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Master’s Dissertation 2011

Resilient Supply Network Structure Design for Fresh Produce

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September 2011

Graduate School of System Design and Management,
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Major in System Design and Management

SUMMARY OF MASTER'S DISSERTATION

Student Identification Number	80934679	Name	Loultiti Moulay Ayyoub

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Resilient Supply Network Structure Design for Fresh Produce

Abstract

On March 11th 2011, Japan experienced an earth quake and a tsunami of cataclysmic magnitude. Although the areas affected by the earth quake were the ones most prepared in the world to face this type of events, the disaster cause widespread disruption that hindered businesses not only in area of impact, but throughout Japan and beyond. This event put more focus than ever before on the vulnerability of today's highly lean and tuned supply networks to disruptions. The case of contaminated food products in the Fukushima prefecture showed how sensitive the fresh produce supply network, in particular, can be to disruptions due to natural or industrial disasters. In this paper we study the supply disruptions affecting the fresh produce supply networks and we propose a mitigation strategy to improve the network's resilience. After reviewing the various solutions to disruptions proposed in literature, this paper highlights some specificities of the fresh produce supply network that make these solutions inadequate. As an example, we focus on the fresh oranges sector and we use related trade data for validating the model assessing the results. We propose the introduction of fresh produce options for hedging the supply risk. Thereafter, we examine the effect of introducing hedging options on the supply network topology and thus, its resilience. As there is nowadays no platform for trading of such options, we consider three different types of platforms. And we compare the effect of introducing options through every one of these platforms and the corresponding effect on the network's resilience and the single demand nodes' profitability. We find that, though having a number of restrictive requirements, the PEM (Private Electronic Market) is the platform that makes introducing hedging options most effective. Further research is necessary evaluate the feasibility of the best solution-PEM, - but the other two alternatives evaluated here –though not as effective- are available or can easily be.

Key Word(5 words)

Supply network, Resilience, Disruptions, Hedging options, Fresh Produce.

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Chapter 1- **Introduction**

In April 2010, the explosive phase on Eyjafjallajökull volcano's eruption caused the largest aviation shutdown in history [1]. As wind blew volcanic ashes towards Central Europe, Great Britain and Scandinavia, it caused closure of most of the European airspace [1]. The impact on the economy was tremendous. According to the International Air Transport Association (IATA), airlines alone were losing $200M of revenues every single day [2].

In March 11, 2011, the earthquake and tsunami that stroke the Sendai area in Japan caused widespread devastation and major disruptions that affected the whole country. Total losses were estimated to $300 Billion [3]. Among the devastating effects of that event, the damage that happened to the Fukushima Daiichi Nuclear Plant was probably the most notorious. The nuclear crisis resulting from the damages at Daiichi Nuclear Plant, and the detection of radioactive contamination in some agricultural products produced in the vicinity of the plant caused a shortage in many food products in the Japanese market [4].

These two examples show how vulnerable the logistic and economic systems in today's world have become to the event of unpredicted catastrophes.

1- 1- Disruptions

Because of decades of focus on optimization, Supply Chains have become very efficient in creating value in the most effective ways. This extreme optimization has made today’s Supply Chains inherently fragile to external and internal disruption factors.[5] Therefore, disruptions management became a very import field of research in the past few years and extensive work has been done to define management solutions that answer this need.

Developing monitoring, mitigation and recovery mechanisms are core elements in any strategy for making an enterprise resilient [6] –that is flexible and robust enough to go through any unexpected disruptions with the least possible damage .-

The aim of this paper is to provide a tool that helps in designing a mitigation strategy for supply disruption in supply chains similar to the global fresh citrus one that is used as an example.

The proposed solution is therefore not applicable for other types of supply chains that do not share the same characteristics: Perishable goods, long life cycle -causing an inelasticity supply, [7] - and international trading –where compliance to various regulations is necessary for every country or destination market.-

Most of the work that has been done in disruption management is focusing on manufacturing supply chains. In this paper, we tackle the issue of disruptions facing a different kind of supply chain with a specific product that is fresh produce. The specificities of the fresh produce are such that many of the so far developed approaches such as using extra inventory as a mitigation mechanism are not be applicable [8].

1- 2- **Fresh Oranges Supply Chain and Disruptions**

In this paper we will use one specific fresh produce's supply network as an example to validate and demonstrate the value of our research. We chose for this purpose the fresh oranges for many reasons. First of all, I have a personal interest in fresh oranges sector because of my previous work experience in a company that partly operates in his sector. Second, from my previous work I have contacts with experts in the field who helped me understand many aspects of the fresh oranges and fresh produce supply network in general. And finally, fresh oranges are one of the most widely traded fresh produce in the world in terms of value traded [11]. Therefore, they are a good choice for represent the whole fresh produce sector.

– The Fresh Oranges Supply Chain

Some differences might exist from one producing country to the other, but the general structure of fresh citrus industry is essentially the same [12]. As illustrated on Fig. 1, at the upstream end, a myriad of farmers –most of which of small to medium size-constitute the production base that supplies the whole chain with fresh fruits on a seasonal basis. Some vertically integrated exporting firms own farming operations of their own, yet the bulk of the production comes from independent farmers.

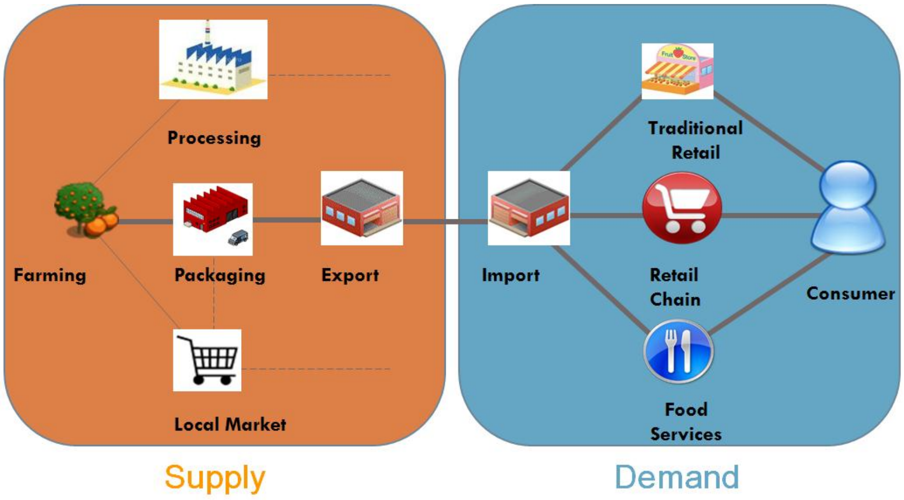


Fig. 1: Fresh Citrus Supply Chain

In order to face the post-harvest challenges of packaging, marketing and exporting, those farmers need to go through other operators. They either sell their production to independent pack-houses that go through exporting companies –either independent or owned by the same operator,- or they gather into cooperatives that buy their production and assume the tasks of packaging, logistics, marketing, export and selling. Because the cooperatives are for nonprofit, they are generally the most present in this part of the chain as they can guaranty the best and most reliable revenues for their members.

After export, the merchandize is bought by importers that can be independent or belonging to the next operator that is either a wholesaler or a retail chain. While retail chains buy merchandize they sell to the final consumer directly, the wholesalers usually sell to smaller traditional retail stores or to food service industry.

Prices of fresh citrus fruits are set by the market according to supply and demand. Because of the fluctuations in supply and demand, prices can show high levels of volatility. As for the supply, it is affected by controllable factors such as the planted area, age of plantations and production techniques and processes; and by uncontrollable factors such as weather conditions and the incidence of diseases. On the other hand, demand depends mainly on income levels, population growth, consumer preferences and availability and price of substitute products.

- Description of the Fresh Oranges Supply Chain Disruptions

Overall, like most crops, citrus fruits end results are highly dependent on weather conditions. While mild effects due to climate, pests or diseases affect the yields and quality every season, occasionally, severe incidence of such elements can have very destructive effects on the production. Among others, frosts, freezes, strong winds and diseases specific to citrus trees –such as the Citrus Cancer,- can and do affect the production both qualitatively and quantitatively resulting in severe supply disruptions, insufficient supply and increase in prices.

Moreover, supply of fresh citrus fruits is characterized by very low price elasticity due to the long life cycle of the trees that need several years before reaching full productivity levels. As a consequence, supply cannot adapt rapidly to any gap between supply and demand even if it is foreseen months in advance. Therefore, when there are supply disruptions it is inevitable to have to have increased prices and unsatisfied demand. In case of oversupply on the other hand, producers do not have the option to reduce their production accordingly because they have already committed to significant investments and face important exit costs.

Furthermore, -unlike the orange juice sector- the fresh citrus market lacks appropriate tools for hedging against volatility in the demand and prices. The demand and supply being uncontrollable to a great extent over the short term and the trading intermediaries generally dealing on a commission basis; the producers end up being the operator bearing most of the risk.

All of these elements make that producers tend to prefer dealing with reliable customers that besides providing good prices, are also present every year and willing to buy most of their production. Other reasons such as higher transaction costs and high quality and service risks associated with dealing with unfamiliar customers/suppliers, makes operators at both ends –supply and demand side- prefer long term relationships with a limited number of partners.

When a supply disruption occurs, affecting a major supplier, his customer finds himself short of supply to satisfy the demand. The customer –importer- looks for alternative supply from other sources. But due to the business structure previously described when the shortage of supply is too important, the gap cannot be filled –even for higher prices- by other suppliers who are committed to their usual customers.

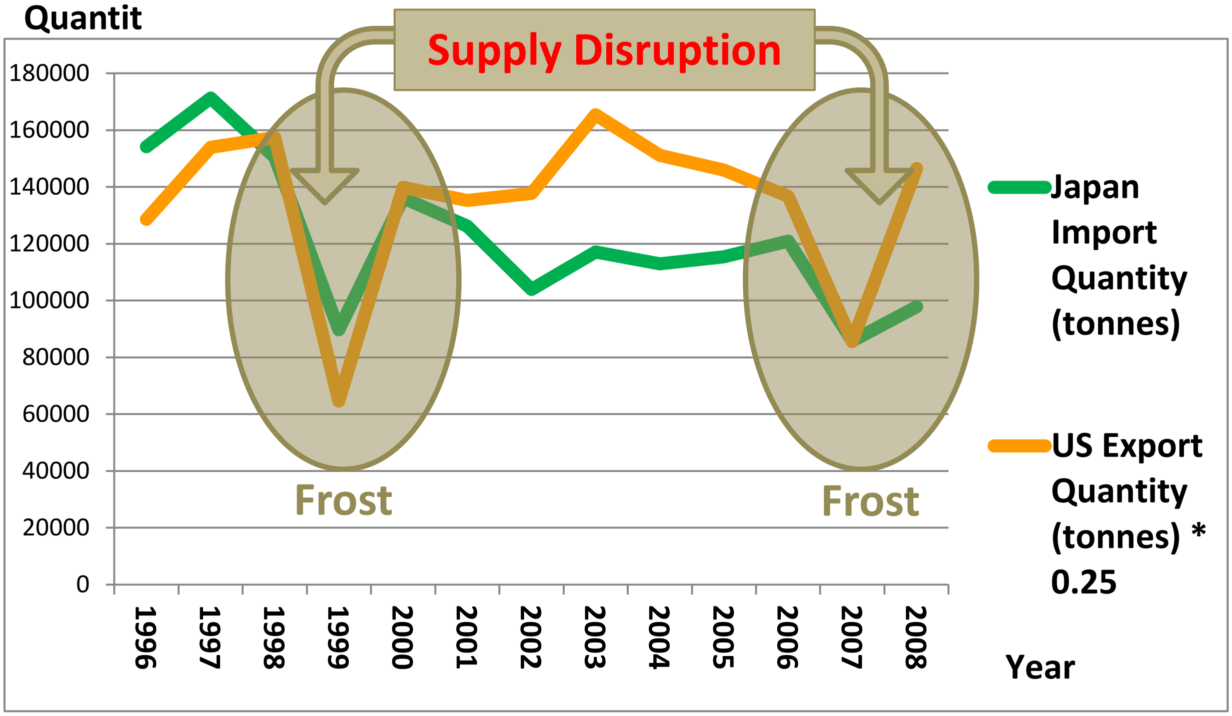


Fig. 2: Effect of Supply Disruption in California on the Japanese Import of Fresh Oranges

