Decentralized decision-making in retail chains: Evidence from inventory management

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This paper deals with:

- **Allocation of decision rights within multi-division firms**; trade-offs in this allocation; & implications on firm performance.

- More specifically, it deals with **inventory management in the stores of large retail chain**, and the choice between:

  - **Centralized inventory management** controlled at headquarters

  - Or **Decentralized system** where each local store manager chooses what and when to order for her store.

- **A main trade-off:** Just-in-time information available to store managers; but store managers are heterogeneous in their skills.

Setting: Liquor Control Board of Ontario (LCBO)

- Second largest buyer/seller of liquor in the world.
- In 2021: CAD 7.18 B revenue; CAD 2.54 B profit (net income); 677 stores; $> 22K$ products; $> 10K$ employees.
- **Centralized pricing system:** Uniform pricing across all the stores.
- **Decentralized inventory management:**

  - HQs use store-level sales data to make ordering recommendations to each store. Recommendations are sent **1 week after the sales data.**

  - Local store managers make daily replenishment decisions and can (do) deviate from HQs recommendations.

Empirical strategy / Empirical results [1/2]

1. **Daily data** at store-product level on sales, prices (retail & wholesale), orders, inventories, stockouts for every product & store over 676 days.

2. Estimation of **reduced form (S,s) inventory model** – separately for each store – shows large store heterogeneity in inventory decisions.

3. Estimation of a **structural model of inventory decisions** – separately for each store – shows substantial store heterogeneity in structural parameters: fixed ordering costs, and per unit storage costs, stockout costs, and ordering costs.

4. A very substantial part of store heterogeneity in cost parameters cannot be explained by a rich set of store and location characteristics: it seems **idiosyncratic of store managers**.

Empirical strategy / Empirical results [2/2]

Using the estimated model, we implement **counterfactual experiments**.

5. **Removing store managers' idiosyncratic heterogeneity**

   - Substantial reduction in ordering frequency and inventory-to-sales ratio, but negligible effect on the frequency of stockouts.

   - If the idiosyncratic component of costs is a biased perception by store managers, then it has a substantial negative effect on the firm's profit.

6 **Centralizing the decision-making of inventory management.**

   - Modest (0.4%) increase in annual profit for LCBO. The result of combining two large effects with opposite signs.

   - Delay in forecasting demand has negative impact on profits but it is more than compensated by positive effect from removing store managers' heterogeneity.

Related Literature

1. **Empirical research on allocation of decision rights in multi-division firms**

   DellaVigna & Gentzkow (2019); Hortaçsu et al. (2021); Bloom, Sadun & Van Reenen (2012); Alfaro, Bloom et al. (2019); ...

2. **Structural models of firms' inventory decisions:**

   Hall & Rust (2000); Kryvtsov & Midrigan (2013); Bray et al. (2019, 2021); ...

2. **Structural models of firm behaviour with manager biases:**

   Goldfarb and Xiao (2011), Ellison, Snyder and Zhang (2018), Goldfarb and Xiao (2019); ...

Structural Model: Sequence of Events [1/2]

- **Step (i):** Day t begins with store manager observing: **current stock** (k_t); **price-cost margin** ($p_t - c_t$); demand shifters ($\boldsymbol{z}_t$) that determine **mean and variance of log-demand**: ($\ln d^e(\boldsymbol{z}_t)$ and $\sigma^2(\boldsymbol{z}_t)$); ordering **cost shock** (ε_t).

- **Step (ii):** Store manager **orders** $y_t \in \{0, 1, ..., J\}$ units of inventory. It takes one day for an order to be delivered to the store.

- **Step (iii):** **Demand d_t is realized** with Negative Binomial distrib.

