural supply chain management: A state of the art. European Journal of Operational Research, 254(2), 348–359. https://doi.org/10.1016/j.ejor.2016.03.057

Bortolini, M., Faccio, M., Ferrari, E., Gamberi, M., & Pilati, F. (2016). Fresh food sustainable distribution: Cost, delivery time and carbon footprint three-objective optimization. Journal of Food Engineering, 174, 56–67. https://doi.org/10.1016/j.jfoodeng.2015.11.014

Boyabatli, O., Nasiry, J., & Zhou, Y. H. (2019). Crop planning in sustainable agriculture: Dynamic farmland allocation in the presence of crop rotation benefits. Management Science, 65(5), 2060–2076. https://doi.org/10.1287/mnsc.2018.3044

Braekers, K., Ramaekers, K., & Van Nieuwenhuyse, I. (2016). The vehicle routing problem: State of the art classification and review. Computers and Industrial Engineering, 99, 300–313. https://doi.org/10.1016/j.cie.2015.12.007

Brown, A., and H. Lee. 1998. The Win-win Nature of Options Based Capacity Reservation Arrangements. Vanderbilt University working paper, Nashville, TN.

Busch, G., & Spiller, A. (2016). Farmer share and fair distribution in food chains from a consumer's perspective. Journal of Economic Psychology, 55, 149–158. https://doi.org/10.1016/j.joep.2016.03.007

Byrum, J., Davis, C., Doonan, G., Doubler, T., Foster, D., Luzzi, B., … Mack, S. (2016). Advanced analytics for agricultural product development. Interfaces, 46(1), 5–17. https://doi.org/10.1287/inte.2015.0823

Cachon, G. P., & Lariviere, M. A. (2005). Supply chain coordination with revenue-sharing contracts: Strengths and limitations. Management Science, 51(1), 30–44. https://doi.org/10.1287/mnsc.1040.0215

Camanzi, L., Malorgio, G., & Azcárate, T. G. (2011). The role of producer Organizations in supply concentration and marketing: A comparison between European countries in the fruit and vegetable sector. Journal of Food Products Marketing, 17(2–3), 327–354. https://doi.org/10.1080/10454446.2011.548706

Chopra, S., & Sodhi, M. S. (2004). Supply-chain breakdown. MIT Sloan management review, 46(1), 53-61.

Chu, L. Y., & Shen, Z.-J. M. (2006). Agent Competition Double-Auction Mechanism. Management Science, 52(8), 1215–1222. http://doi.org/10.1287/mnsc.1060.0528

Coelho, L. C., & Laporte, G. (2014). Optimal joint replenishment, delivery and inventory management policies for perishable products. Computers and Operations Research, 47, 42–52. https://doi.org/10.1016/j.cor.2014.01.013

Colantuoni, F., Cicia, G., Del Giudice, T., Lass, D., Caracciolo, F., & Lombardi, P. (2016). Heterogeneous preferences for domestic fresh produce: evidence from German and Italian early potato markets. Agribusiness, 32(4), 512-530.

Cook, R. (2011). Fundamental Forces Affecting U.S. Fresh Produce Growers And Marketers. Choices 26.

Dantzig, G.B., Wolfe, P. (1960). Decomposition principle for linear programs. Oper. Res. 8 (1), 101–111. http://doi.org/10.1287/opre.8.1.101.

Desai, P. S. (1997). Advertising fee in business-format franchising. Management Science, 43(10), 1401–1419. https://doi.org/10.1287/mnsc.43.10.1401

Esteso, A., Alemany, M. M. E., & Ortiz, A. (2018). Conceptual framework for designing agri-food supply chains under uncertainty by mathematical programming models. International Journal of Production Research, 56(13), 4418–4446. https://doi.org/10.1080/00207543.2018.1447706

Faratin, P., Sierra, C., & Jennings, N. R. (1998). Negotiation decision functions for autonomous agents. Robotics and Autonomous Systems, 24(3–4), 159–182. https://doi.org/10.1016/S0921-8890(98)00029-3

FAO, 2009. 2050: A third more mouths to feed [WWW Document]. URL http://www.fao.org/news/story/en/item/35571/icode/ (accessed 06.14.2019).