To illustrate this issue, we can look at the effect of major freezes that affected citrus production in California –the major supplier of oranges for Japan- on the quantity supplied to Japanese market –Fig. 2.-

The effect of this disruption is not compensated because of all the elements previously mentioned. Therefore, what actually happens is there is unsatisfied demand in the Japanese, market which means lost sales for the importers. The increase in price during the disruption seasons show that unsatisfied demand –Fig. 3.-

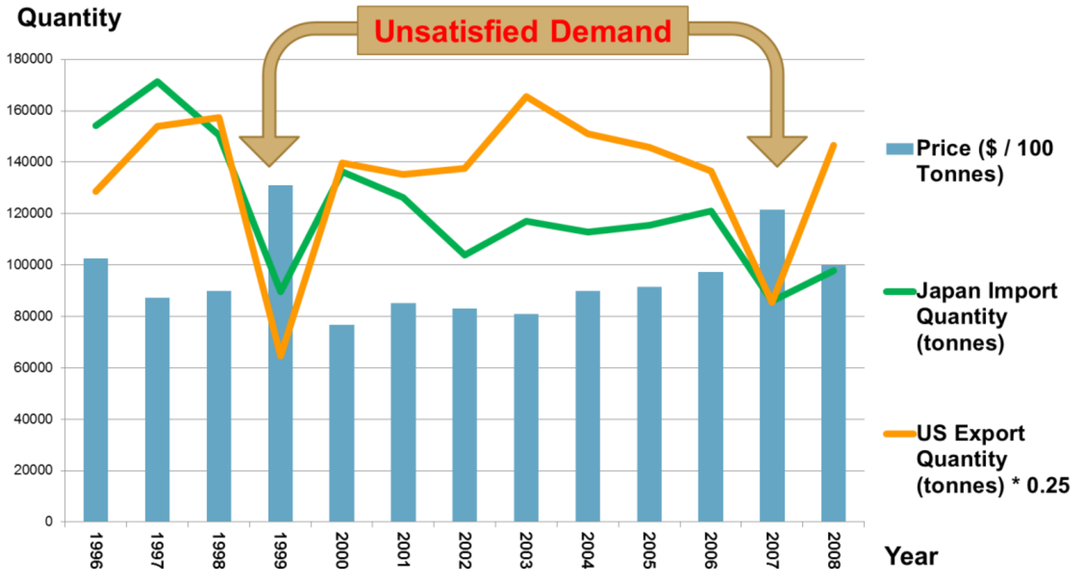


Fig. 3: Unsatisfied Demand Due to Disruptions

In addition to that, when there is an increase in price because of lack of supply, the consumer preferences shift into buying less of the product, and we end up with a long term effect on the demand that stays low for 2 or 3 years after the disruption occurs. Fig. 4 shoes the lost sales because of this.

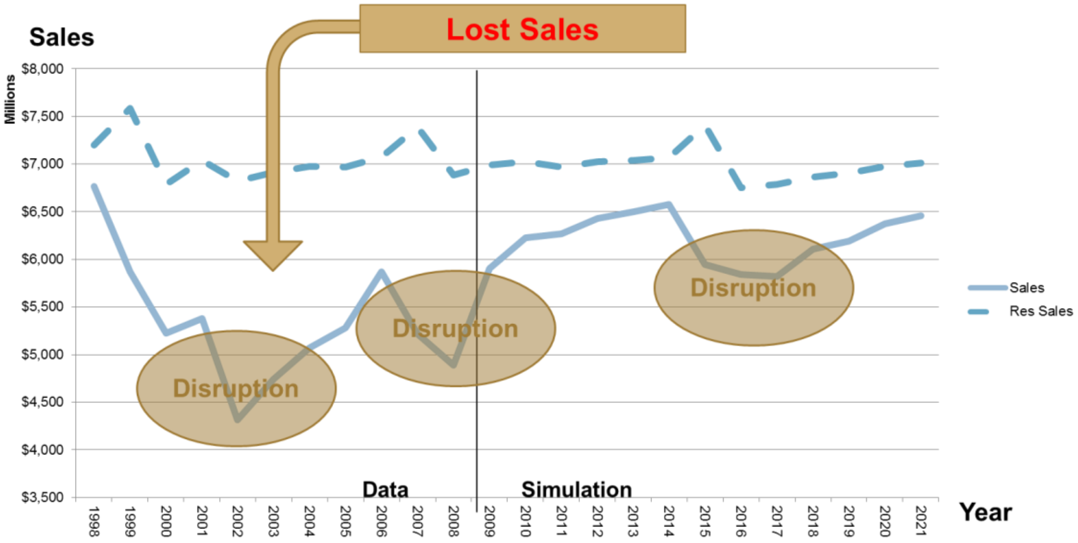


Fig. 4: Lost Sales Due to Supply Disruptions

1- 3- Purpose of research

The purpose of this research is, therefore, to study the resilience for fresh produce supply networks to disruptions. And to describe a way to improve the resilience of the network, while taking into consideration the single enterprises' –that constitute the network- objectives. More precisely, we will aim at answering the question: How can we design a fresh produce supply network that is more resilient to disruptions without compromising enterprise efficiency?

Chapter 2- **Literature Review**

1- 1- **Building resilience in enterprises**

One of the most prominent researches in the field of resilience is The Resilient Enterprise, Sheffi (2005). In this research, Yossi Sheffi defines disruptions and identifies them as a separate category of risks faced by enterprises. He also covers the impact of disruptions on the enterprise and identifies the steps it goes through as it is being subject to a disruption and recovers from it. This research also discusses the impact of the disruption on the market position of the company depending on its level of responsiveness. And it lists a number of categories of mitigation mechanisms that need to be built into the enterprise to improve its resilience to disruptions.

Sheffi (2005) gives a framework for vulnerability assessment to identify the possible disruption that might occur, their likelihood and their impact on the company. High vulnerability is when both the likelihood and the consequence of the disruption are high. And when both likelihood and impact of the disruption are low, then the level of vulnerability is low. The disruptive events that combine high likelihood and low impact are part of the daily operations management activities, but the ones combining high impact and low probability need to be addressed elsewhere than within the daily activities [6].

As an illustration for this idea, Sheffi displays a vulnerability map for a single company shown in Fig. 5. Such map summarizes the different threats facing a given company, their relative likelihoods, and their potential impact on the enterprise –which also explains how resilient is the enterprise to this type of threats.-

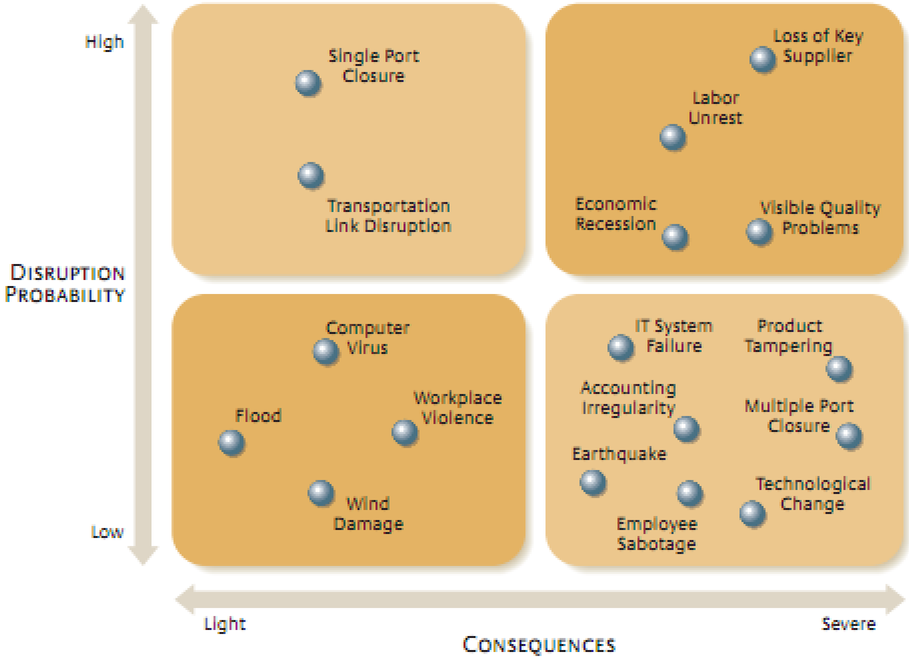


Fig. 5: A Vulnerability Map for a Single Company, Sheffi (2005)

As mentioned earlier, an enterprise can be more or less ready –resilient- to a specific disruption. Sheffi shows the relationship between this readiness –responsiveness- and the market position of the company to illustrate that such element can have a major impact on deciding the fate of the company. In Fig. 6, we can see that companies that have low responsiveness can either risk losing market share –if they are in a competitive marker- or risk facing regulatory interventions if they have great power over the market. Therefore, besides the costs associated with suffering such disruptions, the fate of the company itself might be decided by how ready it is ready when the Big One hits.

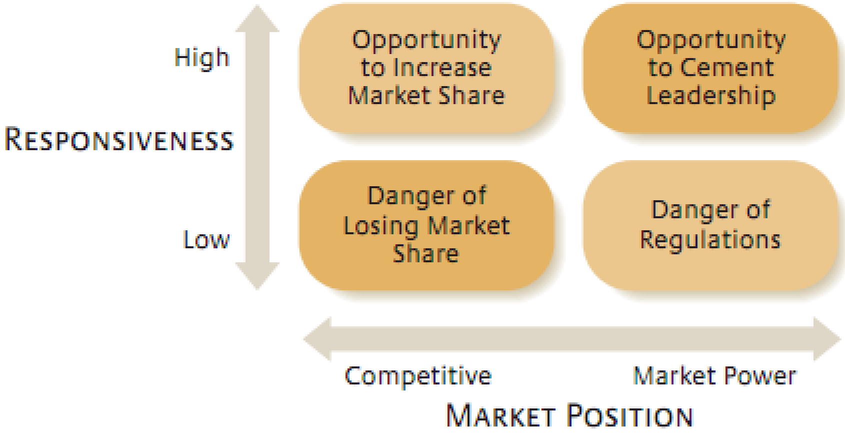


Fig. 6: Company Position and Responsiveness, Sheffi (2005)

Therefore, it is vital to build resilience into the enterprise to face the risk of potential disruptions. The question becomes then: how do you build in resilience in the enterprise? In Fig. 7, we try to summarize the different types of mitigation mechanisms described by Sheffi that he essentially puts in two categories.

The first category is the traditional approach consisting in having some resources in excess as a reserve to be used in case of disruptions called Redundancy. As discussed earlier, modern manufacturing supply chains have undergone major improvement that consisted into reducing waste and making the flow of goods as lean as possible. Such efforts like lean management and JIT management have made great achievements in terms of efficiency and cost reduction. But on the other hand, companies have become more vulnerable to disruptions because of these reserves elimination. Therefore, increasing redundancy again to a level that is adequate to the risks faced by the company can be a solution. But this approach comes at the cost of losing some of the benefits of

JIT and lean management. And on the other hand, increasing redundancy brings –besides resilience- no other benefits, which restricts the extent to which this approach can be used. Hence the second category of disruption mitigation mechanisms proposed by Sheffi.

This second category consists in building flexibility into the enterprise so that its resources that are allocated to some other purpose can be used to mitigate some disruption. This consists in using standard processes and having interoperability built-in multiple locations. We can imagine an example where a manufacturer fails to comply to the production schedule in one plant due to some disruption. Having interoperability and standard processes would make it possible to use other plants resources to help the affected plant recover more quickly.