  Units sold q_t are the minimum of supply and demand:

$$q_t \;=\; \min\{\; d_t \;,\; k_t \;\}$$

Structural Model: Sequence of Events [2/2]

- **Step (iv):** The store generates **flow profits** $\Pi_t =$

$$(p_t - c_t)\ \min\{d_t, k_t\} - \gamma^z \mathbb{1}\{d_t > k_t\} - \gamma^h\ k_t - \gamma^c\ y_t - \gamma^f\ \mathbb{1}\{y_t > 0\} + \sigma_\varepsilon \varepsilon_t($$

$\gamma^z =$ Per unit stockout cost;
$\gamma^h =$ Per unit storage cost;
$\gamma^c =$ Per unit ordering cost;
$\gamma^f =$ Fixed ordering cost;
$\sigma_\varepsilon =$ Std. dev. of transitory shock in order costs

- **Step (v)** **Orders arrive** to the store, and inventory is updated:

$$k_{t+1} = k_t + y_t - q_t$$

Next period price (and margin) is realized from $F_p(p_{t+1}|p_t)$.

Dynamic Programming Problem

- A store manager chooses the order quantity y_t to maximize her store's expected and discounted stream of current and future profits.
- This is a dynamic programming (DP) problem with state variables $\boldsymbol{x}_t \equiv (\boldsymbol{z}_t, k_t, p_t - c_t)$ and $\boldsymbol{\varepsilon}_t$, and Bellman equation:

$$V(\boldsymbol{x}_t, \boldsymbol{\varepsilon}_t) = \max_{y_t \in \mathcal{Y}} \{ \pi(y_t, \boldsymbol{x}_t) + \sigma_\varepsilon \, \varepsilon(y_t) + \beta \, \mathbb{E}[V(\boldsymbol{x}_{t+1}, \boldsymbol{\varepsilon}_{t+1}) \mid y_t, \boldsymbol{x}_t]$$

- Each store-product has its own demand and cost parameters and its own DP problem.

Estimation

- For each of the 634 stores in the chain and each product in our working sample, we estimate:
  - Demand parameters in functions $\ln d^e(\boldsymbol{z}_t)$ and $\sigma^2(\boldsymbol{z}_t)$;
  - Cost parameters:

$$\boldsymbol{\gamma} = (\sigma, \gamma^h, \gamma^z, \gamma^f, \gamma^c)'$$

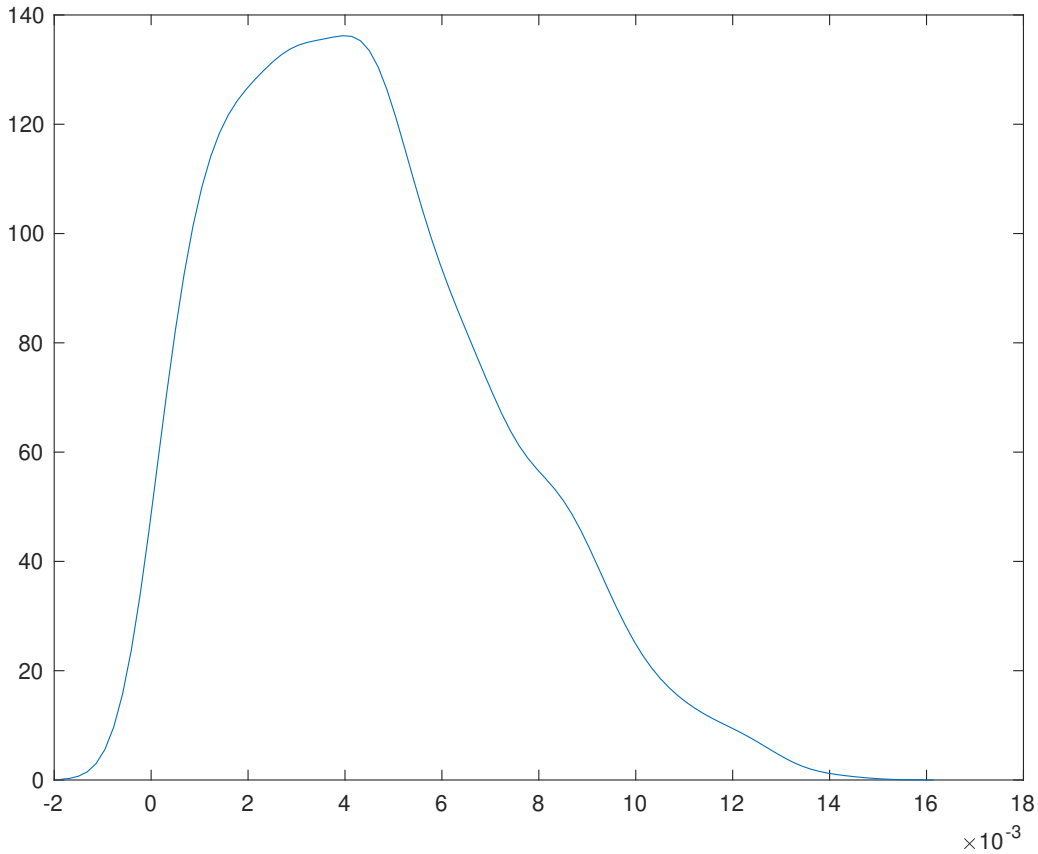
- We estimate demand parameters in a first step, and then cost parameters using a Sequential Pseudo Maximum Likelihood method (Aguirregabiria and Mira, 2002).