Federgruen, A., Lall, U., & Şimşek, A. S. (2019). Supply chain analysis of contract farming. Manufacturing & Service Operations Management, 21(2), 361-378.

Feldmann, C., & Hamm, U. (2015). Consumers' perceptions and preferences for local food: A review. Food Quality and Preference, 40, 152-164.

Flores, H. (2011). Opportunistic fresh-produce commercialization under two-market disintegration. Arizona State University.

Flores, H. (2017). Development of Complementary Fresh-Food Systems Through the Exploration and Identification of Profit-Maximizing, Supply Chains. Doctoral Dissertation. Arizona State University. Retrieved from http://hdl.handle.net/2286/R.A.199048

Flores, H., & Villalobos, J. R. (2018). A modeling framework for the strategic design of local fresh-food systems. Agricultural Systems, 161(November 2017), 1–15. https://doi.org/10.1016/j.agsy.2017.12.001

Flores, H., & Villalobos, J. R. (2020). A Stochastic Planning Framework for the Discovery of Complementary, Agricultural Systems. European Journal of Operational Research. https://doi.org/10.1016/j.ejor.2019.07.053

Freedman, R. G., Magazzeni, D., & Frank, J. D. (2018). User Interfaces and Scheduling and Planning: Workshop Summary and Proposed Challenges. AAAI 2018 Spring Symposium on The Design of the User Experience for Artificial Intelligence (the UX of AI).

Galal, N. M., & El-Kilany, K. S. (2016). Sustainable agri-food supply chain with uncertain demand and lead time. International Journal of Simulation Modelling, 15(3), 485-496.

Gaupp, F., Hall, J., Mitchell, D., & Dadson, S. (2019). Increasing risks of multiple breadbasket failure under 1.5 and 2 °C global warming. Agricultural Systems, 175(May), 34–45. https://doi.org/10.1016/j.agsy.2019.05.010

Guide, V. D. R., & Spencer, M. S. (1997). Rough-cut capacity planning for remanufacturing firms. Production Planning and Control, 8(3), 237–244. https://doi.org/10.1080/095372897235299

Godfray, H, C., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 billion People. Retrieved from http://science.sciencemag.org/

Gumarikiza, J. D., & Curtis, K. (2013). Farmers' Market Consumer Preferences & Premium Pricing for Organically Grown & Local Fresh Produce.

Gumirakiza, J. D., Curtis, K. R., & Bosworth, R. (2017). Consumer preferences and willingness to pay for bundled fresh produce claims at Farmers’ Markets. Journal of food products marketing, 23(1), 61-79.

Hajimirzajan, A., Vahdat, M., Sadegheih, A., Shadkam, E., & Bilali, H. El. (2021). An integrated strategic framework for large-scale crop planning: sustainable climate-smart crop planning and agri-food supply chain management. Sustainable Production and Consumption, 26, 709–732. https://doi.org/10.1016/j.spc.2020.12.016

Herrnstadt, Z., Howard, P. H., Oh, C. O., & Lindell, C. A. (2016). Consumer preferences for ‘natural’ agricultural practices: assessing methods to manage bird pests. Renewable Agriculture and Food Systems, 31(6), 516-523.

Higle, J. L., & Sen, S. (1996). Stochastic decomposition: A statistical method for large scale stochastic linear programming. Springer Science & Business Media.

Howard, P. H., & Allen, P. (2008). Consumer willingness to pay for domestic ‘fair trade’: Evidence from the United States. Renewable Agriculture and Food Systems, 23(3), 235-242.