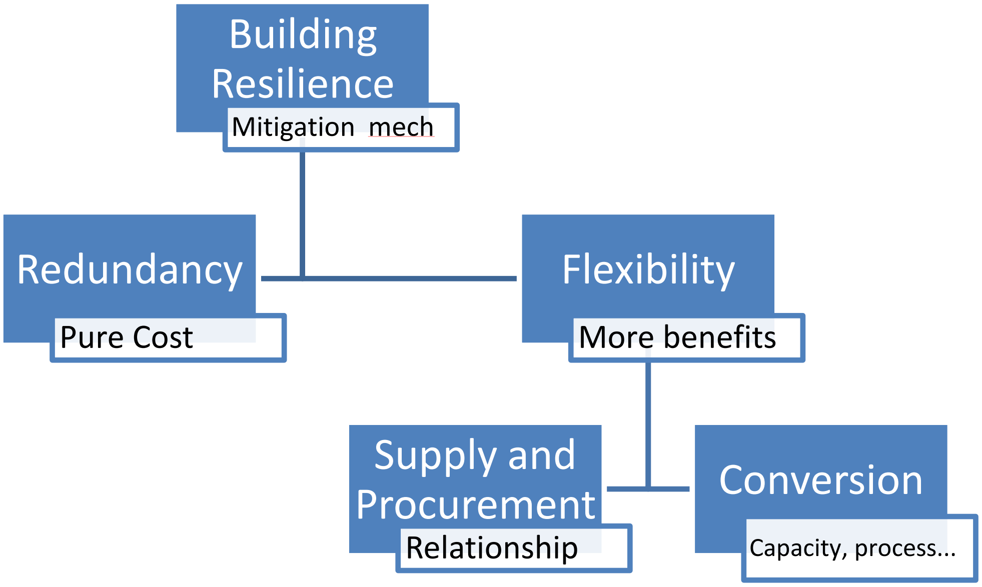
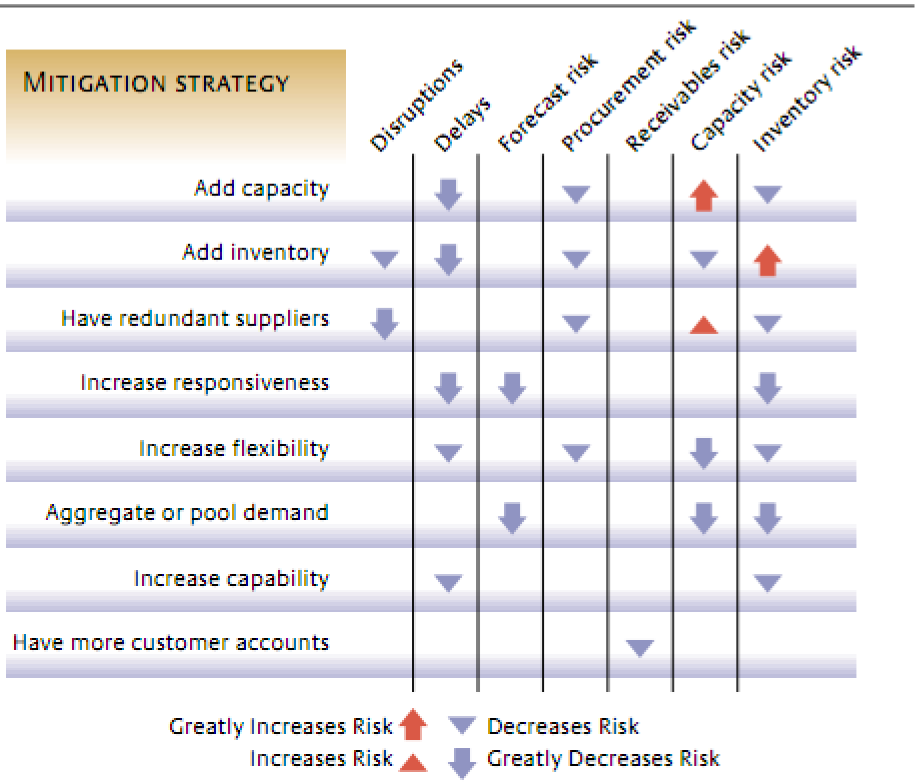


Fig. 7: Building in Resilience –Mitigation Mechanisms-

1- 2- S.C Risks Categories and Management Strategies

In The Resilient Enterprise (2005), Yossi Sheffi was focusing on the resilience of the single enterprise –although sometimes in a supply chain context. - Chopra and Sodhi on the other hand, took a larger view at the risks –including disruptions- faced by supply chains.

In Managing Risk to Avoid Supply-Chain Breakdown (2004), the authors first list the risks faced by supply chains, in categories –including disruptions- along with some driving causes behind each category [13]. They also list a number of mitigation strategies for risks, and their corresponding effect on the level of risk from every category of the ones mentioned earlier –Fig. 8.-



MITIGATION STRATEGY	Disruptions	Delays	Forecast risk	Procurement risk	Receivables risk	Capacity risk	Inventory risk
Add capacity		⬇		▼		⬆	▼
Add inventory	▼	⬇		▼		▼	⬆
Have redundant suppliers	⬇			▼		▲	▼
Increase responsiveness		⬇	⬇				⬇
Increase flexibility		▼		▼		⬇	▼
Aggregate or pool demand			⬇			⬇	⬇
Increase capability		▼					▼
Have more customer accounts					▼		

Greatly Increases Risk ⬆ ▼ Decreases Risk
Increases Risk ▲ ⬇ Greatly Decreases Risk

Fig. 8: Assessing the Impact of Various Mitigation Strategies, Sodhi (2004)

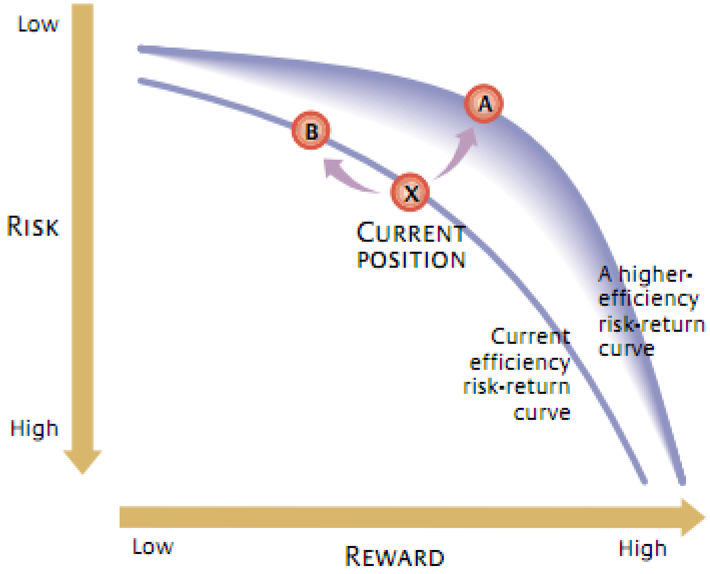


Fig. 9: Choosing Supply-Chain Risk/Reward Trade-offs, Sodhi (2004)

Similarly to Sheffi, Chopra and Sodhi (2004) stress the fact that the major problem faced by decision makers is to decide the level of resilience to be targeted given the cost and risk profile at hand. At the same level of efficiency, one is locked in a trade-off between risk and costs. Instead, one needs to move to a higher level of efficiency in order to be able to reduce risks without eroding rewards –increasing costs. - Fig. 9 illustrates this idea: from current position with high risk, we can accept more costs and reduce the level of risk by moving to point “B”, or we can move to a higher the level of efficiency and thus get to point “A” where risk is lowered and reward is preserved.

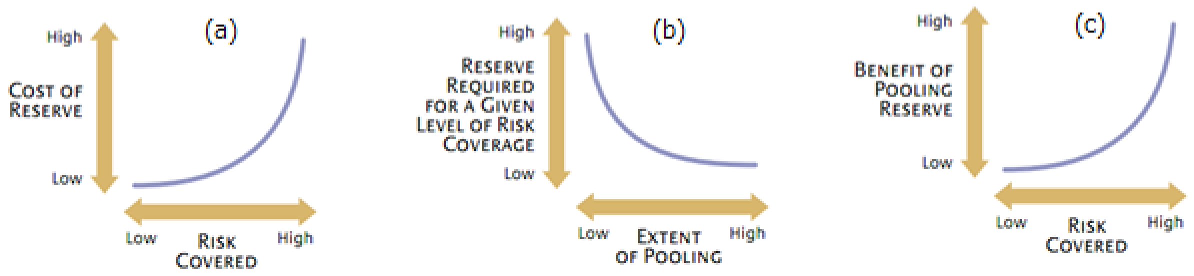


Fig. 10: Balancing Supply-Chain Risk/Reward Relationships, Sodhi (2004)

Chopra and Sodhi (2004) propose a method to customize risk management strategy to the need of the specific supply chain. Since the cost of reserve grows exponentially with the amount of risk to be covered –Fig. 10 (a),- they suggest pooling reserves across the supply chain as a way to move to a high level of efficiency. The higher the level of pooling, the less reserve is required to cover for a given amount of risk –Fig. 10 (b).- This means that the higher the amount of risk covered, the more beneficial it is to adopt pooling reserve as a strategy across the supply chain –Fig. 10 (c).-

Subsequently, a decision making set of rules is proposed to managers decide which mitigation strategy that suits best in their specific context. As described in Fig. 11, when the cost of the reserve used to mitigate the risk is high, pooling the reserves across the supply chain is necessary to avoid having excessive costs. But when these reserves are not expensive, keeping decentralized reserves is a better option. And concerning the level of risk, when it is high, it has to be mitigated by making adequate investment. But if the risk is low, then the manager can focus on reducing the costs of the reserves at risk.

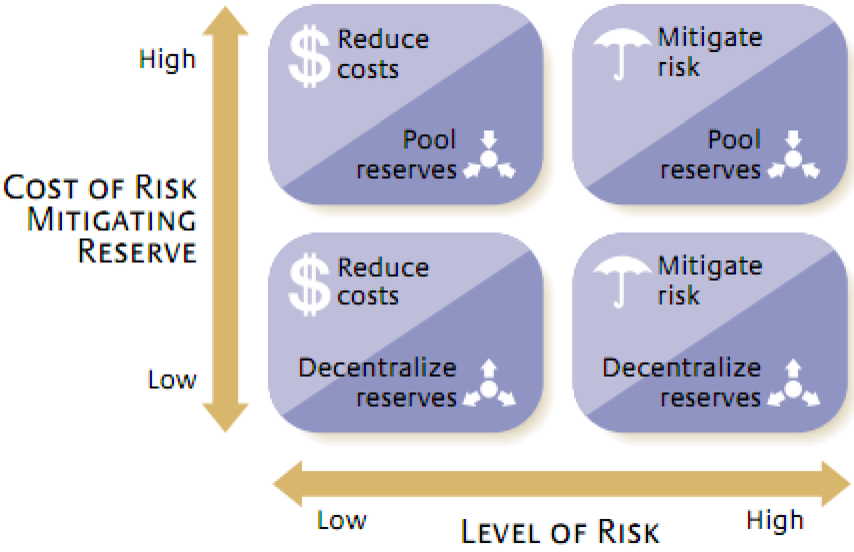


Fig. 11: Rules of Thumb for Tailored Risk Management, Sodhi (2004)

1- 3- Resilience of Supply Network based on Network Topology

There is an abundance of research done on enterprise and supply chain resilience, and we saw earlier two prominent examples of these researches.

There is, however, less research done on the resilience of the supply network as a whole. One of the first researches on this filed is the “Structure-based resilience metrics for service-oriented networks,” Rosenkrantz 2005, where he suggests a concept to quantitatively assess the resilience of nodes and edges-links- within a supply network [14].