Structural Estimates of Cost Parameters (in CAD)

	Median Estimate	*Std. Dev. Estimate*	*Median S.e.*	*Median t-stat.*
γ^h : *Per unit Storage Cost*	0.0040	0.0031	0.0008	5.2331
γ^z: *Stockout Cost*	0.0179	0.3433	0.1477	0.2545
γ^f: *Fixed Ordering Cost*	2.9626	1.1403	0.2403	12.3417
γ^c: *Per-Unit Ordering Cost*	0.0336	0.0697	0.0285	1.4282
# store-product pairs	3,076			

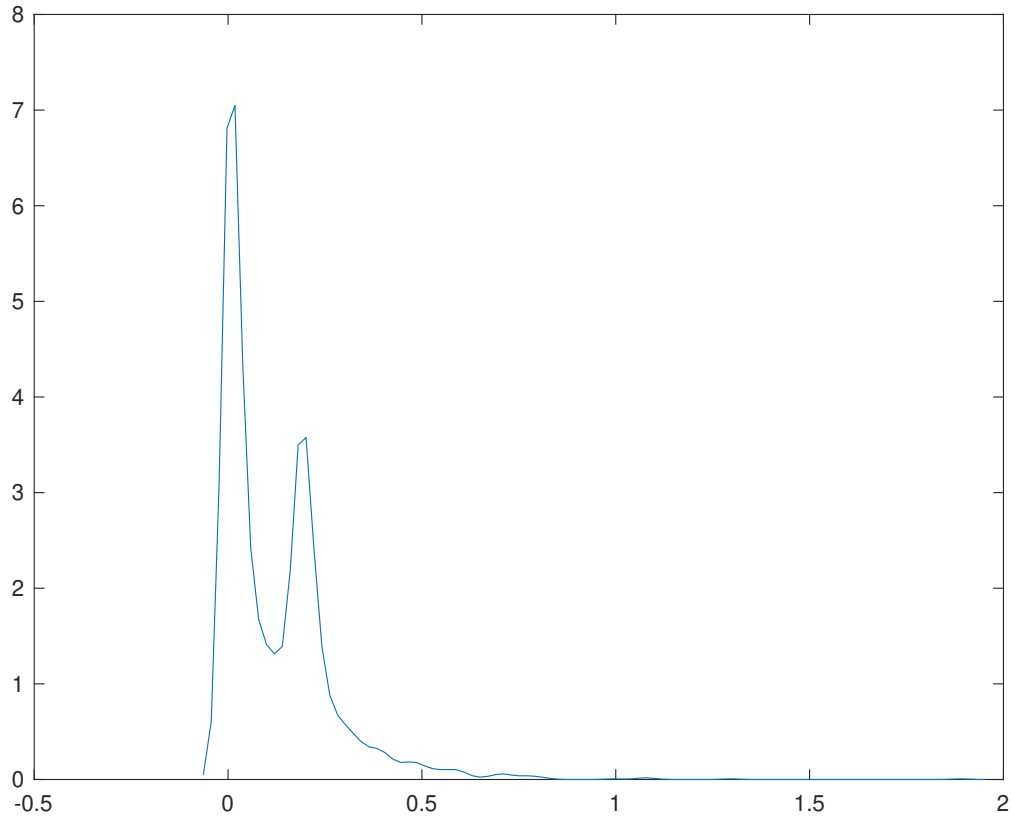
Store Heterogeneity in Storage Cost (Shrinkage Estimator)

