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A Counterexample for the Bullwhip Effect in a Supply Chain

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Previous Studies

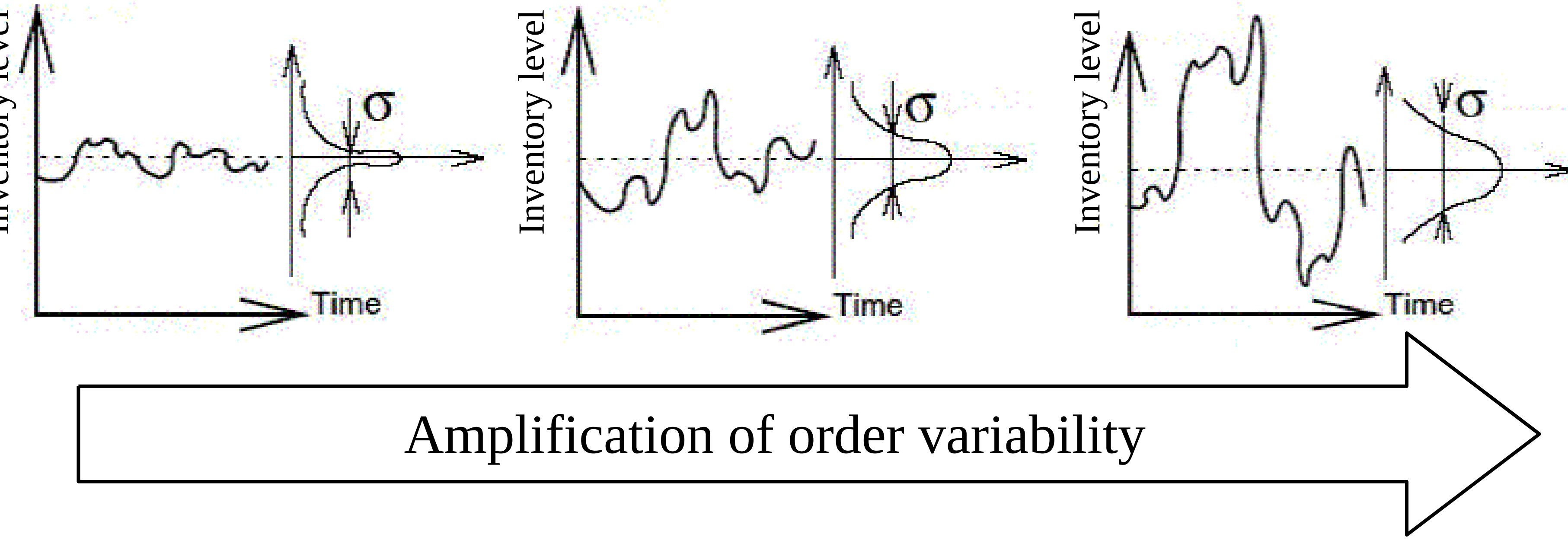
- Environmental variables are fixed, and strategy of each firm is changed.
  - Moyaux, Chaib-draa, and D'Amours (1999) find that combinations of more collaborative strategies are likely to be Nash equilibria.
  - Croson, Donohue, Katok and Sterman (2004) show that reducing coordination risk between firms is important to reduce order amplification.

Outline of Our Research

- Strategy of each firm is fixed and environmental variables are changed.
- Counterexample for the bullwhip effect
  - Inventory level of the upstream firm is not always larger than that of the downstream firm
- Propose quantitative definitions of the bullwhip effect and evaluate them systematically
  - Frequency based statistical measure such as a stochastic dominance is not appropriate to capture the bullwhip effect quantitatively. On the other hand, descriptive statistics such as mean and standard deviation works well.

What is the Bullwhip Effect?