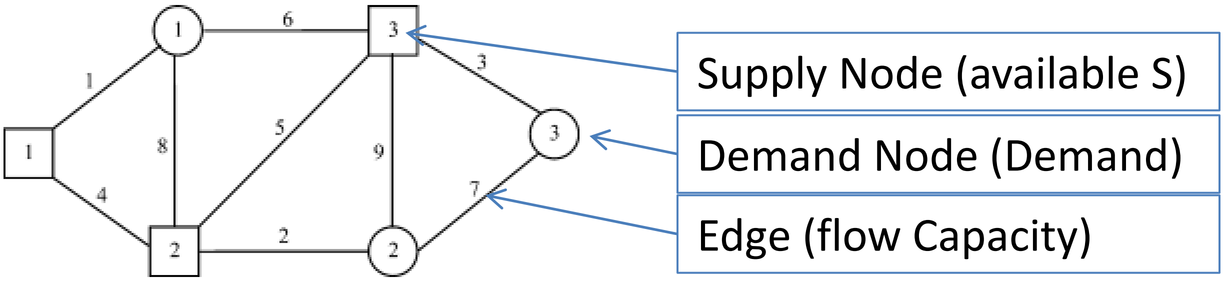


Fig. 12: Elements of Supply Network Resilience, Wang (2009)

On the other hand, Wang (2009) proposes a model to quantify the resilience of the whole network based on the network topology [15]. He first defines computation method for the demand nodes based on the connections they have to supply nodes, then, based on that he defines the resilience of the network as a function of the resilience of the demand nodes and their relative importance in the network.

As we can see on Fig. 12, the main elements of the resilience measurement model presented by Wang are the supply nodes' available supply, the demand nodes' demand quantity, and edge capacity –that is the capacity of the links between nodes.- Based on these elements, the model allows the calculation of a numerical value for the resilience of single demand nodes. Thereafter, these single nodes resilience values are summed up in a weighted sum –depending on the relative importance of every node- while accounting for the redundancy of supply for every node –that is how much supply in excess is available for every demand node,- to give us a numerical value for the resilience of the whole network.

1- 4- Literature Review Summary

The previous research that proposes mitigation solutions for disruption is mainly focused in manufacturing supply chains. These types of supply chains characterized by JIT practices and lean management motivated by efficiency and profitability has increased their vulnerability to unaccounted for disruptions. The fresh produce supply chains, on the other hand, are a de Facto JIT and lean systems because of the nature of their products: fresh and perishable. Therefore, they suffer from the same resilience issues as do the other previously mentioned supply chains and supply networks. Yet, most of the solutions developed for improving resilience do not apply for fresh produce supply networks. As we can see on Table 1, any strategy that includes adding redundancy to the system is not applicable to fresh produce because of its perishable nature. The strategies that deal with building flexibility in the system are also not feasible because the production processes for fresh produce, are natural process that allow a very small amount of control from the user/producer.

Therefore, we need to look at other approaches to improve the resilience for such supply chains. Approaching the problem from a wider and more holistic view can be beneficial for this purpose. However, we could find no literature treating the issue of fresh produce resilience from such perspective.

Table 1: Mitigation Strategies Vs. Type of Supply Chain

Mitigation Strategy	Manufacturing	Fresh Produce
Redundancy cost reduction via pooling of inventory	Using Inventory for mitigation of disruption	Using inventory is not possible (perishable product)
Building flexibility into the enterprise	Make resources and production processes more flexible to be adapted in case of disruption	Production is a natural process, it is also seasonal and production planning is not controllable

Fig. 13 illustrates the links missing in the literature. We could find no research combining the resilience at two or more of the three levels: Single Enterprise, Supply Chain and Supply Network.

This research will there for try to fill this gap, with a focus of the fresh produce sector. We will describe how single enterprises' make their sourcing decisions to optimize their value. And how these decision at the level of the single enterprise affect the topology of the whole supply network and therefore its resilience.

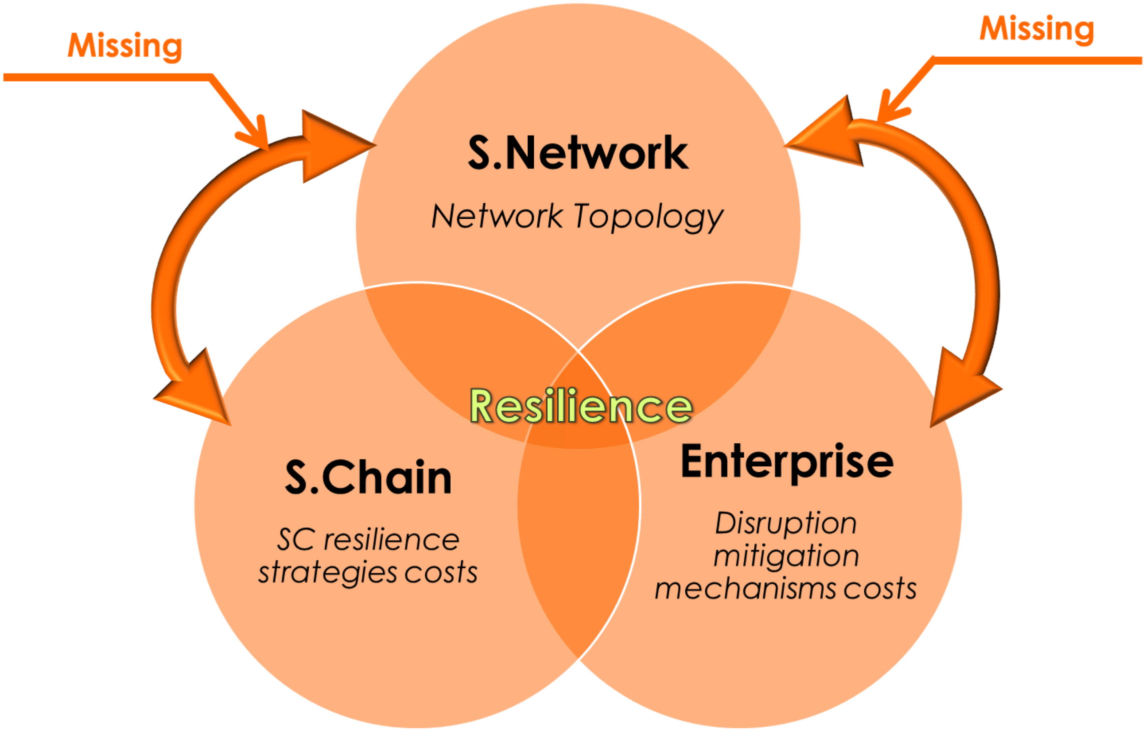


Fig. 13: Missing Parts in Resilience Litterature

We explained earlier that the purpose of this research is to find a way to improve the supply network’s resilience without affecting single enterprises’ profitability. Therefore, we will two main objectives. First, at the enterprise level, we will provide a model that explains the risk-costs tradeoffs at the level of single enterprises, and how it affects the topology -and thus the resilience- of the whole supply network. And second, at the network level, we will use a model that quantifies the resilience of the network to disruptions and while taking into consideration the risk-cost tradeoffs at the enterprise level, we will propose a solution to improve the supply network topology for a better resilience without eroding single enterprises’ profitability.

This research comprises three points of originality. First, as we can see on Fig. 13, we could find no research that investigates the issue of resilience from both the single enterprise and the supply network point of views combined. In this research we actually include the single enterprise's risk-cost tradeoffs for managing disruptions, its impact on the supply network topology and how that affects both the single enterprise's and the supply network's resilience to disruptions. The second point of originality consists of the use of a trust factor to capture the perceived risk from dealing with specific suppliers. As a matter of fact, the dealers of fresh produce –being a perishable good- face very high loss risk in case there is a lack of cooperation and trust with the supplier. Therefore, this element is an important element of our model. The third point of originality is the concept of flexible of supply. As mentioned earlier, the fresh produce supply chain is characterized by a high preference for dealing mainly with the most regular customers. Therefore suppliers have a limited amount of their production they can actually supply to other non-regular customer through options as we will see later in this paper. Therefore, we need to evaluate the amount of flexible supply to determine the volume of produce available to be traded on the options market.

Chapter 3- **Methodology**

1- 1- **Supply Network's Resilience Measurement Model**

For the network resilience measurement model, we use an adaptation of the model proposed by Wang (2009). Fig. 14 explains the different types of building blocks of a network structure. We use Wang’s model because it is one of the very few available models that quantify the resilience of a supply network based on its structure, which is necessary for the purpose of our research. Wang proposes a calculation method for the resilience of the demand node in each case. In this research, we do not cover cases where there are multi paths of supply. We will be then covering cases such as Fig. 14 (a) and Fig. 14 (d). Therefore, for the purpose of our study, we will use the formula proposed for case Fig. 14 (d) as the general formula –Eq. (1)- for computing the resilience of a demand node within a network since it is a general expression valid both for Fig.14 (a) and Fig.14 (d) cases.

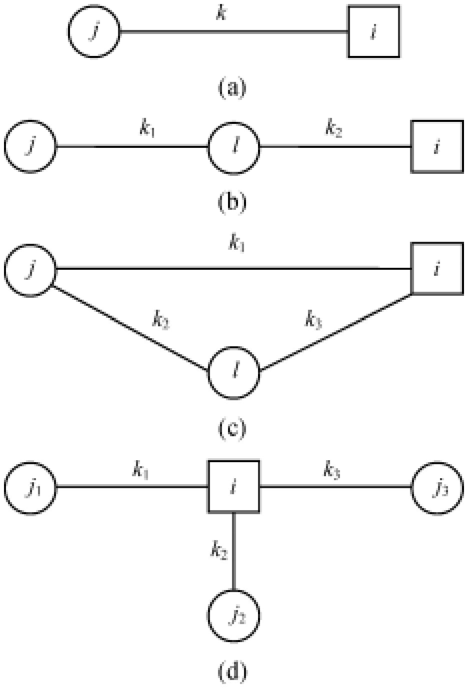


Fig. 14: Resilience of Single Node Supplied by One or More Suppliers, Wang (2009)

Thus, for a demand node “i”, its resilience r_i can be expressed as follows:

$$r_i = \frac{\sum_j k_j l_j min\{d_i, s_j, c_{i,j}\}}{d_i} \qquad (1)$$

Where

k_j is the supply reliability of supply node “j”

l_j the reliability of edge –link to supply node- “j”

d_i the demand quantity of node “i”

s_j the available supply of supply node “j”

$c_{i,j}$ the capacity of edge “i-j”

In this research we focus on the resilience to supply disruption, we do not include –therefore- logistic disruptions. Consequently, we ignore any disruptions due to logistic reasons by assuming these are 100% reliable. This means that for the purpose of our study we use the following assumption:

$l_j = 1$

Eq. (1) becomes then:

$$r_i = \frac{\sum_j k_j min\{d_i, s_j, c_{i,j}\}}{d_i} \qquad (2)$$

Concerning the edge capacity$c_{i,j}$, we use in it the quantity supplied to “i” by “j” -$q_{i,j}$- and we add to it the flexible volume from supplier “j”- F_j-:

$$c_{i,j} = q_{i,j} + F_j \qquad (3)$$

This definition of the edge capacity as expressed in the Eq. (3) above will capture the fact that the supplier cannot supply more than a certain level to every customer depending on his flexibility and the importance of the customer to him.

Based on the demand nodes' resilience, we can then compute the resilience of the whole network.

We first need to have the weight w_i of every single demand node "i", to capture each node's relative importance in the network:

$$w_i = \frac{d_i}{\sum_j d_j} \tag{4}$$

Then we need to compute the redundancy factor v_i that captures how much supply is available in excess compared to every demand node's demand quantity:

$$v_i = min\{ \frac{\Delta}{d_i}, 1 \} \tag{5}$$

Where Δ is the extra available supply, that is the difference between total supply from all supply nodes, and the total demand from all demand nodes.

The final expression of the network's resilience then becomes:

$$\text{Res} = \sum_i v_i w_i r_i \tag{6}$$

1- 2- Fresh Produce Buyer's Sourcing Decision Making Model

We will cover in this part the model used to describe the cost-risk tradeoffs behind the sourcing decisions for importers of fresh produce. Our objective is to include both the risks and costs associated with a given selection of suppliers and the portion of the expected demand sourced from every supplier.

We define the total expected cost of a customer "j" given a specific sourcing decision as follows:

$$ETC_j = C_j + L_j \qquad (7)$$

With:

L_j being the expected loss of customer ""j" when a given sourcing decision is taken.

And

C_j being the costs of customer "j" when a given sourcing decision is taken.

We express L_j as follows:

$$L_j = VAR_j * p + T_j \qquad (8)$$

We use the variable VAR to represent the total Value At Risk [16] from the chosen supplier selection. That is the amount expected to be lost at a given probability with a certain level of confidence. Follow is the expression chosen for VAR:

$$\forall j,\ VAR_j = \left(\sum_i q_{j,i} * \%VAR_i - o_j\right) * P_j \qquad (9)$$

Where

p is the probability for that VAR to be lost, since we are using a 95% confidence level, $p = 0.05$.