Han, J., Lin, N., Ruan, J., Wang, X., Wei, W., & Lu, H. (2021). A Model for Joint Planning of Production and Distribution of Fresh Produce in Agricultural Internet of Things. IEEE Internet of Things Journal, 8(12), 9683–9696. https://doi.org/10.1109/JIOT.2020.3037729

Hasan, M. B., Hossain, M. D., & Wahid, A. N. (2018). application of forward contract and crop insurance as risk management tools of agriculture: A case study in Bangladesh. Asian Economic and Financial Review, 8(12), 1394-1405.

Haydu, J. J., Myers, R. J., & Thompson, S. R. (1992). Why do farmers forward contract in factor markets? Journal of Agricultural and Applied Economics, 24(1), 145-151.

Hsu, C. I., Hung, S. F., & Li, H. C. (2007). Vehicle routing problem with time-windows for perishable food delivery. Journal of Food Engineering. https://doi.org/10.1016/j.jfoodeng.2006.05.029

Hu, F., Lim, C.-C., & Lu, Z. (2014). Optimal production and procurement decisions in a supply chain with an option contract and partial backordering under uncertainties. Applied Mathematics and Computation, 232, 1225–1234. https://doi.org/10.1016/j.amc.2014.01.149

Hu, W., Batte, M. T., Woods, T., & Ernst, S. (2011). Consumer preferences for local production and other value-added label claims for a processed food product. European Review of Agricultural Economics, 39(3), 489-510.

Huang, C. L. (1996). Consumer preferences and attitudes towards organically grown produce. European Review of Agricultural Economics, 23(3), 331-342.

Huh, W. T., & Lall, U. (2013). Optimal crop choice, irrigation allocation, and the impact of contract farming. Production and Operations Management, 22(5), 1126–1143. https://doi.org/10.1111/poms.12007

Jang, W., & Klein, C. M. (2011). Supply chain models for small agricultural enterprises. Annals of Operations Research, 190(1), 359–374. https://doi.org/10.1007/s10479-009-0521-8

Jedermann, R., Nicometo, M., Uysal, I., & Lang, W. (2014). Reducing food losses by intelligent food logistics. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 372(2017). https://doi.org/10.1098/rsta.2013.0302

Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (2020). Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications. International Journal of Production Economics, 219(March 2019), 179–194. https://doi.org/10.1016/j.ijpe.2019.05.022

Kauffman, P., Handy, C., McLaughlin, E.W., Park, K., & Green, G.M. (2000). Understanding the Dynamics of Produce Markets: Consumption and Consolidation Grow. U.S. Department of Agriculture-Economic Research Service, Market and Trade Economics Division. Agricultural Information Bulletin No. 758.

Klein, R., Koch, S., Steinhardt, C., & Strauss, A. K. (2020). A review of revenue management: Recent generalizations and advances in industry applications. European journal of operational research, 284(2), 397-412.

Komarek, A. M., De Pinto, A., & Smith, V. H. (2020). A review of types of risks in agriculture: What we know and what we need to know. Agricultural Systems, 178(November 2019), 102738. https://doi.org/10.1016/j.agsy.2019.102738

Kumar, S. N., & Panneerselvam, R. (2012). A Survey on the Vehicle Routing Problem and Its Variants. Intelligent Information Management, 04(03), 66–74. https://doi.org/10.4236/iim.2012.43010

Lehoux, N., Damours, S., & Langevin, A. (2014). Inter-firm collaborations and supply chain coordination: Review of key elements and case study. Production Planning and Control, 25(10), 858–872. https://doi.org/10.1080/09537287.2013.771413

Li, J., Zhou, Y., & Huang, W. (2017). Production and procurement strategies for seasonal product supply chain under yield uncertainty with commitment-option contracts. International Journal of Production Economics, 183, 208–222. https://doi.org/10.1016/j.ijpe.2016.10.019

Lieberman, H. (1997). Autonomous interface agents. Conference on Human Factors in Computing Systems - Proceedings, 67–74.

