15.093 Optimization Methods Project Final Report

Jason Jia and Virginia Maguire

December 2023

1 Problem and Motivation

1.1 Problem

Is Just-in-Time (JIT) really the most profitable supply chain strategy for Nike in an uncertain world?

1.2 Motivation

The JIT system is a well-known lean manufacturing system pioneered by Toyota that seeks to eliminate waste, which often implied minimizing inventory levels and finding the lowest cost suppliers. While many businesses have pursued JIT as their supply chain strategy, low inventory levels and supplier concentration caused severe shortages when factories and transportation routes were shut down during Covid-19. As seen from a spike in supply chain resilience articles from McKinsey, Bain and BCG during 2021-2023, the missed sales opportunity and reputational damage from unmet demand has generated strong business interest to re-evaluate if JIT is truly the best supply chain strategy.

However, to the best of our knowledge, there is no publicly available research quantifying the potential profitability improvements under different conditions. This is why we want to explore to what extent do disruptions in supply (modelled by ϵ) and penalties for unmet demand (modelled by α) affect differentially robust supply chain strategies for Nike (modelled by δ), in terms of profit, inventory levels and concentration of suppliers.

2 Data

We use 3 main data sources for this project: Nike Factory Worker Data, Nike 10-K Reports, Drewry World Container Index (for shipping costs).

2.1 Nike 10-K Reports and Factory Worker Data

We pulled information from Nike's 10-K reports for revenues, cost of sales, and inventory costs for 2016-2023. We also found a dataset that had the number of worker's Nike had in each factory.

2.1.1 Factory Worker Data

We used Nike's publicly disclosed Manufacturing Map. For each factory, we had the type of good produced and the number of workers. We filtered down to just footwear factories and only included factories that worked on final goods rather than inputs. We also focus on the total number of workers in each specified region. We make the assumption that this is the total number of workers for 2023. We estimate prior year worker count by assuming that there has been 5 percent growth in the workers count each year.

2.1.2 Revenue to Shoes Sold

Revenue was available by category and region. For simplicity, we chose to only focus on the footwear category, as it was the largest of the three categories provided, accounting for more than 60 percent of revenue in each region. Additionally, Nike reported Asia Pacific and Latin America together for revenue, however, for estimating shipping cost later, we decided to proportionally split these into 2 separate groups based on the GDP of each region. We accounted for 73.3 percent of revenue reported for Asia Pacific and the remaining 26.7 percent to Latin America.

Once we had the shoes revenue for each region, we estimated the number of shoes sold in each region based on the average price of the top ten best selling shoes on Nike's website currently. This price came out to \$116.50. We assumed a constant price for the entire period for the purpose of estimating the number of shoes sold, which we consider our demand.

2.1.3 Estimating Factory Availability

Based on the factory dataset and the estimated number of shoes in 2023, we can obtain the output per worker. We assume this to be constant overtime and apply this same output per worker for the number of workers each year. This is considered our factory availability over time.

2.1.4 Costs of Sales and Inventory Holding Cost

Inventory Cost and Cost of Sales were only available at the Region/Yearly level, not by product. To obtain the information for just footwear, we assume that it is proportional to the percentage of footwear revenue generate in each region.

Based on preliminary research, we found estimates that inventory holding cost is approximately 20-30 percent of reported inventory costs. We decided that for each year, we would randomly vary the holding cost percentage to fall within that range. For each year, we then assume the remaining inventory cost is the value of inventory and estimate the number of shoes in inventory each year (assuming the cost is \$116.50 again). We then are able to obtain the holding cost per shoe estimate.

For the Cost of Sales, we obtain a Cost of Sales per Shoe each year by dividing the total cost of sales by the number of shoes produced in that year. Since we want to obtain this at the production region level, we then add random noise of up to 20 percent to vary the cost between regions.

2.2 Drewry World Container Index (shipping costs)

We used the Drewry World Container Index, scaled by relative distances between representative countries of producer and consumer regions as a good measure of shipping distance. The representative country of a producer region is chosen as the country with the most Nike factory workers in that region, and the representative country of a consumer region is chosen as the country with the highest GDP in that region.

3 Methods

3.1 Decision Variables

The primary decision variable is: X_{it} (quantity of shoes produced by producer region i at time t). The other decision variables are:

- E_{it} (holding quantity of shoes by producer region i at time t)
- S_{ijt} (the quantity of shoes made by producer region i sold in consumer region j at time t). The relationship is defined as $\sum_j S_{ijt} = X_{it} + E_{it-1} - E_{it}$.
- M_{jt} is defined as the unmet demand and is defined as $D_{jt} - \sum_i S_{ijt}$ where D_{jt} is the demand.

We require all decision variables be integer and greater than or equal to 0.