$q_{j,i}$ is the quantity sourced from supplier i

$\%VAR_i$ is the Value At Risk of unsatisfied demand from supplier “i” expressed in percentage of the quantity demanded $q_{j,i}$.

o_j is the quantity secured trough options by customer “j”.

P_j is the market price in customer “j” ’s market.

As for T_j, it is the loss perceived by customer “j” due to trust issues. And we define it as follows:

$$T_j = \sum_i T_{j,i} \qquad (10)$$

$T_{j,i}$ is the loss perceived by customer “j” from sourcing a given quantity from supplier “i” due to trust issues:

$$T_{j,i} = \begin{cases} V_{j,i} * \frac{q_{j,i}}{Q_j} * \left(1 - t_{j,i}\right) & , \frac{q_{j,i}}{Q_j} > t_{j,i} \\ 0 & , \frac{q_{j,i}}{Q_j} \leq t_{j,i} \end{cases} \qquad (11)$$

Where

$V_{j,i}$ is the value of the quantity sourced from supplier “i” by customer “j”

$q_{j,i}$ is the quantity sourced from supplier “i” by customer “j”.

Q_j is the quantity sourced from all suppliers by “j”.

And

$t_{j,i}$ is a trust factor computed based on the history of transactions between the customer "j" and supplier "i" as follows:

$$t_{j,i} = \frac{s_{j,i}}{\sum_k s_{j,k}} \tag{12}$$

Where $s_{j,i}$ is the adjusted average of the volume traded between customer "j" and supplier "i". We compute this adjusted average as follows:

$$s_{j,i} = \sum_{p=n_1}^{n_2-1} \frac{Transaction\ volume_{j,i,p}}{n_2-p} \tag{13}$$

$Transaction\ volume_{j,i,p}$ is the volume of transactions between customer "j" and supplier "i" in year "p".

n_1 is the year of first data point.

n_2 is the year of last data point.

Since $\forall$ j, i, $s_{j,i} \geq 0$:

$$0 \leq t_{j,i} \leq 1$$

And: $\forall$ j, i, $\sum_i t_{j,i} = 1$

The reason we use this trust factor is because in fresh produce, the risk of loss is very important due the perishable nature of the product. Thus, the buyer tends to work mainly with suppliers with whom they have long experience of doing business. In that case, they know that the supplier is reliable in terms of quality and delivery, and they also know that the supplier will try his best to overcome any difficulties that might happen to avoid losing an important longtime customer.

Therefore, the more business is done with a specific supplier and the more recent that business was the higher the trust factor is. The purpose of including the time factor is to show that the trust factor diminishes with time. For example a given supplier might have had large volume of transactions with a customer as an average of the total transactions done by that customer in the past. But if those transactions happened many years ago, the customer's trust level should be lower than when these transactions happened more recently.

Also, when the portion sourced by a customer "j" from a supplier "i" " $\frac{q_{j,i}}{Q_j}$ " is smaller or equal to the trust factor corresponding to that supplier "$t_{j,i}$", the expected loss due to trust issues is set to 0 because the specific supplier provides the same or smaller quantity that he usual provides, thus causing no trust problem based on the history of the transactions done in the past.

We now describe the effect of the trust factor on the expected loss from sourcing a given quantity $q_{j,i}$ from that supplier. Fig. 15 shows that the risk increases exponentially with the quantity supplied $q_{j,i}$. The smaller the trust factor the faster the expected loss grows.

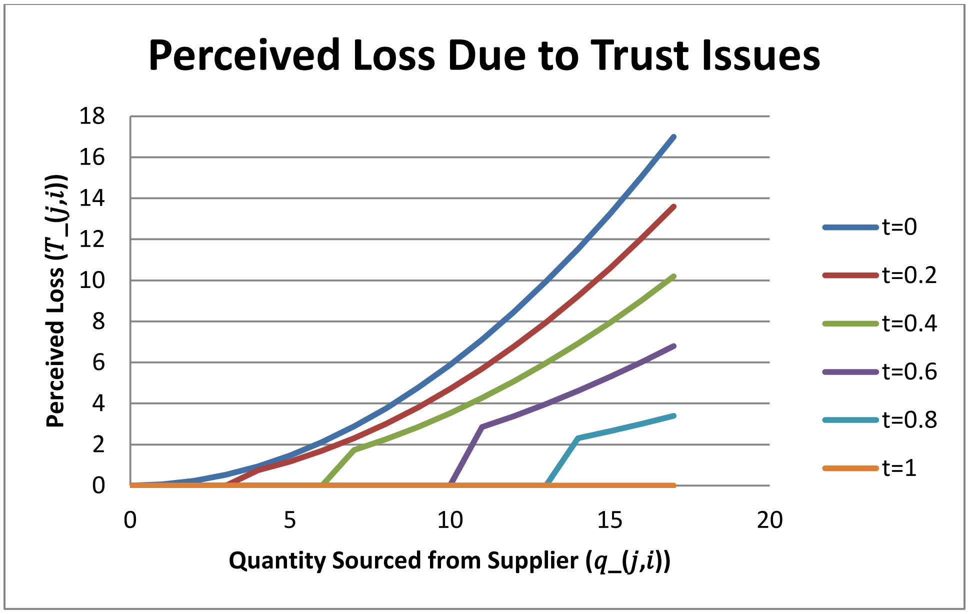


Fig. 15: Effect of Trust Factor on Perceived Loss Due to Trust Issues

Constraints

Following are some constraints that need to be applied to the variables used in this model:

$\forall$j, i, $q_{j,i}$, o_j are positive integers

$q_{j,i}$ being the quantity sourced by the customer "j" from supplier "i", $\sum_j q_{j,i} <$ the expected exports from supplier i

P_j price doesn't 'vary largely, we use a constant value for every "j" for simplicity.

o_j < total flexible volume for all suppliers $\sum_j F_j$.

We use the concept of flexible volume to take into account the fact that suppliers prefer to secure the selling of the majority of their production every season. In order to do so, they sell a part of their production –generally most of it- to customers with whom they have long lasting partnerships. As discussed in the explanation for the concept of trust factor, the partnership guarantees that to the customer that the supplier will try his best to satisfy his demand even at the expense of other customers who are less critical. Accordingly, the data –from the fresh oranges sector- shows that the volume supplied to some customer has almost no variation over the seasons, and other show different levels of variation.

We define Flexible Volume F_j for a supplier “j” as the volume that can be freely supplied to any customer. For that purpose, for every supplier, we compute the coefficient of variance of the quantity supplied to every customer. We called flexible volume, the total volume supplied minus the one supplied to any customer that shows a coefficient of variance≤ 1. This means the volume that is sold to these customers can go from 100% to 0% in one season.

As for the cost:

$$C_j = C_{p_j} + C_{o_j} \tag{14}$$

C_p is the Total cost of transportation. We use C_p as the main cost, because fresh produce generally travel long distances such that transportation constitutes a significant part of its total costs. The rest of the cost factors can be very similar regardless of the location of production when compared to transportation that is directly affected by the suppliers chosen and there location.

$$C_{p_j} = \sum_i q_{j,i} * c_{p_{j,i}} \qquad (15)$$

Where

$q_{j,i}$ the quantity sourced by customer “j” from supplier “i”

$c_{p_{j,i}}$ the unit cost of transportation from supplier “i” to customer “j”

C_{o_j}, on the other hand, is the cost of buying options for fresh produce for customer “j”.

$$C_o = q_{o_j} * P_j * O_r \qquad (16)$$

Where

q_{o_j} being the quantity secured through options by customer “j”.

P_j Price for import for customer “j”

And O_r the rate of the hedging options – option fees as a percentage of the value of the transaction.-

Given what precedes, the optimization objective of the buyer is to minimize its ETC.

We start with a set of potential suppliers i $\epsilon \{1, \dots, n\}$ and s set of buyersj $\epsilon \{1, \dots, m\}$.

Every buyer “j” tries to minimize its Total Expected Cost ETC_j by choosing the right suppliers and the right quantity to source from every supplier. The solution of this optimization for all buyers is a matrix of all the suppliers and buyers featuring the amounts traded between every buyer and supplier as described below:

$$\begin{cases} \begin{bmatrix} q_{1,1}^{*} & \cdots & q_{1,n}^{*} \\ \vdots & \ddots & \vdots \\ q_{m,1}^{*} & \cdots & q_{m,n}^{*} \end{bmatrix} \\ \forall \ j \epsilon \{1 \ldots m\} \quad ETC_j^{*} = \min(ETC_j) \end{cases} \tag{17}$$

Chapter 4- **Data**

As stated earlier in this paper, we use trade data from the fresh oranges sector as a an example for the validation of our model, as well as a showcase for the introduction of hedging options and their impact on the supply network topology and the resilience both of single demand nodes and of the supply network as a whole.

As a source of data, we use data available at the FAOSTAT database. This data base provides data for various agriculture products worldwide. We use the fresh oranges trade data as well as data about the production, the planted area and the yields of fresh oranges plantations in various countries.

We use the aggregate country data instead of single companies’. We thus treat the courtiers here as demand or supply nodes.

Given the seasonal nature of fresh produce, we focus on one season only, thus limiting our supplier selection to the north hemisphere of the globe, which provides the supply of fresh oranges for the winter season. The results obtained in this research can be applied –by symmetry- the other half of the globe.

Table 2: Most Important Exporting and Importing Countries for Fresh Oranges

Selected Importers	Selected Exporters
Germany	Spain
France	USA
Russia	Morocco
U.K	Greece
S.Ar	Egypt
Netherlands	Turkey
Canada	Lebanon
China, H.K	Israel
Japan	Tunisia
Belgium	Italy

Given that there is a myriad of countries that produce fresh oranges, we use the Pareto approach to focus on the essential few countries that provide most of the supply in the market and the ones that consume most of it. Table 1 lists the most important exporting and importing countries.

Based on the network data, we compute the resilience of the demand nodes, and then, of the whole supply network. Table 3 shows the resilience values obtain from the computation based on Eq. (6).

Table 3: Nodes and Network Resilience from Data

Nodes	Node weight	Redundancy Factor	Node Resilience
Germany	0.194	0.967	0.686
France	0.155	1.000	0.784
Russia	0.136	1.000	0.607
UK	0.116	1.000	0.450
S.Ar	0.097	1.000	0.523
Netherlands	0.078	1.000	0.710
Canada	0.078	1.000	0.631
China, HK	0.058	1.000	0.477
Japan	0.047	1.000	0.503
Belgium	0.043	1.000	0.644
Network Resilience		0.618	

Chapter 5- **Model Validation**

For validation, we use the data from FAOSTAT to get the input for our model. Based on the single demand nodes decision making part of the model –minimizing ETC, - we get the output of the model: a network topology. This topology is described by the demand and supply nodes included, their corresponding demand and supply quantities and the quantity sourced by every demand node supplied from every supply node. We then compare the network topology output by the model to the network topology of the real network –as described by the data. - We use the percentage of the quantity supplied instead of the quantity itself because it is more accurate than absolute values. Table 4 shows the network topology as it is according to the data and Table 5 shows the network topology that the model yields based on the data.

The data we use as an input to the model for validation is an estimate based on the yield risks and latest planted area data for every supply node. Further details about this data are available in Appendix 2, 3 and 4.

As we can see in Fig. 16, there is a strong correlation between the model output $Y_{i,j}$ and the data $X_{i,j}$. We did a regression at a 95% confidence level, and we had an R square of 0.98. This means that the model is valid for predicting the decision made by single nodes as for how much of their demand quantity to source from which supplier.