Littlechild, S. C., & Thompson, G. F. (1977). Aircraft Landing Fees: a Game Theory Approach. Bell J Econ, 8(1), 186–204. https://doi.org/10.2307/3003493

Lopes, F., Wooldridge, M., & Novais, A. Q. (2008). Negotiation among autonomous computational agents: Principles, analysis and challenges. Artificial Intelligence Review, 29(1), 1–44. https://doi.org/10.1007/s10462-009-9107-8

Low, S. A., Adalja, A., Beaulieu, E., Key, N., Martinez, S., Melton, A., Perez, A., Ralston, K., Stewart, H., Suttles, S., & Vogel, S. (2015). Trends in U.S. local and regional food systems. Local and Regional Food Systems: Trends, Resources and Federal Initiatives, 068, 87–195.

Martinez, S., Hand, M., Da Pra, M., Pollack, S., Ralston, K., Smith, T., Vogel, S.,; Clark, S., Lohr, L., Low, S., Newman, C. (2010). Local Food Systems Concepts, Impacts, and Issues. Economic Research Report Number 97, ERS (Economic Research Service).

Marx-Pienaar, N. J., & Erasmus, A. C. (2014). Status consciousness and knowledge as potential impediments of households' sustainable consumption practices of fresh produce amidst times of climate change. International Journal of Consumer Studies, 38(4), 419-426.

Mason, N. (2015). Development of Horizontal Coordination Mechanisms for Planning Agricultural Production. Arizona State University.

Mason, A. N., & Villalobos, J. R. (2015). Coordination of perishable crop production using auction mechanisms. Agricultural Systems, 138, 18–30. https://doi.org/10.1016/j.agsy.2015.04.008

Meyerding, S. G., Trajer, N., & Lehberger, M. (2019). What is local food? The case of consumer preferences for local food labeling of tomatoes in Germany. Journal of cleaner production, 207, 30-43.

Mirzapour Al-E-Hashem, S. M. J., Malekly, H., & Aryanezhad, M. B. (2011). A multi-objective robust optimization model for multi-product multi-site aggregate production planning in a supply chain under uncertainty. International Journal of Production Economics, 134(1), 28–42. https://doi.org/10.1016/j.ijpe.2011.01.027

Molnar, V., Musinszki, Z., & Faludi, T. (2018). Profit allocation in supply chains on the basis of revenue-sharing rates. 3, 47–52.

Müller, A. B., Avellán, T., & Schanze, J. (2020). Risk and sustainability assessment framework for decision support in'water scarcity–water reuse'situations. Journal of Hydrology, 591, 125424.

Munhoz, J. R., & Morabito, R. (2014). Optimization approaches to support decision making in the production planning of a citrus company: A Brazilian case study. Computers and Electronics in Agriculture, 107, 45–57. https://doi.org/10.1016/j.compag.2014.05.016

Mishra, A. P., Sengupta, S., Sreedharan, S., Chakraborti, T., & Kambhampati, S. (2019). Decision Support for Crew Scheduling using Automated Planning. Poster presented at Arizona State University.

Myerson, R. B. (1979). Incentive Compatibility and the Bargaining Problem. Econometrica, 47(1), 61. https://doi.org/10.2307/1912346

Myerson, B., R. (1981). Optimal Auction Design. Mathematics of Operations Research, 6(1), 58-73.

Myerson, R. B., & Satterthwaite, M. A. (1983). Efficient mechanisms for bilateral trading. Journal of Economic Theory, 29(2), 265–281. https://doi.org/10.1016/0022-0531(83)90048-0

Nakandala, D., Lau, H., & Zhang, J. (2016). Cost-optimization modelling for fresh food quality and transportation. Industrial Management and Data Systems, 116(3), 564–583. https://doi.org/10.1108/IMDS-04-2015-0151

Oberholtzer, L., Dimitri, C., & Jaenicke, E. C. (2013). International trade of organic food: Evidence of US imports. Renewable agriculture and food systems, 28(3), 255-262.