Figure: γ^h



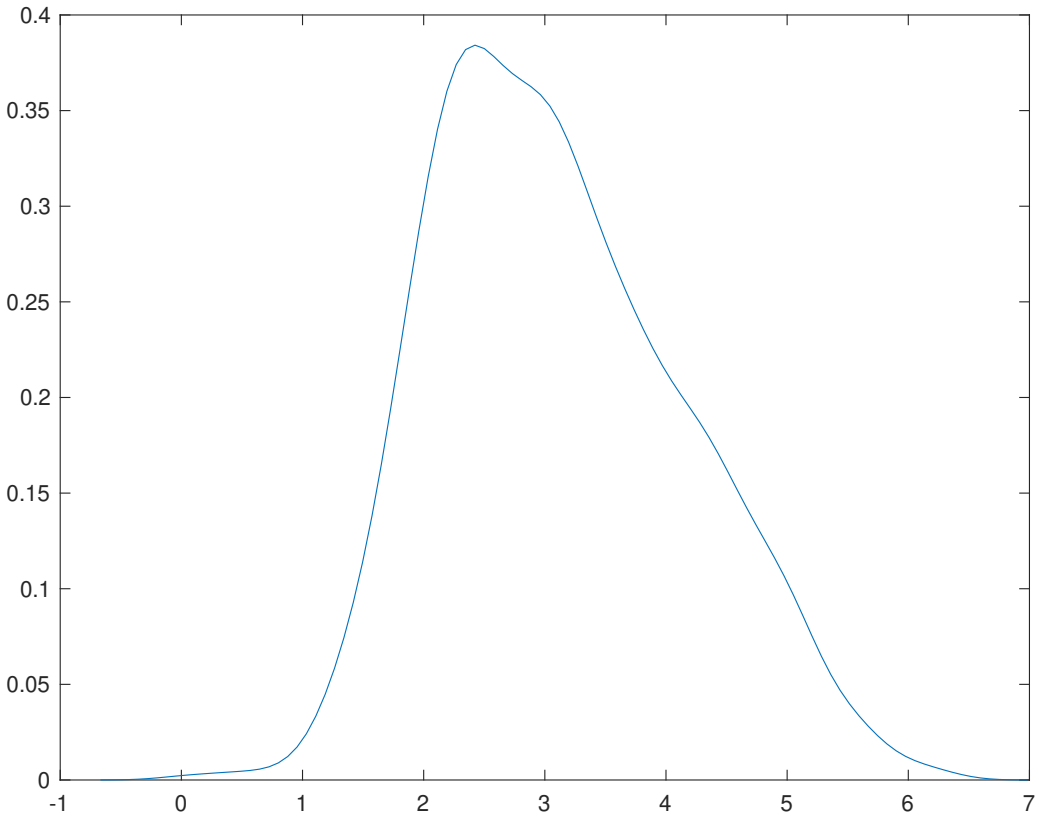
Store Heterogeneity in Stockout Cost (Shrinkage Estimator)