Table 4: Network Topology from Data

countries	Egypt	Greece	India	Israel	Italy	Lebanon	Morocco	Spain	Tunisia	Turkey	USA
Germany	0%	7%	0%	1%	0%	0%	3%	89%	0%	0%	0%
France	1%	0%	0%	1%	1%	0%	9%	83%	5%	0%	0%
Russia	32%	2%	0%	1%	0%	0%	39%	5%	0%	21%	0%
UK	17%	1%	0%	1%	0%	0%	19%	58%	1%	2%	0%
S.Ar	80%	1%	0%	0%	0%	16%	0%	3%	0%	1%	0%
Netherlands	10%	3%	0%	1%	0%	0%	27%	57%	2%	1%	1%
Canada	0%	0%	0%	0%	1%	0%	3%	2%	0%	0%	95%
China, HK	3%	0%	1%	0%	0%	0%	0%	6%	1%	0%	89%
Japan	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	98%
Belgium	3%	0%	0%	2%	0%	0%	4%	91%	0%	0%	0%

Table 5: Network Topology Yielded by the Model

countries	Egypt	Greece	India	Israel	Italy	Lebanon	Morocco	Spain	Tunisia	Turkey	USA
Germany	0%	8%	0%	0%	8%	0%	1%	83%	0%	0%	0%
France	0%	0%	0%	0%	1%	0%	7%	86%	5%	0%	0%
Russian Federation	36%	0%	0%	1%	0%	0%	37%	2%	0%	24%	0%
UK	22%	1%	0%	6%	1%	0%	17%	49%	0%	3%	0%
S.Ar	83%	0%	0%	1%	0%	15%	0%	0%	0%	1%	0%
Netherlands	14%	3%	0%	0%	0%	0%	26%	55%	0%	1%	1%
Canada	0%	0%	0%	0%	1%	0%	3%	2%	0%	0%	95%
China, HK	2%	0%	0%	0%	0%	0%	0%	1%	0%	0%	97%
Japan	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	98%
Belgium	2%	0%	0%	2%	5%	0%	14%	77%	0%	0%	0%

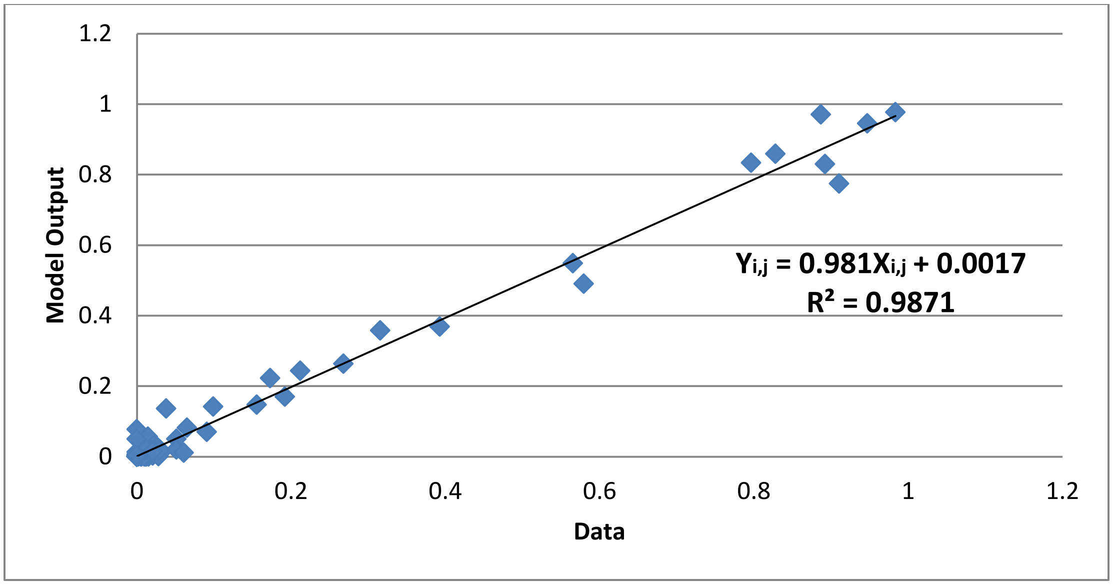


Fig. 16: Model Output-Data Correlation

Chapter 6- **Discussion**

1- 1- **Introducing Hedging Options**

After validation of the model, we use it to evaluate the impact of introducing the possibility for buying firms –demand nodes- to hedge the supply risk through purchasing options –or futures contracts.-

We compare the introduction of hedging options based on three different platforms: OEM –Open Electronic Market, - BEM –Buyers developed Electronic Market, - and PEM –Private Electronic Market. - Table 6 summarizes major differences between these three platforms.

Table 6: Comparing Options Trading Platforms

	OEM	BEM	PEM
Feasibility	Easy	Medium	Hard
Trust	Low	Medium	High
Requirements	- Open Access	- Information sharing among buyers	- Pre-Selected Suppliers - Guaranties / Insurance

OEM is simply an electronic market that allows open access to any buyer or seller. This platform allows simply access to the information about suppliers, but no other information such as trustworthiness of these suppliers is shared among the buyers. Since there is no sharing of information between buyers, every buyer will develop a certain trust level for the options purchased on the OEM. We use the average of the trust factors per supply node from every demand node as the value of this trust level. –See Table 7-

BEM like OEM is an electronic market with open access, but in addition to the features or OEM, it allows sharing of trust information about the suppliers among the different buyers. The fact of sharing information about supplier will allow a better trust of the value of the options purchased on the BEM through better trust of the individual supply nodes. Since this information is shared among buyers, we thus will recomputed the level of trust for the options traded on the BEM including –this time- the maximal trust level for every supplier –among all the demand nodes- and the relative importance of the supply node in the network, its weight. Then as shown in Table 8, we compute a weighted trust factor for the options purchased on the BEM.

Table 7: OEM Trust Factor

		Supply Node										
		Egypt	Greece	India	Israel	Italy	Lebanon	Morocco	Spain	Tunisia	Turkey	USA
Demand Nodes	Germany	0.001	0.065	0.000	0.001	0.084	0.000	0.030	0.816	0.000	0.002	0.000
	France	0.003	0.002	0.000	0.007	0.015	0.000	0.091	0.828	0.052	0.001	0.001
	Russia	0.316	0.021	0.000	0.008	0.001	0.000	0.393	0.027	0.000	0.212	0.002
	UK	0.173	0.014	0.000	0.100	0.013	0.000	0.192	0.447	0.000	0.022	0.003
	S.Ar	0.797	0.000	0.000	0.003	0.000	0.156	0.003	0.001	0.000	0.010	0.000
	Netherlands	0.099	0.037	0.000	0.005	0.004	0.000	0.268	0.565	0.000	0.010	0.006
	Canada	0.003	0.000	0.000	0.001	0.005	0.000	0.027	0.018	0.000	0.000	0.931
	China, HK	0.028	0.000	0.000	0.000	0.000	0.000	0.002	0.009	0.000	0.000	0.855
	Japan	0.000	0.000	0.000	0.013	0.002	0.000	0.000	0.007	0.000	0.000	0.974
	Belgium	0.027	0.001	0.000	0.023	0.051	0.000	0.103	0.790	0.000	0.001	0.002
	Averages	0.145	0.014	0.000	0.016	0.017	0.016	0.111	0.351	0.005	0.026	0.277
Trust Level for OEM				**0.09**								

Table 8: BEM Trust Factor

Supply Nodes:	**Egypt**	**Greece**	**India**	**Israel**	**Italy**	**Lebanon**	**Morocco**	**Spain**	**Tunisia**	**Turkey**	**USA**
Max "t"	0.797	0.065	0.000	0.100	0.084	0.156	0.393	0.828	0.052	0.212	0.974
Node Weight	0.169	0.021	0.000	0.009	0.023	0.015	0.112	0.454	0.009	0.040	0.148
Product	0.135	0.001	0.000	0.001	0.002	0.002	0.044	0.376	0.000	0.008	0.144
BEM trust		0.7146									

PEM is a more specific type of electronic markets. It is characterized by the fact that it is designed to include only a closed group of trusted and verified suppliers. It is generally created by a buyer or a consortium of buyer, and tries to attract trustworthy suppliers [17]. Such platform would include only preselected suppliers that had complied with a number of requirements that guaranty the conformance of participants to their obligation. Such guaranties could include for example deposits, and insurance plans that will avoid losses for the buying party in case of defaulting.

We therefore, for PEM, exclude the trust factor and assume the buyer of an option is 100% confident about the commitment of the seller to satisfy the terms of the option.

1- 2- Resulting Topology and Resilience Improvement

In this chapter, we use the supply strategy selection model to determine what network topology emerges under different scenarios. We first examine the network topology that emerges when we do not allow demand nodes to buy purchasing options. After that, we look at the emerging topology when they have the possibility to buy options on a PEM platform at various fee rates. Then, we look at the topology that emerges when we use an OEM or a BEM platform, and we compare the results from theses 4 scenarios and what they mean in terms of costs and resilience for the single nodes and in terms of resilience of the whole supply network.

Table 9: Fresh Oranges Flexible Volume

Supply Node	Flexible Volume (tons)
USA	10256

Egypt	164203
Greece	31224
Israel	12372
Italy	10288
Lebanon	8712
Morocco	41159
Spain	20869
Tunisia	392
Turkey	87740
Total	387215

First we need to determine the amount of flexible supply that is the available supply on which options could be sold. We defend this supply earlier by the amount supplied non regular customers, such that the quantity supplied to them can go from 100 to 0% in one season. Table 9 summarizes the flexible supply, computed on a 5 years average basis. An example of the calculation of the flexible volume can be seen in Appendix 1.

So we will allow for a maximum of 387215 tons worth of options to be purchased by the whole demand nodes in all 3 cases.

We start by taking a look at the topology generated when there is no possibility of hedging through buying options in Table 10. As mentioned previously in the validation part, the resulting topology resembles significantly the one defined by the data. Demand nodes tend to vary their sources of supply to include sources that are less profitable in order to minimize the risk associated with every individual supplier. As we can see in table 6, in average, every demand node has 6 suppliers.

Table 10: Network Topology with no Options Trading

	Egypt	Greece	India	Israel	Italy	Lebanon	Morocco	Spain	Tunisia	Turkey	USA
Germany	0	32,523	0	6,157	0	0	15,053	446,267	0	0	0
France	5,503	770	0	2,782	2,860	0	36,261	331,201	20,623	0	0
Russia	110,458	7,215	0	2,757	0	0	137,451	17,908	0	74,211	0
UK	51,836	4,142	0	4,307	0	0	57,587	173,900	1,583	6,645	0
S.Ar	199,184	1,573	0	0	0	38,929	802	7,022	0	2,490	0
Netherlands	19,788	5,155	0	1,056	625	0	53,618	113,091	3,084	1,984	1,599
Canada	559	0	0	0	1,003	0	5,437	3,512	0	0	189,489
China, HK	4,241	0	1,707	0	0	20	329	9,146	1,455	28	133,074
Japan	0	0	0	1,551	185	0	0	0	231	0	118,033
Belgium	3,300	0	0	2,320	0	0	4,187	100,193	0	0	0
	Average # of suppliers		**6**								

Table 11: Network Topology with Options Trading over PEM

	Egypt	Greece	India	Israel	Italy	Lebanon	Morocco	Spain	Tunisia	Turkey	USA	PEM
Germany	0	29,939	0	0	4,673	0	18,310	447,078	0	0	0	188,012
France	0	0	0	0	0	0	197,951	202,049	0	0	0	138,406
Russia	1	15,675	0	0	0	0	93,319	124,387	0	116,618	0	93,151
UK	0	0	0	0	0	0	1,145	298,855	0	0	0	144,178
S.Ar	199,184	0	0	24,118	0	26,698	0	0	0	0	0	38,470
Netherlands	197,88	6,251	0	1,075	0	0	53,619	113,090	0	1,984	4,193	4,616
Canada	0	0	0	0	0	0	0	0	0	0	200,000	46,806
China, HK	1	0	27,805	0	0	0	0	0	0	0	122,194	39,519
Japan	0	0	0	0	0	0	0	0	0	0	120,000	35,959
Belgium	3,300	0	0	0	0	0	0	106,700	0	0	0	22,014
Average # of Suppliers			**3**									

Then we introduce the possibility of buying hedging options over a PEM. As stated earlier, buying options on this market involves no trust issues and these options will be 100% reliable. Table 11 shows the resulting topology matrix when there is the possibility of buying options over a PEM –the option fees for the calculations shown on Table 10 is 3%.- We can see that when having the possibility to buy hedging option over the secure PEM platform, demand nodes purchase enough options to cover their risk. By doing so, they can reduce their costs associated with sourcing from less profitable suppliers. We can see that the average number of suppliers has been reduced by half to 3.

