Effects and Mitigation of Natural Hazards in Retail Networks

By Jorge García Castillo
Advisor: Dr. Jarrod Goentzel
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Summary:

The objective of this thesis was to understand the effects of natural hazards in retail sales and provide a framework to invest in resilience. We used daily sales and inventory data from a Colombian retail network and natural hazards historical data to quantify the variability generated by these events. We provided a decision model that allows to invest in additional buffer stock or real options contracts that execute when a declared natural emergency occurs. We show that a risk averse approach reduces worst-case cost by 15% while increasing average cost by only 2%. We describe how various risk profiles shape the location of investments.

Before coming to MIT, Jorge obtained a double bachelor's degrees in computer engineering and mathematics from Universidad Autónoma de Madrid in Spain. He worked for 4 years in the optimization sector in companies like IBM and Decide. Later, he moved into the humanitarian sector to work in refugee camps. After leaving MIT we will be joining the Center for Logistics Innovation in Latin-America as Innovation Manager.

KEY INSIGHTS

1. The effects of natural hazards in retail sales vary per category. Beer sales decrease by 25% after and emergency while coffee sales increase.

2. Risk-averse profiles can reduce the worst case cost by 13% while increasing average cost only by 2%.

3. Real options is the first choice to provide a risk sharing strategy between manufacturers and retailers.

Introduction

The number of natural hazards has been increasing over the last 10 years. Understanding the impact of natural hazards is crucial to make effective planning against disruptions. When allocating resources to create new facilities, there are clear techniques that help making these decisions. However, making investments in resilience has no systematic approach that organizations can follow. We analyzed the variability in product and financial flows in a retail network in Colombia to quantify which products are impacted and how. We also provided a decision-making model to allocate resources to invest in resilience options. We used different risk profiles to align the investments with the financial preferences of the organization.

Understanding the effects

To understand the effects of natural hazards we used 20 years of natural emergencies historical data from Colombia. We modeled the natural hazards by analyzing its frequency, impact and geographical distribution. We found that the frequency and impact of natural hazards follow a Power Law distribution with long tails (See Figure 1). This implies that frequent disruptive events have a significant probability of occurrence.

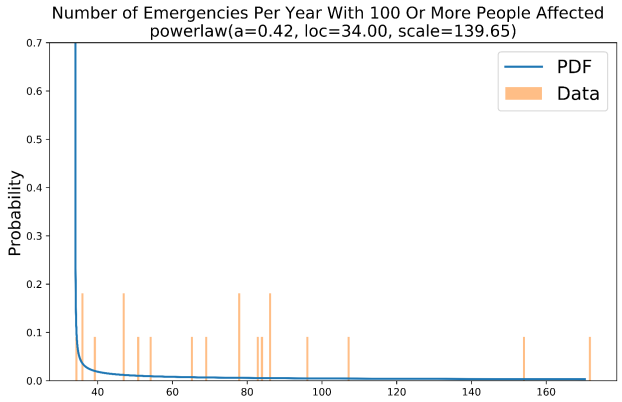

Figure 1. Number of Emergencies per Year (People affected > 100)

The geographical location and seasonality indicated that natural hazards are not uniformly distributed along the different regions and times of the year.

The effects of natural hazards can be measured looking at the variation in sales of every product in every point of sale (POS) after an emergency. The data available was the daily sales an inventory from POS and distribution centers (DC) of a Colombian retail company. The information per day was the quantity sold per product, the price, the cost and the units in inventory.

We selected 5 product categories to analyze the effects:

- Beer
- Family Pasta
- Coffee
- Bread
- Personal Care.

The criteria to select the categories were: high selling items and meaningfulness after a disaster.

We found that the effects were diverse for each of the categories. Beer showed a decrease in sales of 25% the first week after the events. Personal care and coffee products showed an increase in sales after a natural emergency (See Figure 2). The variation in sales of Family Pasta items showed a symmetric behavior with similar instances of increases and decreases.

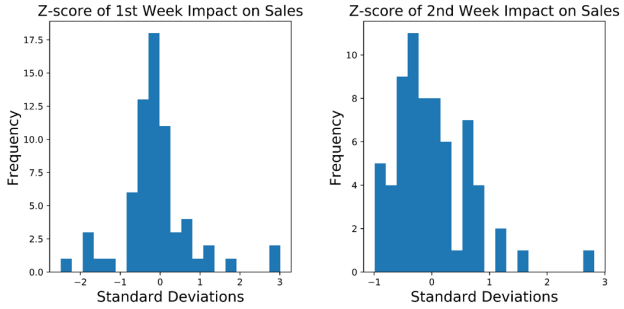

Figure 2. Deviation over Average Sales Of Personal Care Items after an Event

Resilience Investment Model

Once we understood the possible effects of emergencies on certain categories, we developed a mathematical model to make investments against those effects. The Resilience Investment Model (RIM) is a multi-period multi-echelon inventory flow mixed-integer stochastic program.

The investment options against resilience consist in the acquisition of extra buffer stock at the beginning of the planning period or the use of real options contracts with the suppliers. This contracts are executed when a declared emergency occurs. The extra stock is replenished only once, as its objective is to mitigate the variability of events that have sparse patterns of occurrence. The real options contracts have a pre-specified maximum capacity that the manufacturer will provide in case a disaster occurs. The investments are made at the regional level, meaning that the resiliency policy can vary amongst regions but has to be the same for all the POS in that region.

The objective function of the RIM model minimizes the average cost of the future scenarios and associates and additional penalty to the future costs based on a risk function. The objective of a scenario minimizes transport cost, inventory cost and opportunity cost for lost sales.