Figure: γ^z



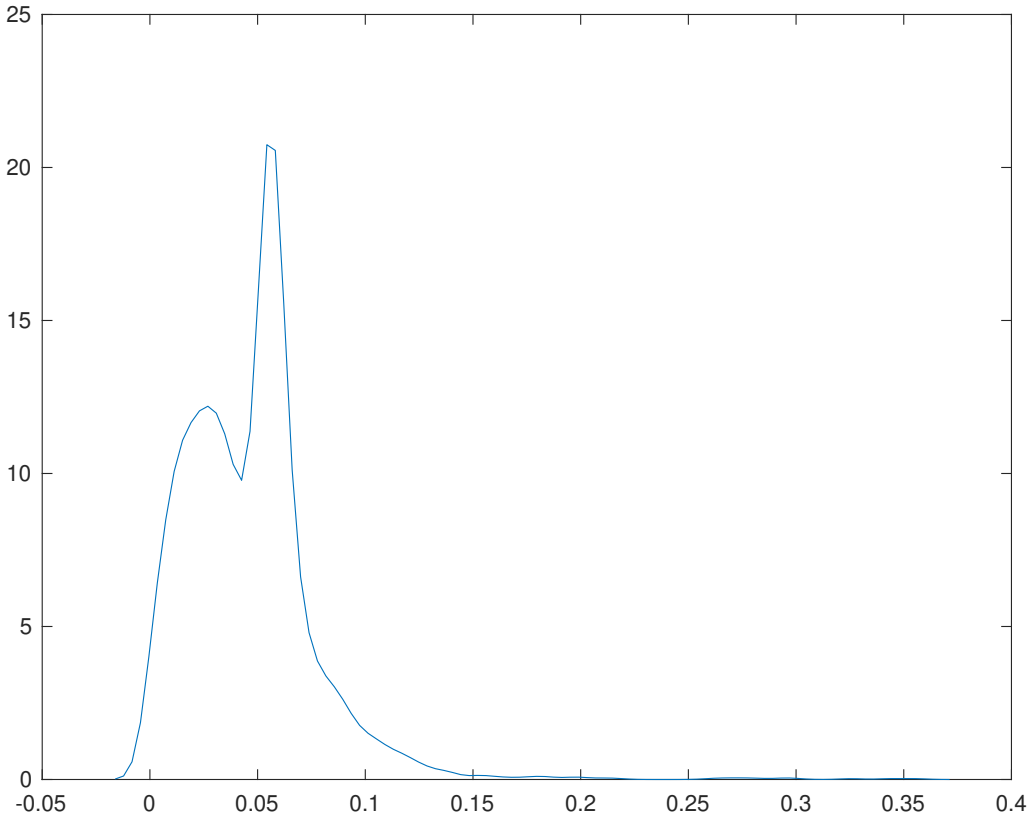
Store Heterogeneity in Fixed Ord Cost (Shrinkage Estimator)

Figure: γ^f



Store Heterogeneity in Unit Ord Cost (Shrinkage Estimator)

Figure: γ^c



Contribution of Inventory Costs to Profits

Table: Realized Inventory Management Costs to Revenue Ratios

	Median	*St. Dev.*
Inventory Holding Cost to Revenue Ratio (%)	0.3219	0.2139
Stockout Cost to Revenue Ratio (%)	0	0.0079
Fixed Ordering Cost to Revenue Ratio (%)	0.8677	0.7203
Variable Ordering Cost to Revenue Ratio (%)	0.2034	0.1951
Total Inventory Cost to Revenue Ratio (%)	1.4903	0.8451

Regression for Estimated Costs on Store Characteristics

Table: Regression of Cost Parameters on Store and Location Characteristics

	γ^f	γ^h	γ^z	γ^c
Store Class (6 groups)				
ln(Product Assortment Size)				
ln(Population in City)				
ln(Median Income in City)				
Location dummies (30 locations)				
R-squared	0.4982	0.3971	0.0764	0.0416

Counterfactual: Centralized Decision Making [1/4]

- Centralizing decision making entails a trade-off between eliminating potential managerial biases and losing valuable store-level information.

1. Based on the own firm's reports, we assume that in the centralized system, predictions about demand at the store level are generated with one week delay.