3.2 Notation

The sets of our problem are:

- $i \in [1, 5]$ for producer (supplier) regions
- $j \in [1, 5]$ for consumer regions
- $t \in [1, 8]$ for each year (2016-2023)

The following matrices or arrays define our data inputs:

- $p[t]$ is the consumer price per shoe sold. We assume this increases 2 percent each year.
- $T[i, j, t]$ is the shipping cost from producer region i to consumer region j in time t
- $C[i, t]$ is the cost of production in producer region i in time t
- $H[t]$ is the holding cost in time t
- $A[i, t]$ is the supply availability in time t for producer region i
- $D[j, t]$ is the demand in time t for consumer region j

We have 3 parameters:

- $\alpha \in [0, 1]$ controls the penalty on not fully meeting demand. We use $\alpha \in \{0, 0.1, 0.25, 0.5\}$.
- $\delta \in [0, 1]$ controls the magnitude of the supply shock Nike wants to protect against (robustness of its supply chain strategy). We use $\delta \in \{0, 0.01, 0.02, ..., 0.1\}$.
- $\epsilon \in [0, 1]$ controls the magnitude of the supply shock. We use $\epsilon \in \{0, 0.1, 0.25, 0.5\}$.

3.3 Model

Our optimization model starts with:

$$\max \quad \sum_{t=1}^{8}\sum_{j=1}^{5}\sum_{i=1}^{5}(p_t - T_{ijt}) \cdot S_{ijt} - \sum_{t=1}^{8}\sum_{i=1}^{5}(C_{it} \cdot X_{it} + H_t \cdot E_{it} + \alpha \cdot p_t \cdot M_{it}) \tag{1}$$

s.t:

$$\begin{aligned}
X_{i,0} = 0 &\quad \forall i \in \ [1, 5] \\
E_{i,0} = 0 &\quad \forall i \in [1, 5] \\
\sum_{j=1}^{5} S[i, j, t] = X_{it} + E_{i,t-1} - E_{i,t} &\quad \forall i \in [1, 5], \forall t \in [1, 8] \\
\sum_{i=1}^{5} S_{i,j,t} \leq D_{j,t} &\quad \forall j \in [1, 5], \forall t \in [1, 8] \\
X_{i,t} \leq A_{i,t} &\quad \forall i \in [1, 5], \forall t \in [1, 8] \\
M_{j,t} = D_{j,t} - \sum_{i=1}^{5} S_{i,j,t} &\quad \forall j \in [1, 5], \forall t \in [1, 8]
\end{aligned}$$

3.4 Robustness: Incorporating Uncertainty in Availability

We use a conservative robustness strategy by optimizing as if a shock to availability will occur in each year. As a result, we incorporate uncertainty into the model by defining the uncertainty set:

$$A_{i,t} \in \{\overline{A}_{i,t} - \Delta_t \overline{A}_{i,t} u_t : \|u_t\|_1 \leq 1\} = U_t$$

where $\overline{A}_{i,t}$ is the known availability. We define Δ as a random vector of ten values that encapsulates the possible reductions in variability that year.

Our constraint $X_{i,t} \leq A_{i,t}$ therefore becomes: $X_{i,t} \leq \overline{A}_{i,t} - 1 * \|\Delta_t \overline{A}_{i,t} u_t\|_\infty \Leftrightarrow X_{i,t} \leq \overline{A}_{i,t} - \max\{\Delta_t\}\overline{A}_{i,t}$ where $\max\{\Delta_t\} \approx \delta$.

3.5 Evaluation of various strategies under different settings

For each combination of $(\alpha, \delta, \epsilon)$, we run the following steps:

1. Run the robust model for all years with the given α and define our uncertainty set based on the δ. We extract only the net profit and decision variables for the pre-Covid years 2016-2020.

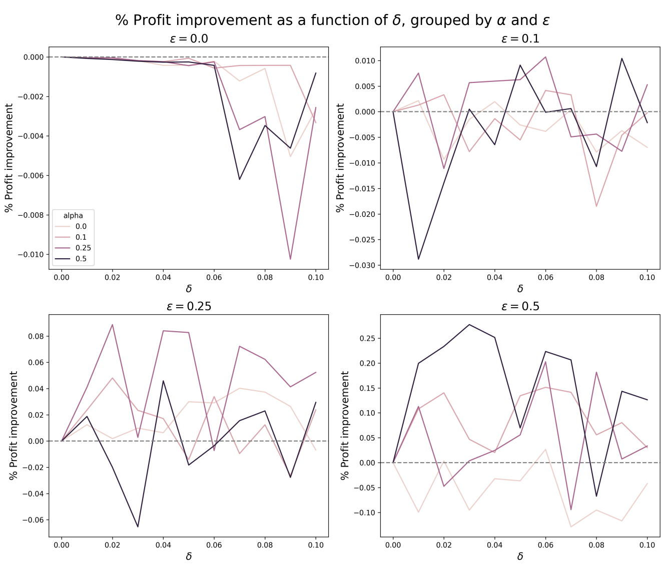
2. We evaluate the model when the actual Covid-19 supply shock ϵ is known for 2021-2023. We run the model only for 2021-2023, with the new availability reduction as well as feeding the production and inventory levels in 2020 as initial values to the model. We obtain the net profit and decision variables for the Covid years 2021-2023.