Onozaka, Y., & McFadden, D. T. (2011). Does local labeling complement or compete with other sustainable labels? A conjoint analysis of direct and joint values for fresh produce claim. American Journal of Agricultural Economics, 93(3), 689–702. https://doi.org/10.1093/ajae/aar005

Osvald, A., & Stirn, L. Z. (2008). A vehicle routing algorithm for the distribution of fresh vegetables and similar perishable food. Journal of Food Engineering. https://doi.org/10.1016/j.jfoodeng.2007.07.008

Pan, M., Chen, F., Yin, X., & Fang, Y. (2009). Fair profit allocation in the spectrum auction using the shapley value. GLOBECOM - IEEE Global Telecommunications Conference. https://doi.org/10.1109/GLOCOM.2009.5425718

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. Philosophical transactions of the royal society B: biological sciences, 365(1554), 3065-3081.

Polanco, J., Villalobos, R., Flores, H., Kempf, K., & Runger, G. (2012). Managing the Reservation of Manufacturing Capacity through Real Options. Arizona State University. (Working paper)

Polinsky, A. M. (1987). Fixed Price versus Spot Price Contracts: A Study in Risk Allocation. Journal of Law, Economics, and Organization, 3(1).

Rodríguez, L. F., & Ramos, F. (2014). Development of Computational Models of Emotions for Autonomous Agents: A Review. Cognitive Computation, 6(3), 351–375. https://doi.org/10.1007/s12559-013-9244-x

Routroy, S., & Behera, A. (2017). Agriculture supply chain: A systematic review of literature and implications for future research. Journal of Agribusiness in Developing and Emerging Economies, 7(3), 275–302. https://doi.org/10.1108/JADEE-06-2016-0039

Sandholm, T. W. (1999). Distributed Rational Decision Making. In Multiagent systems: A modern approach to distributed artificial intelligence.

Schieffer, J., & Vassalos, M. (2015). Risk and the Use of Contracts by Vegetable Growers. Choices (Ames, Iowa), 30(3), 1–4

Sengupta, S., Chakraborti, T., Sreedharan, S., Vadlamudi, S. G., & Kambhampati, S. (2017). RADAR - A Proactive Decision Support system for human-in-the-loop planning. AAAI Fall Symposium - Technical Report, FS-17-01-FS-17-05, 269–276.

Sengupta, S., Chakraborti, T., & Kambhampati, S. (2018). MA-RADAR -A Mixed-Reality Interface for Collaborative Decision Making. International Conference on Automated Planning and Scheduling - User Interfaces, Scheduling and Planning, ICAPS UISP, (1).

Shukla, M., & Jharkharia, S. (2013). Agri-fresh produce supply chain management: A state-of-the-art literature review. International Journal of Operations and

Production Management, 33(2), 114–158. https://doi.org/10.1108/01443571311295608

Sodhi, M. S., & Tang, C. S. (2013). Supply-Chain Research Opportunities with the Poor as Suppliers or Distributors in Developing Countries. https://doi.org/10.1111/poms.12161

Singh, A. K., Subramanian, N., Pawar, K. S., & Bai, R. (2018). Cold chain configuration design: location-allocation decision-making using coordination, value deterioration, and big data approximation. Annals of Operations Research, 270(1–2), 433–457. https://doi.org/10.1007/s10479-016-2332-z

Strauss, A. K., Klein, R., & Steinhardt, C. (2018). A review of choice-based revenue management: Theory and methods. European journal of operational research, 271(2), 375-387.

Tan, B., & Çömden, N. (2012). Agricultural planning of annual plants under demand, maturation, harvest, and yield risk. European Journal of Operational Research, 220(2), 539–549. https://doi.org/10.1016/j.ejor.2012.02.005

Tijs, S H; Driessen, T. S. H. (1986). Game Theory and Cost Allocation Problems. Management Science, 32(8), 1015.