2. We assume that the residual component (from regression on store characteristics) in store costs is not an actual cost but managerial bias.

Counterfactual: Centralized Decision Making [2/4]

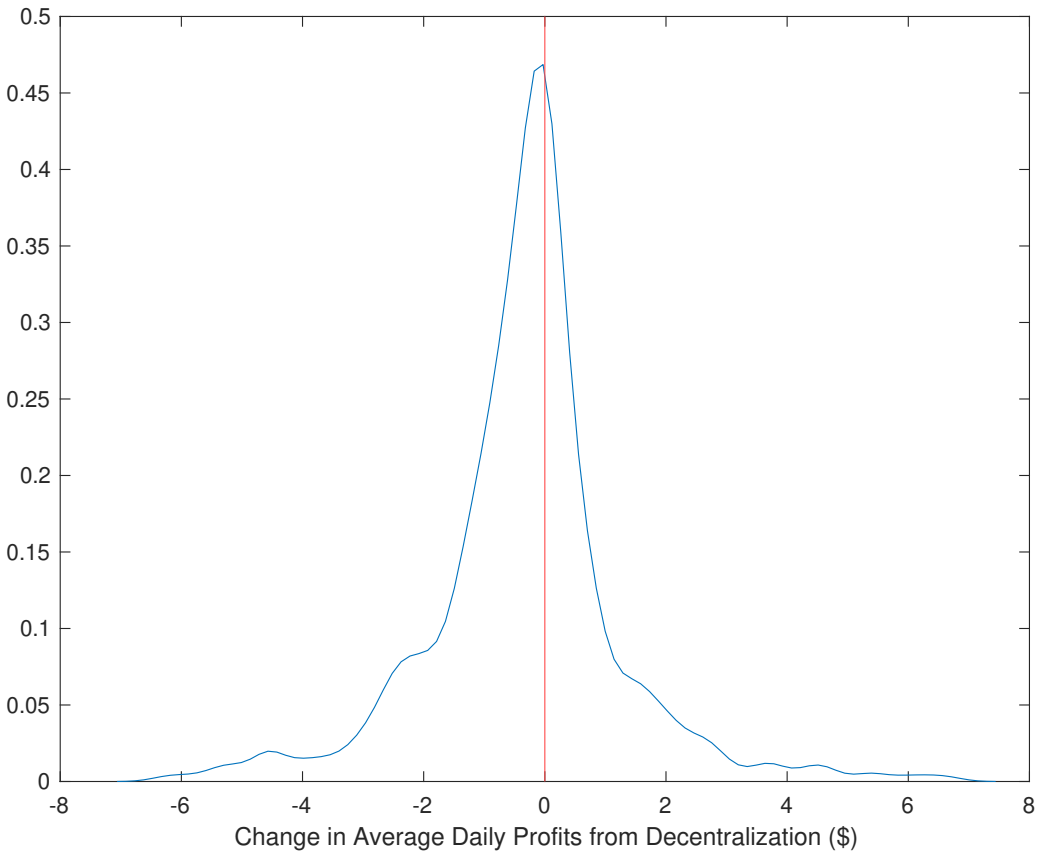
Table: Decentralized vs. Centralized Profits: Average Daily Profit Per-Store Per-Product (in CAD)

	Mean	*P 10%*	*P 25%*	*Median*	*P 75%*	*P 90%*
Centralized Solution ($)	54.93	9.75	18.28	43.91	82.21	116.13
Decentralized Solution ($)	54.64	9.75	18.15	44.01	81.92	116.35
Gains in Profit from Decentralization ($)	-0.29	-2.29	-1.01	-0.20	0.26	1.45
Gains in Profit from Decentralization (%)	-0.41	-3.52	-2.26	-0.73	1.02	3.27
Change Inventory Cost from Decentralization (%)	25.45	-5.52	0.10	6.30	23.01	56.97

1% change in profit per store-product is approximately $17 million in total annual profit for LCBO.