Concerning the option fees, we compared the results when varying option fees from 1% to 10% of the value of the purchased quantity. We noticed that demand nodes, always buy the same quantity necessary to cover the risks associated with their sourcing decision until the point where these fees exceed the expected loss. After that point, demand nodes do not purchase any options and the model output is then similar to the case where no hedging through options is possible.

Now we compare the previous results when purchasing options is possible through a PEM platform, to the scenarios where we use an OEM or a BEM platform.

As discussed earlier, buying options over an OEM platform involves some trust issues that we will accounted for by introducing the trust factor for the options as an average of the trust factors of all the supply nodes in the network. For the OEM we will use a trust factor of 0.1, an approximation of the value computed earlier. Table 12 shows the resulting network topology. We can see that, in the OEM scenario, the model yields similar network topology to the case with no possibility for hedging through options. The fact that there is not enough trust in the options purchased on such platform, makes that it is not worth it for demand node to buy any options, and thus behave as if there was no such possibility to begin with. Thus making similar decisions to when there is no such possibility. We also see that that the average number of supplier is similar since varying the supply sources is necessary to minimize the individual risk associated with every supply node.

Finally we explore the results from introducing hedging options via the BEM platform. We discussed earlier how this platform is hybrid solution between the PEM and OEM. It does not require the drastic constrains required for the PEM, but it still incorporates information sharing among user, which allows for a better level of trust in the option purchased over this platform. We use a trust level of 0.8 –an approximation of the value computed earlier.- As we can see on Table 13, the introduction of hedging options over the BEM platform allows for emerging of a topology very close to the one emerging when we introduce hedging option via PEM concerning the number of options purchased. The average number of suppliers per demand node is closer to the OEM and the case with no possibility for hedging options.

Table 12: Network Topology with Options Trading over OEM

	Egypt	Greece	India	Israel	Italy	Lebanon	Morocco	Spain	Tunisia	Turkey	USA	OEM
Germany	655	32,523	0	0	0	0	15,053	451,769	0	0	0	0
France	1,015	768	0	2,783	4,033	0	36,261	334,517	20,623	0	0	0
Russia	76,116	7,215	0	2,757	0	0	137,452	52,248	0	74,212	0	0
UK	51,836	4,142	0	11,490	0	0	57,574	165,663	2,649	6,646	0	211,958
S.Ar	199,184	0	0	0	0	41,633	802	3,122	0	5,259	0	69,766
Netherlands	0	0	0	1,075	452	0	0	198,472	0	1	0	48,974
Canada	559	44	0	0	3	0	0	3,512	0	0	195,882	211,958
China, HK	2,171	0	0	0	0	0	325	17,010	2,179	36	128,279	87,948
Japan	0	0	0	1,551	185	0	0	0	231	0	118,033	155,556
Belgium	2,972	912	0	2,476	0	14,690	63,258	15,574	2,804	7,314	0	199,538
Average # of Suppliers		**5.9**										

Table 13: Network Topology with Options Trading over BEM

	Egypt	Greece	India	Israel	Italy	Lebanon	Morocco	Spain	Tunisia	Turkey	USA	BEM
Germany	0	183,398	0	0	0	0	77,576	239,026	0	0	0	211,958
France	1	461	0	0	3,476	0	33,187	349,935	12,861	79	0	82,963
Russia	72,329	6,582	0	3,303	0	762	157,608	41,213	4,684	63,519	0	84,134
UK	0	18,368	0	0	0	2,435	0	251,565	10,861	16,771	0	91,589
S.Ar	199,184	0	0	101	0	50,496	45	45	58	71	0	25,143
Netherlands	0	736	0	435	660	0	42,309	155,860	0	0	0	41,537
Canada	335	0	0	0	528	0	0	0	0	0	199,137	57,642
China, HK	1	22	26,806	0	0	42	0	0	22	23	123,085	17,269
Japan	0	0	0	9	9	0	0	10	0	0	119,972	27,359
Belgium	0	3,304	0	0	0	0	0	106,692	0	4	0	27,877
Average # of Suppliers	**5.2**											

We thus saw that introducing hedging options can –depending on the platform used- allow single demand nodes to make different sourcing decision and reduce the number of suppliers in the case of PEM. Now we will compare the hedging options introduction via these different platforms and their effect on the resilience of single demand nodes. We use the resilience evaluation model discussed earlier in the chapter about the model to compute the resilience of single demand nodes and resilience of the whole supply network. As we can see in Table 14, having no possibility for hedging through options forces the demand node to made sourcing decision that make the supply network less resilient with a resilience value of 0.759. Introducing hedging options over an OEM platform –as discussed earlier- provides the demand nodes with the possibility for buying hedging options that present trust issues. Therefore, the introduction of hedging options via an OEM does not allow much improvement of the network resilience. When there is information sharing among the buyers as it is the case in the BEM platform, the trust level for the options is better than in the OEM case. Thus, introducing the possibility for buying hedging options via BEM allows the improvement of the network resilience. However, the PEM platform that provides the possibility to buy hedging options that present no trust issues at all, allow the demand nodes to make sourcing decisions that make the supply network even more resilient.

Now that we covered the effect of introducing hedging options via the three previously stated platforms on the demand nodes and the supply network’s resilience, we will compare the efficiency of these different solutions concerning the single demand nodes profitability. Table 15 compares the reduction in ETC –Expected Total Cost- for every demand node depending on the scenarios.

Table 14: Nodes and Network Resilience by Option Trading Platform

	No Options	OEM	BEM	PEM
Germany	0.812	0.813	1.173	1.040
France	0.816	0.816	1.028	1.144
Russia	0.697	0.696	0.965	1.034
UK	0.765	1.038	1.115	1.308
S.Ar	0.609	0.887	0.708	0.755
Netherlands	0.779	1.023	1.021	0.801
Canada	0.785	1.020	1.073	1.019
China, HK	0.781	1.374	0.876	1.023
Japan	0.784	1.011	1.013	1.085
Belgium	0.814	2.632	1.075	1.020
NETWORK	**0.759**	**0.977**	**1.015**	**1.033**

Table 15: Reduction in ETC by Trading Platform

	PEM	BEM	OEM
Germany	68%	67%	1%
France	26%	14%	0%
Russia	28%	19%	0%
UK	64%	56%	9%
S.Ar	29%	23%	14%
Netherlands	18%	23%	13%
Canada	99%	99%	97%
China, HK	56%	56%	47%
Japan	63%	48%	4%
Belgium	73%	71%	53%
Average	52%	48%	24%

Fig. 17 shows the distribution of the different demand nodes' resilience and ETC reduction –from the No options scenario-. We can see that the EPM option is the one that allows better resilience and better ETC reduction. The BEM resilience level is close to the EPM's but comes at a cost: less ETC reduction. And the OEM is the least efficient of the three solutions allowing only a slight improvement in resilience with a very small ETC reduction.

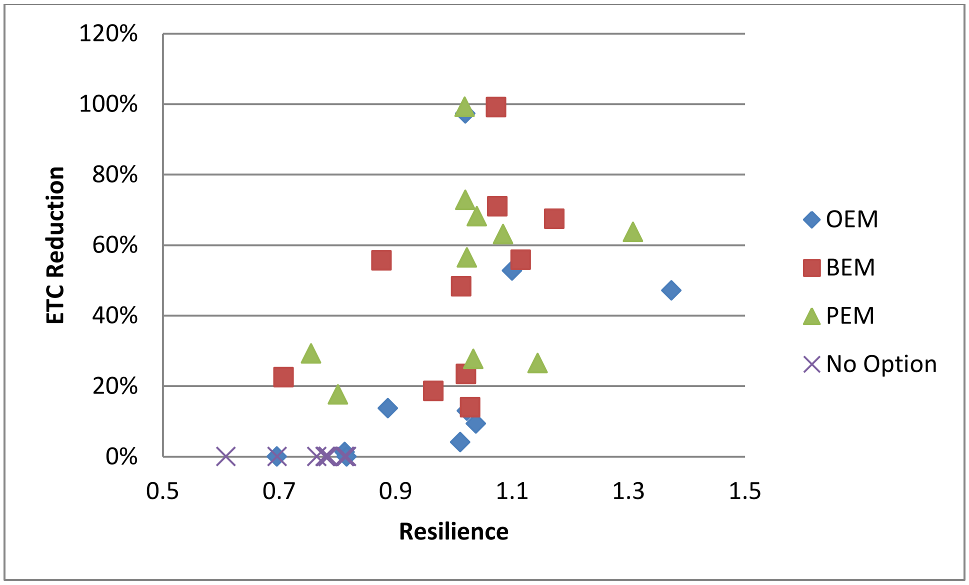


Fig. 17: Resilience and ETC reduction by Options Trading Platform

Chapter 7- **Conclusion**

In this paper we discussed the issue of disruptions and how to build resilience into enterprise, supply chains and supply network to mitigate those risks.

We showed that the solutions proposed in the literature are not adapted o the special case of fresh produce supply chains.

To overcome this issue, we moved from treating the resilience issue at the single enterprise or at the supply chain level to the more holistic supply network level.

We proposed a model for describing the logic behind the decision making of firms when it comes to their sourcing strategies. And we validated the model using data from the fresh oranges sector. We then showed how this decision making model when applied by all the demand nodes in the network yields a certain network topology that defines the networks resilience to disruptions.

Thereafter, we used this model to evaluate the value of introducing hedging through option as a mean of reducing the risk associated with supply disruptions that affect this supply network, and the effect of introducing these options on the network topology and its resilience.

Having currently no platform to support the trading of such options, we compared three different solutions: OEM, BEM and PEM. OEM –Open Electronic Market- is characterized by ease of entry for suppliers and the availability of similar platforms that can be used immediately but also with a low level of confidence in the value and trustworthiness of options if traded on such platform. On the other hand, a BEM –Buyers Electronic Market, - though similar to OEM, feature more information sharing among users about the trust level they have for the buyers selling on this platform. Therefore, BEM has less trust issues that the OEM. Finally, we consider the use of a PEM –Private Electronic Market- which is a closed network of only trusted suppliers that in addition to that have to satisfy a number of requirements and provide guaranties of their commitment to provide the necessary merchandise when they sell options on the PEM.

We saw, that given the enterprise’s sourcing decision making model, the resulting topologies depending on the different cases show that the PEM gives the best results in terms of ETC –Expected Total Cost- reduction and network resilience, followed by the BEM, the OEM and finally the case with no possibility of hedging through options.

Therefore, if we make hedging through options available from fresh produce buyers, we can have a more resilient supply network while maintaining or reducing single demand nodes’ expected costs. The extent of the improvement will depend, however, on the availability of an adequate trading platform.