Trigeorgis, L., & Reuer, J. J. (2017). Real options theory in strategic management. Strategic management journal, 38(1), 42-63.

Trigeorgis, L., & Tsekrekos, A. E. (2018). Real options in operations research: A review. European Journal of Operational Research, 270(1), 1-24.

Tsolakis, N. K., Keramydas, C. A., Toka, A. K., Aidonis, D. A., & Iakovou, E. T. (2014). Agrifood supply chain management: A comprehensive hierarchical decision-making framework and a critical taxonomy. https://doi.org/10.1016/j.biosystemseng.2013.10.014

United Nations Environment Programme. (2021). Food Waste Index.

USDA U.S. Department of Agriculture. (2019). Food Price Outlook, 2019-2020. Retrieved from USDA website: https://www.ers.usda.gov/data-products/food-price-outlook/

Vafa Arani, H., Rabbani, M., & Rafiei, H. (2016). A revenue-sharing option contract toward coordination of supply chains. International Journal of Production Economics, 178, 42–56. https://doi.org/10.1016/j.ijpe.2016.05.001

Vahdani, B., Niaki, S. T. A., & Aslanzade, S. (2017). Production-inventory-routing coordination with capacity and time window constraints for perishable products: Heuristic and meta-heuristic algorithms. Journal of Cleaner Production, 161, 598–618. https://doi.org/10.1016/j.jclepro.2017.05.113

Vassalos, M., Dillon, C. R., & Coolong, T. (2013). Optimal Land Allocation and Production Timing for Fresh Vegetable Growers under Price and Production Uncertainty. Journal of Agricultural and Applied Economics (Vol. 45). https://doi.org/10.1017/s1074070800005204

Veres, S. M., Molnar, L., Lincoln, N. K., & Morice, C. P. (2011). Autonomous vehicle control systems - A review of decision making. Proceedings of the Institution of Mechanical Engineers. Part I: Journal of Systems and Control Engineering, 225(3), 155–195. https://doi.org/10.1177/2041304110394727

Vickrey, W. (1961). American Finance Association Counterspeculation , Auctions , and Competitive Sealed Tenders Author (s): William Vickrey Source : The Journal of Finance , Vol. 16 , No. 1 (Mar ., 1961), pp . 8-37 Published by: Wiley for the American Finance Associat. 16(1), 8–37.

Villa, G., Adenso-Díaz, B., & Lozano, S. (2019). An analysis of geographic and product diversification in crop planning strategy. Agricultural Systems, 174(December 2018), 117–124. https://doi.org/10.1016/j.agsy.2019.05.006

Villalobos, J. R., Soto-Silva, W. E., González-Araya, M. C., & González–Ramirez, R. G. (2019a). Research directions in technology development to support real-time decisions of fresh produce logistics: A review and research agenda. Computers and Electronics in Agriculture, 105092.

Villalobos J.R., Miguel Peinado-Guerrero, Rodrigo Ulloa, Hector Flores, Arnold Maltz, Xaimarie Hernández-Cruz, Omar Ahumada, George Runger, Patrick E. Phelan, Paul Gutierrez, Madhav Regmi, Chadelle Robinson, "Technology-enabled, Rapid-Response Fresh Food Supply Chains: a paradigm for the new market conditions", Working Paper, International Logistics and productivity Improvement Laboratory, Arizona State University, Tempe AZ, January 2022.

Von Martial, F. (1992). Coordinating plans of autonomous agents (Vol. 2, No). Berlin: Springer-Verlag.