3. Adding the two numbers gives our total net profit for this particular $(\alpha, \delta, \epsilon)$ combination. We also get the total inventory holding levels $\sum_i E_{i,5}$ and regional Herfindahl (supplier concentration index) $\sum_i (E_{i,5}/\sum_i E_{i,5})^2$ in 2020.

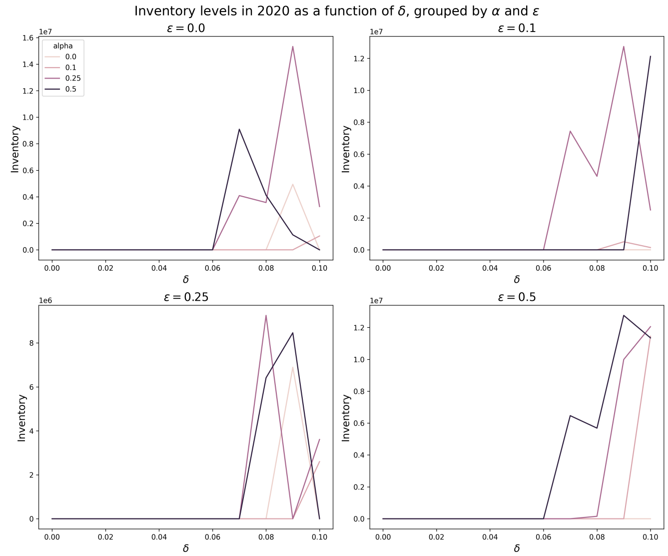
4 Key Findings

First, we find that with greater unexpected supply chain disruptions, a somewhat robust strategy almost always performs better than a non-robust strategy. As ϵ increases, the percentage profit improvement of a δ-robust strategy compared to a non-robust strategy ($\delta = 0$) tends to be increasingly positive.

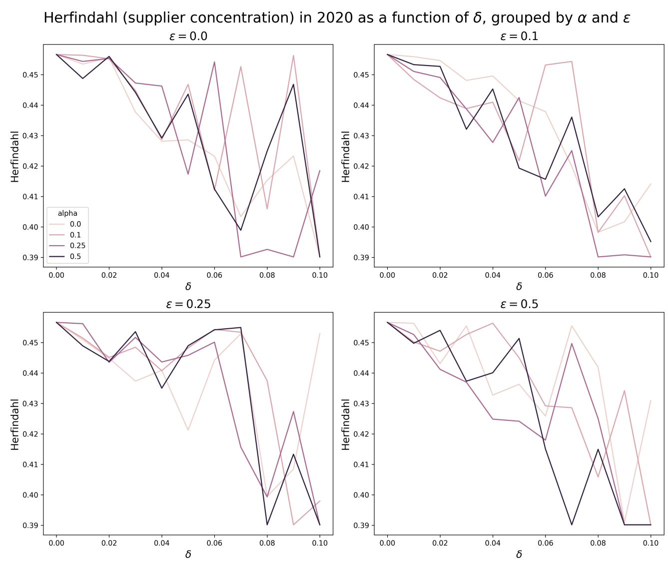
In a world with no shocks, a non-robust strategy is clearly optimal. But with shocks of 10% 25% and 50%, a robust strategy can achieve up to 1%, 8% and 25% higher profits than a non-robust one. This is notable given that the robustness strategy is actually highly conservative and incurs an opportunity cost whenever a supply shock fails to realize. That being said, the optimal δ, while usually greater than 0, is greatly dependent on the value of ϵ and α.



Next, in line with expectations, we observe that inventory levels right before Covid-19 rise as Nike's supply chain strategy becomes more robust, up to a point.



Finally, also in line with expectations, we note that regional Herfindahls right before Covid-19 decrease as Nike's supply chain strategy becomes more robust, up to a point. This points to regionalization, a strategy to pursue greater supplier diversification at a regional level.



5 Impact

Our model showed that even with a blunt robust strategy, it can be more profitable to maintain healthier inventory levels and source from more diverse suppliers. In practice, this could involve actions such as dual sourcing of raw materials, increasing inventory of critical products, near-shoring and increasing supplier base, as well as regionalization.

While costly to guard against supply chain uncertainty, the benefits come through during disruptions such as Covid-19, which should not be dismissed as a one-off event. If businesses such as Nike are still adopting a Just-in-Time model, they should take immediate action to transition towards a more resilient, "Just-in-Case" strategy.