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Appendix 1: Example of Flexible Volume Identification

Supplier	**Spain**														
Years **Buyer**	1998	2002	2003	2008	1997	1999	2001	2004	2005	2006	2007	2000	Std Dev	Mean	Coef of Var
Afghanistan (Quantity)	23173	24766	27437	23823	24558	21223	22190	29510	24246	27512	27935	24955	2500	25111	0.10
Albania (Quantity)	291672	331938	315443	305891	307848	261644	243904	364609	290419	314954	325987	298876	31584	304432	0.10
Algeria (Quantity)	20395	22224	20746	18815	23816	17366	17335	18625	16109	18454	19683	21391	2236	19580	0.11
Andorra (Quantity)	148683	165054	150543	130934	147580	129997	110363	155450	121015	148318	158944	154987	16619	143489	0.12
Angola (Quantity)	304867	412510	421607	372730	344147	303683	320311	406207	308333	350308	374201	397484	43959	359699	0.12
Antigua and Barbuda (Quantity)	16274	16850	18455	15723	14009	16682	13601	20356	13827	16315	20889	20070	2544	16921	0.15

Argentina (Quantity)	74852	103041	105417	80299	59945	79341	71301	105406	81041	103604	99517	101983	16005	88812	0.18
Armenia (Quantity)	87457	89239	76088	59585	72914	71798	78985	65160	39979	58786	66581	87222	14320	71150	0.20
Australia (Quantity)	16582	23709	23065	21803	14686	11928	21071	26797	18462	23862	25266	21058	4464	20691	0.22
Austria (Quantity)	7750	7889	7895	6745	4538	5825	4424	9703	6663	7636	9320	7220	1633	7134	0.23
Bahrain (Quantity)	37471	24668	24911	27957	36598	28388	23157	26766	15427	21817	30764	33967	6379	27658	0.23
Belarus (Quantity)	28999	36827	37915	38282	17207	20651	26078	42599	28188	31606	35963	26347	7683	30889	0.25
Belgium (Quantity)	61660	47402	67943	54536	42510	66378	26378	81342	37218	59111	43704	51318	15099	53292	0.28
Belgium-Luxembourg (Quantity)	15266	13129	12521	8688	11222	15323	11800	15115	10000	7618	7721	19431	3569	12320	0.29

Bolivia (Plurinational State of) (Quantity)	Bosnia and Herzegovina (Quantity)	Brazil (Quantity)	Bulgaria (Quantity)	Canada (Quantity)	Cape Verde (Quantity)	China (Quantity)
2057	26897	7008	1650	785	356	1061
2351	22903	5266	2022	1692	588	5650
1793	17037	4982	2137	1570	338	4781
2237	12032	4733	1135	1778	643	4263
2294	18281	4920	1024	609	329	1113
1168	39022	4921	1490	667	381	2023
1433	29835	2861	890	956	524	3874
1179	18906	7461	3116	681	917	4171
1160	18459	1972	1801	920	621	2879
2197	15042	2491	1497	1332	1008	4571
2448	18967	4741	2177	1249	899	4808
1037	25689	4243	1343	1003	757	4040
547	7429	1632	617	413	241	1498
1780	21923	4633	1690	1104	613	3603
0.31	0.34	0.35	0.36	0.37	0.39	0.42

China, Hong Kong SAR (Quantity)	Colombia (Quantity)	Costa Rica (Quantity)	Côte d'Ivoire (Quantity)	Croatia (Quantity)	Cyprus (Quantity)	Czech Republic (Quantity)	Democratic Republic of the Congo (Quantity)
13885	418	1035	2151	0	0	1369	475
8863	235	3192	6696	69234	425	442	885
8433	329	2418	5305	71273	658	87	427
4520	106	1920	10327	66124	419	522	22
11731	293	417	4037	0	0	523	347
11024	0	489	2437	0	0	431	418
8325	281	1762	3468	52136	559	273	697
6722	270	887	2668	73190	677	129	219
3410	216	1374	2451	62083	489	514	99
4341	228	2246	3554	70838	446	694	32
4887	171	2443	7284	64059	462	773	18
11757	410	2275	5248	67108	446	456	599
3444	118	868	2468	30442	245	335	285
8158	246	1705	4636	49670	382	518	353
0.42	0.48	0.51	0.53	0.61	0.64	0.65	0.81

Denmark (Quantity)	61	0	39	46	0	76	64	20	0	18	0	48	28	31	0.91
Ecuador (Quantity)	1255	4682	3138	1197	619	256	2660	1456	759	616	504	453	1350	1466	0.92
El Salvador (Quantity)	24	72	28	5	149	41	79	22	29	12	4	67	42	44	0.94
Equatorial Guinea (Quantity)	0	41	27	52	0	0	28	5	15	55	38	0	21	22	0.97
Estonia (Quantity)	0	87	237	204	0	0	0	136	122	232	237	0	103	105	0.99
	↓↓↓ Flexible Volume ↓↓↓														
Finland (Quantity)	1238	4564	632	1490	0	3490	2206	787	659	2249	7281	210	2130	2067	1.03
France (Quantity)	40	0	117	142	72	0	91	164	0	139	307	0	92	89	1.03

Gabon (Quantity)	28	76	95	772	61	61	195	514	750	809	1172	32	402	380	1.06
Gambia (Quantity)	0	1098	499	305	0	2143	1186	150	19	0	1475	2244	845	760	1.11
Germany (Quantity)	0	302	333	44	0	601	949	34	0	140	1007	392	363	317	1.15
Ghana (Quantity)	12	397	288	806	0	10	549	154	142	927	1467	58	459	401	1.15
Gibraltar (Quantity)	610	13204	4945	3178	507	898	13800	1389	900	776	2023	9240	4980	4289	1.16
Greece (Quantity)	0	18	0	14	0	0	3	11	3	26	22	1	10	8	1.18
Guatemala (Quantity)	0	0	24	168	0	0	48	98	116	256	117	0	83	69	1.21
Guinea-Bissau (Quantity)	2	0	0	10	0	6	3	0	0	0	9	3	4	3	1.33

Honduras (Quantity)	0	72	0	46	0	45	0	0	0	0	45	16	26	19	1.39
Hungary (Quantity)	271	200	108	0	213	80	46	1160	501	0	0	234	326	234	1.39
Iceland (Quantity)	0	0	0	0	35	43	22	359	20	96	298	253	131	94	1.40
India (Quantity)	0	0	0	0	0	90	44	12	7	23	82	0	33	22	1.53
Indonesia (Quantity)	0	50	0	0	0	219	99	0	0	0	126	300	102	66	1.54
Ireland (Quantity)	0	154	115	0	0	764	357	0	0	48	925	88	318	204	1.56

Appendix 2: Yields VARs

countries		1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Mean	95% VAR
Egypt	Yield	164268	141298	164749	181177	188103	179668	136427	169099	180976	191650	177531	171555	175318	183631	202888	216399	212843	222321	203295	101381	96592	96223	100000	167712.7	
Variation from mean		-2%	-16%	-2%	8%	12%	7%	-19%	1%	8%	14%	6%	2%	5%	9%	21%	29%	27%	33%	21%	-40%	-42%	-43%	-40%		-43%
Greece	Yield	140066	214757	255921	233684	205822	244909	234031	237656	238736	248550	252097	201374	303627	231805	285207	296766	237379	173960	233935	220811	204474	203037	200000	230374.1	
Variation from mean		-39%	-7%	11%	1%	-11%	6%	2%	3%	4%	8%	9%	-13%	32%	1%	24%	29%	3%	-24%	2%	-4%	-11%	-12%	-13%		-36%
India	Yield	133928	116666	146564	145652	145384	118750	149212	98803	76545	94155	111965	101125	107646	97581	103194	88241	66524	86350	87671	77927	91329	93773	92332	105709.4	
Variation from mean		27%	10%	39%	38%	38%	12%	41%	-7%	-28%	-11%	6%	-4%	2%	-8%	-2%	-17%	-37%	-18%	-17%	-26%	-14%	-11%	-13%		-35%

Variation from mean	Morocco	Variation from mean	Lebanon	Variation from mean	Italy	Variation from mean	Israel
	Yield		Yield		Yield		Yield
-24%	127647	22%	285600	-29%	129880	38%	456698
4%	175098	21%	284511	15%	209694	1%	334147
14%	192069	22%	286296	8%	197300	-9%	300676
-11%	150000	20%	280617	-8%	167436	50%	499111
25%	210754	11%	260542	-5%	174190	6%	352827
-10%	151119	13%	264464	11%	201847	4%	344880
-2%	165009	-1%	233333	9%	199918	-11%	295206
3%	172992	6%	247925	-8%	168431	-7%	307822
-20%	135000	7%	250000	-19%	147347	9%	362275
11%	185720	8%	252494	-12%	160401	12%	373019
-7%	157031	-5%	223371	-9%	166836	19%	394517
28%	215165	-7%	219156	-34%	120366	2%	337868
2%	170939	-1%	232380	-11%	162616	-22%	260559
1%	169921	-26%	172789	-4%	175916	4%	344898
-16%	141035	-25%	175056	-11%	162070	23%	408141
-14%	144331	-25%	176590	-11%	161726	-12%	292299
-1%	166991	-7%	218568	-10%	164659	-21%	263253
-12%	147700	-6%	221381	10%	201236	-33%	221659
2%	171106	-2%	230980	20%	218271	8%	358015
-4%	160529	-6%	220000	24%	225583	-12%	291290
-3%	163636	-6%	220966	33%	243028	3%	343696
18%	197555	-6%	219903	16%	211816	-31%	230671
14%	191776	-7%	219047	26%	229513	-20%	264832
	167961.9		234607.3		182612.2		332102.6
-23%		-26%		-33%		-33%	

Variation from mean	USA	Variation from mean	Turkey		Tunisia	Variation from mean	Spain
	Yield		Yield	Variation from mean	Yield		Yield
-7%	302946	-19%	226537	32%	163333	-4%	193212
3%	333643	-17%	232142	8%	133333	-10%	180160
5%	340755	-18%	229956	30%	160000	6%	212648
-11%	290428	-20%	224633	14%	140575	1%	201860
-12%	287158	-11%	249024	7%	131738	1%	201893
-4%	312046	-15%	237681	-11%	109760	9%	218661
10%	358061	-14%	239268	40%	172490	-11%	178556
0%	325234	-9%	252976	-12%	108819	0%	199411
2%	332297	-18%	228289	-9%	112222	-4%	192794
-2%	316906	-15%	237124	3%	126666	-18%	164484
4%	337258	-30%	195943	-9%	112222	5%	209835
14%	370090	-8%	257779	14%	140381	-11%	177797
-18%	265322	3%	287867	-7%	115088	-1%	198971
10%	358412	-2%	275064	2%	125875	-3%	194466
4%	336226	14%	318066	-11%	109343	5%	209887
7%	348740	14%	318877	-11%	110084	22%	243983
1%	326897	10%	307351	-16%	104109	11%	223182
16%	378130	13%	314769	-12%	108953	2%	203964
-13%	281184	28%	358560	-18%	101400	-15%	171236
11%	359361	34%	375320	-7%	115000	21%	242576
-22%	252366	25%	350348	-9%	112800	-6%	187875
5%	340629	18%	328233	-8%	114000	11%	222271
-4%	311778	36%	378481	-11%	109381	-11%	179294
	324602.9		279316.9		123372.7		200392
-21%		-28%		-17%		-17%	

Appendix 3: Production Capacity (Planted Area) in Ha

countries	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Egypt	85737	84034	93350	87704	83607	83576	83052	83214	88000	209116	212712	222236
Greece	40100	40400	37000	40800	39000	40200	40100	40141	40015	40719	39891	39500
India	229000	232800	227300	274100	249500	325300	288900	377900	378000	441100	467200	518300
Israel	9120	9261	8689	7753	5650	5662	5527	5531	5240	5030	5540	5120
Italy	109307	107470	106535	106652	106367	106577	105289	104606	103605	104000	104000	102301
Lebanon	9674	8300	8400	8820	8900	8800	10157	10570	10200	10500	10350	10400
Morocco	51200	51300	51100	51200	50200	50100	49200	48700	48800	49100	55000	63000
Spain	135584	138100	135223	134533	138092	121445	136757	135668	138769	140039	145856	153429
Tunisia	9000	8655	9080	9136	10060	9629	9125	9270	10000	11000	12500	15000
Turkey	37766	37629	38212	38900	39300	39200	40670	41300	40300	40920	40730	43480
United States of America	341400	335080	335900	328970	329739	321887	320391	308817	298497	227250	274097	268350

Appendix 4: Forecasted Production Volume (tons)

Egypt	549487
Greece	213789
India	41870
Israel	24118
Italy	4674
Lebanon	89892
Morocco	310726
Spain	1241887
Tunisia	28487
Turkey	116618
USA	442195

Appendix 5: Validation Regression Statistics

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.993544							
R Square	0.987129							
Adjusted R Square	0.98701							
Standard Error	0.0264							
Observations	110							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	5.7729187	5.772919	8282.967	6.4E-104			
Residual	108	0.075272	0.000697					
Total	109	5.8481907						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.00057	0.0027104	-0.21015	0.833948	-0.00594	0.004803	-0.00594	0.004803
w	1.006265	0.0110565	91.01081	6.4E-104	0.984349	1.028181	0.984349	1.028181

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