Wang, C., & Chen, X. (2017). Option pricing and coordination in the fresh produce supply chain with portfolio contracts. Annals of Operations Research, 248(1–2), 471–491. https://doi.org/10.1007/s10479-016-2167-7

Winter, E. (2002). The shapley value. Handbook of game theory with economic applications, 3, 2025-2054

WWF. (2012) Living planet report 2012: biodiversity, biocapacity and development. [WWW document]. URL https://www.worldwildlife.org/publications/living-planet-report-2012-biodiversity-biocapacity-and-better-choices

Xu, Z., Peng, Z., Yang, L., & Chen, X. (2018). An improved Shapley value method for a green supply chain income distribution mechanism. International Journal of

Environmental Research and Public Health, 15(9). https://doi.org/10.3390/ijerph15091976

Yan, C., Banerjee, A., & Yang, L. (2011). An integrated production-distribution model for a deteriorating inventory item. International Journal of Production Economics. https://doi.org/10.1016/j.ijpe.2010.04.025

Yiridoe, E. K., Bonti-Ankomah, S., & Martin, R. C. (2005). Comparison of consumer perceptions and preference toward organic versus conventionally produced foods: A review and update of the literature. Renewable agriculture and food systems, 20(4), 193-205.

Yu, J., Zheng, X., Zhou, Y., & Zhang, Q. (2018). The Principal–Agent Leasing Model of "Company + n Farmers" under Two Division Modes. Sustainability, 10(6), 2015. https://doi.org/10.3390/su10062015

Yue, C., Dennis, J. H., Behe, B. K., Hall, C. R., Campbell, B. L., & Lopez, R. G. (2011). Investigating consumer preference for organic, local, or sustainable plants. HortScience, 46(4), 610-615.

Yue, C., & Tong, C. (2009). Organic or local? Investigating consumer preference for fresh produce using a choice experiment with real economic incentives. HortScience, 44(2), 366-371.

Yue, D., & You, F. (2014). Fair profit allocation in supply chain optimization with transfer price and revenue sharing: MINLP model and algorithm for cellulosic biofuel supply chains. AIChE Journal, 60(9), 3211–3229. https://doi.org/10.1002/aic.14511

Zhang, X., Qing, P., & Yu, X. (2019). Short supply chain participation and market performance for vegetable farmers in China. Australian Journal of Agricultural and Resource Economics, 63(2), 282–306. https://doi.org/10.1111/1467-8489.12299

Zhao, Y., Ma, L., Xie, G., & Cheng, T. C. E. (2013). Coordination of supply chains with bidirectional option contracts. European Journal of Operational Research, 229(2), 375–381. https://doi.org/10.1016/j.ejor.2013.03.020

Zhao, C., Liu, B., Xiao, L., Hoogenboom, G., Boote, K. J., Kassie, B. T., ... & Asseng, S. (2019). A SIMPLE crop model. European Journal of Agronomy, 104, 97-106.

Zhou, L., Zhou, G., Qi, F., & Li, H. (2019). Research on coordination mechanism for fresh agri-food supply chain with option contracts. Kybernetes, 48(5), 1134–1156. https://doi.org/10.1108/K-08-2017-0291

APPENDIX A

PROOF OF THE VALUES INSIDE THE INVERSE CUMULATIVE PROBABILITY DISTRIBUTION IN THE BUYER'S OPTIMAL QUANTITY OF PURCHASE OPTIONS

As part of the results, we obtained the following expression for the optimal quantity of purchase options in the buyer's decision-making process:

$$Q_B^* = G^{-1}\left(\frac{c_{opt} + c_{strike} - c_{spot}}{c_{strike} - c_{spot}}\right) - F$$

Where $G(y)$ corresponds to the cumulative distribution function for the random variable representing the demand, thus it accepts inputs from the real numbers and returns values in the range of $[0,1]$. For the inverse of the cumulative function, $G^{-1}(D)$, it takes values from the range $[0,1]$ and those are mapped to the real numbers corresponding to the demand values. Thus, it is important to determine if the input of this function is properly defined under the scope of our problem.