To align the investments with the different financial circumstances of organizations, we propose the use of the risk profiles mentioned by You, Wassick & Grossman (2008). These risk profiles allow stakeholders to reshape the distribution of future costs depending on their preferences.

The 5 risk profiles are:

- **Risk Neutrality**: assigns no penalty to scenarios were large costs occur.
- **Variance Minimization**: minimizes the dispersion of the costs giving the most robust options.
- **Variability Index:** penalizes scenarios with cost above average.
- **Probabilistic Financial Index:** penalizes equally any scenario that exceeds a predefined cost target.
- **Downside Risk:** penalizes the scenarios that exceed a cost target by the amount of excess.

The main decision variables are what to invest and where at the begging of the planning period. The variables for the future scenarios represent the inventory flow and sales along the retail network.

The technique used to solve the stochastic program was Sample Average Approximation with the Multicut L-Shaped method.

How to invest in resilience in Colombia

We used the RIM model for a planning period of 52 weeks, 24 administrative regions in Colombia and 94 municipalities. The network considered had 486 POS, 10 DCS and 1 manufacturer. We used one commodity to be able to understand the nature of the investments. The model provided a budget limit for the investment. We sampled the natural emergencies from the empiric distribution obtained as part of the data analysis.

We saw that all the profiles spent all the budget. This is due to the lost sales generated by hazards being higher than the budget provided. The different risk profiles invested the majority of the budget, between 87% and 99%, in real options contracts. This effect can be dependent on the price of the contract. The number of regions invested in varied between 11, for the variability index profile, and 17 for the probabilistic financial risk.

The risk neutral profile provided the biggest worst-case cost and the biggest coefficient of variation of the solutions (CV=0.21). The variance minimization generated the maximum average cost solution, but also the smallest dispersion of future costs.

We observed that the sampling of scenarios used to make the investments influenced the distribution of future costs due to the high variance of the natural hazards distribution.

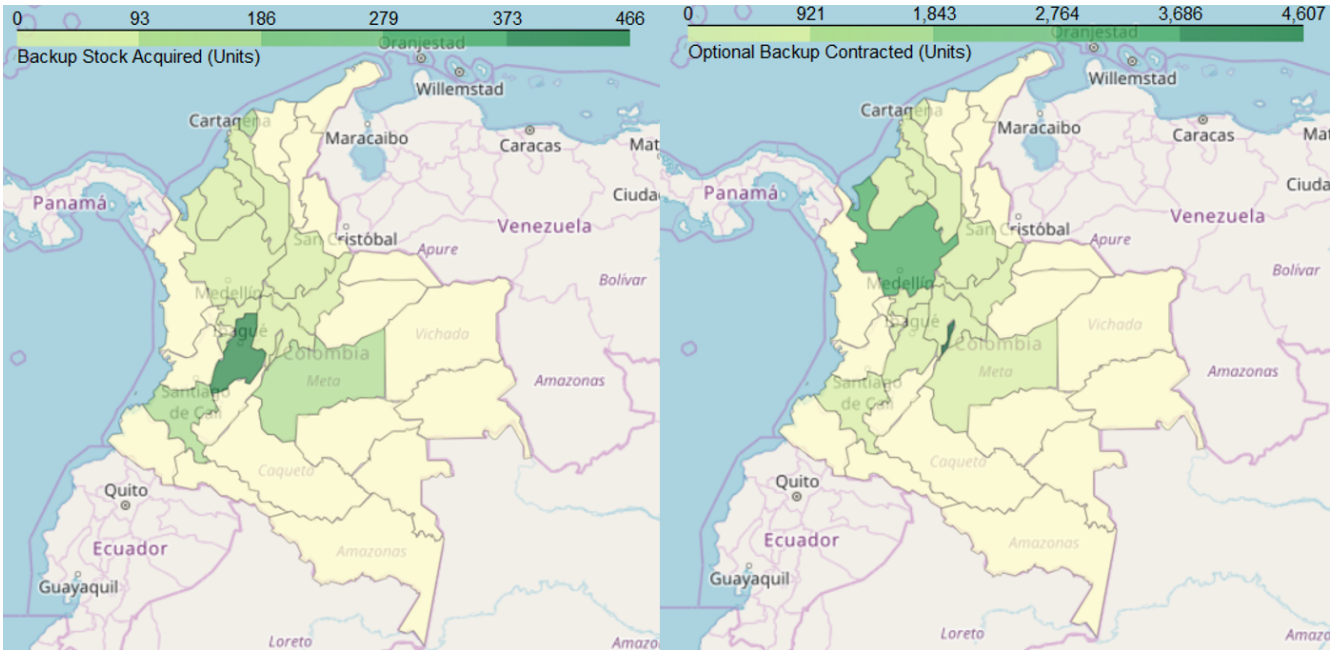

Figure 3. Investment in Stock and Optional Backup for Risk Neutral Profile

Conclusions

The effects of natural hazards vary for different categories of products. The quantification of the variability generated is necessary to invest effectively in resilience.

The RIM model provides the means to make investments in resilience based on the risk profile of the organizations. We observed that the use of risk hedging contracts are more cost-effective than acquiring additional buffer stock for a complete planning period.

We expect this research to open a new path to mitigate the impact of natural hazards in retail companies. Different types of organizations can also benefit from this decision making tool to understand and shape the distribution of future costs from their decisions against low-likelihood high-impact events.

References

You, F., Wassick, J. M. & Grossmann I. (2008), “Risk Management for a Global Supply Chain under Uncertainty: Models and Algorithms.” Dept. Of Chemical Engineering, Carnegie Mellon University.