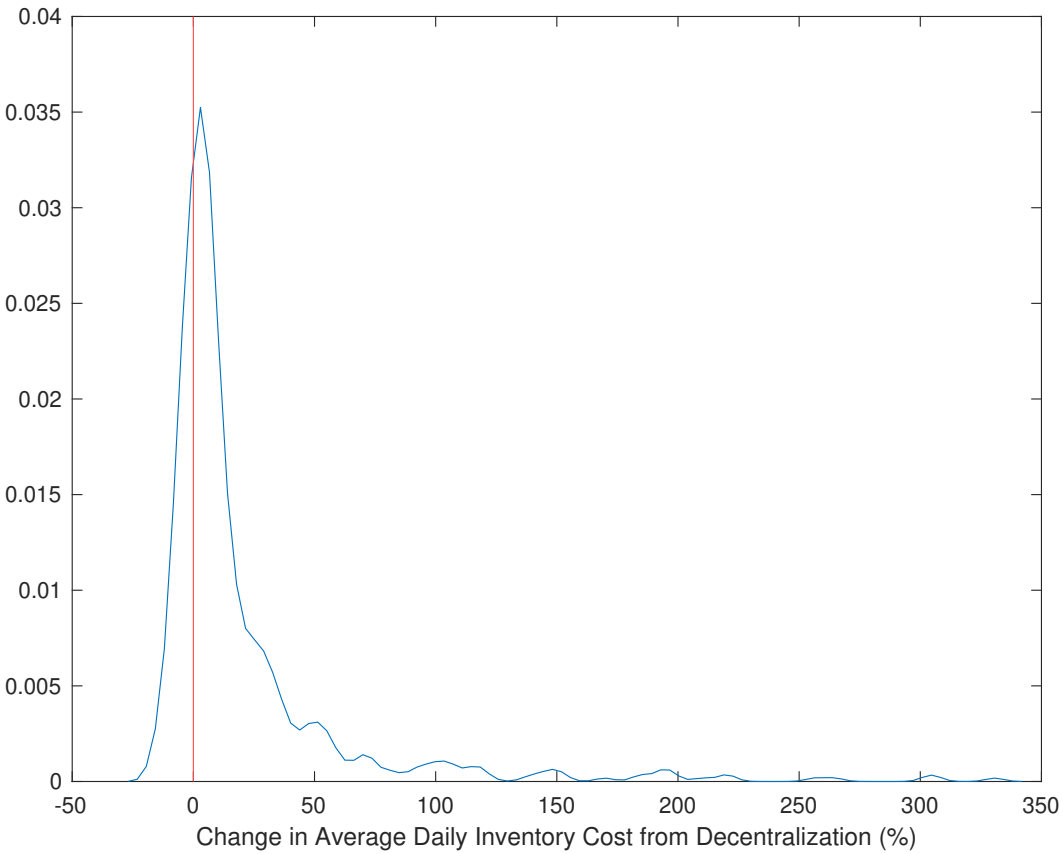
Counterfactual: Centralized Decision Making [3/4]

Figure: Change in Daily Profit From Decentralization ($)



Counterfactual: Centralized Decision Making [4/4]

Figure: Change in Daily Inventory Cost From Decentralization (%)



Conclusion [1/2]

- Retail chains are complex organizations with multiple divisions and teams, each with its own decision rights.
- Store managers play an important role in retail chains.
- Store managers can collect and process information just-in-time about their own stores. Processing this store level information at HQs can generate delays of days or even weeks.
- On the other hand, store managers can have heterogeneous skills, motivations, and can put different levels of effort.
- We investigate this trade-off in the context of inventory management in a large retail chain.

Conclusion [2/2]

- We find that a centralized inventory management system would yield a 0.4% increase in annual profit.

- This modest effect is the result of combining two substantial effects with opposite signs.

  - A negative impact on profits of losing the *just-in-time* information from store managers.

  - A large reduction in ordering and storage costs from eliminating store managers' behavioral biases and heterogeneous skills.

- The gains/losses from centralization are very heterogeneous across stores in the retail chain.