Thus, we need to prove that

$$0 < \frac{c_{opt} + c_{strike} - c_{spot}}{c_{strike} - c_{spot}} < 1$$

<u>Proof</u>:

Form the problem structure we have that the relationship between the option purchase cost (c_{opt}), the option exercise price (c_{strike}), and the spot purchases cost (c_{spot}) is given by

$c_{opt} < c_{strike} < c_{opt} + c_{strike} < c_{spot}$	**Relationship A**

a) Let's start with the left inequality and prove that it holds by contradiction, this means we are assuming that

$$0 > \frac{c_{opt} + c_{strike} - c_{spot}}{c_{strike} - c_{spot}}$$

The result of this division being negative can only be obtained if the division of the numerator by the denominator results in a negative number.

This means that either:

i) The numerator is negative, and the denominator is positive, or

ii) The numerator is positive, and the denominator is negative

For i):

For the denominator to be positive, we will require that

$$c_{strike} - c_{spot} > 0$$

But we know, from Relationship A, that $c_{strike} < c_{spot}$ which is a contradiction. Thus, the case where i) holds is not possible.

For ii)

For the numerator to be positive we have that

$$c_{opt} + c_{strike} - c_{spot} > 0$$

Which means that

$$c_{opt} + c_{strike} > c_{spot}$$

But we know, from Relationship A, that *this* is a contradiction. Thus, the case where ii) holds is not possible.

In summary, we have shown that the initial assumption of $0 > \frac{c_{opt}+c_{strike}-c_{spot}}{c_{strike}-c_{spot}}$ results in a contradiction in both i) and ii). This implies that

$$0 < \frac{c_{opt} + c_{strike} - c_{spot}}{c_{strike} - c_{spot}}$$

Which proves the first inequality.

b) To prove the second inequality, we can also use contradiction and assume that it does the opposite holds, as follows:

$$\frac{c_{opt} + c_{strike} - c_{spot}}{c_{strike} - c_{spot}} > 1$$

By rearranging the terms, we obtain

$$\frac{c_{opt}}{c_{strike} - c_{spot}} + \frac{c_{strike} - c_{spot}}{c_{strike} - c_{spot}} > 1$$

Which is equivalent to

$$\frac{c_{opt}}{c_{strike} - c_{spot}} + 1 > 1$$

and

$$\frac{c_{opt}}{c_{strike} - c_{spot}} > 0$$

We already know that $c_{opt} > 0$, thus the numerator is always positive. We also know, from Relationship A, that $c_{strike} < c_{spot}$, which means that $c_{strike} - c_{spot} < 0$ which results in a negative denominator. The division of a positive number by a negative number is always negative, which contradicts the initial assumption.

By combining the proofs from a) and b) we obtain that the restriction on the values inside of the inverse cumulative probability function holds as required:

$$0 < \frac{c_{opt} + c_{strike} - c_{spot}}{c_{strike} - c_{spot}} < 1$$

□

In addition to the proof, a set of numerical examples are presented below.

Numerical example based on the case study

In the studied case study have that $c_{opt} = \$0.15$, $c_{strike} = \$0.6$, and $c_{spot} = \$1.1$. This results in:

$$\frac{c_{opt} + c_{strike} - c_{spot}}{c_{strike} - c_{spot}} = \frac{-\$0.35}{-\$0.5} = 0.7 < 1$$

The question arises as the numerator is actually higher than the denominator. But given the relationship between these values it always holds that both values are negative terms (by Expression A), which results in a final value between 0 and 1.

Other examples of possible combinations of these values and the resulting coefficient inside the inverse cumulative probability function are presented in Table A-1 below:

Table A-1: Numerical Examples

c_{opt}	c_{strike}	c_{spot}	Numerator (A)	Denominator (B)	Division Result (A/B)	Equivalent Demand $G^{-1}\left(\frac{A}{B}\right)$
0.15	0.6	1.1	-0.35	-0.5	0.7	7,048
0.5	1	2	-0.5	-1	0.5	6,000
1	3	4	-3	-4	0.75	7,348
5	20	35	-10	-15	0.67	6,879
10	40	55	-5	-15	0.33	5,120