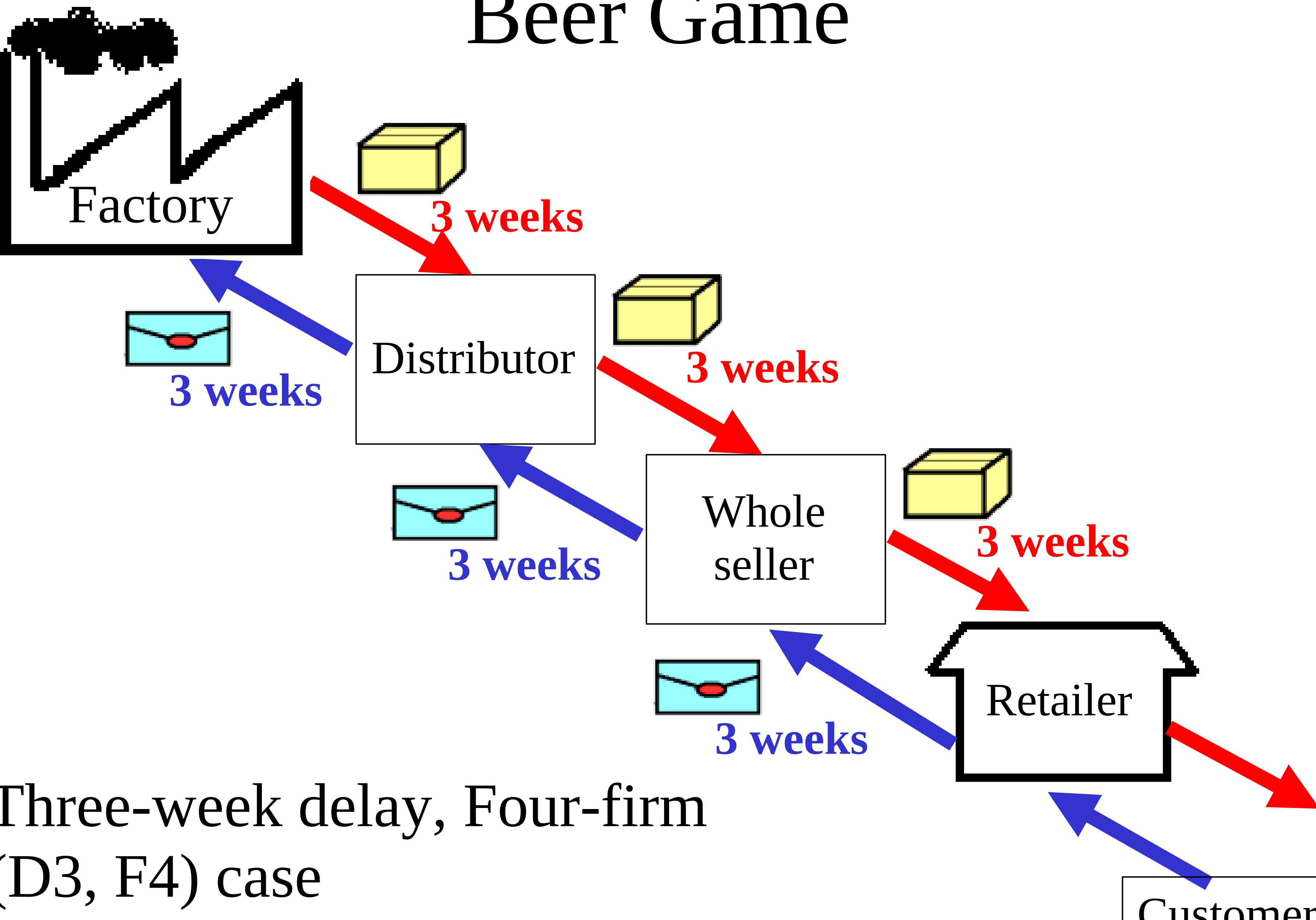
Retailer Distributor Factory



The demand order variability in the supply chain is amplified as they moved up the supply chain.

Lee, Padmanabhan, Whang (1997)

Beer Game



Three-week delay, Four-firm (D3, F4) case

Simulation Setup

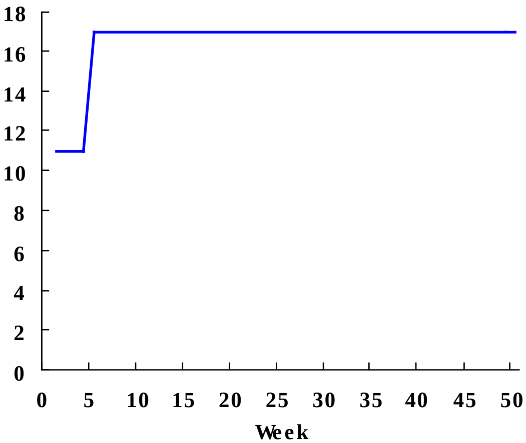
- There is no centralized agent controlling whole activities in a supply chain.
- Information of the customer's orders is not shared among firms.
- Each firm, as an agent, decides its orders to the upstream firm by a simple, deterministic, and non-optimal algorithm.
- Beer Game is repeated 50 weeks.

Inventory Strategy of Each Firm

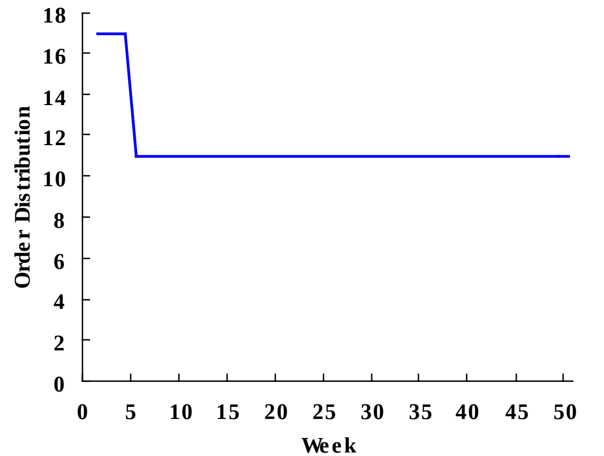
- Each firm forecasts orders from the downstream firm by a moving average of past orders.
- If each firm has enough inventories in its stock,
  - It ships products immediately to the downstream firm.
  - Then it makes orders to fill its stock if the rest of its stock is not enough to meet forecasted next week orders. otherwise it does not make orders.
- If each firm doesn't have enough inventories in its stock,
  - the amount that orders minus inventories are recorded in the backorders to be shipped in later weeks.
  - Then it orders enough amount of products to clear backorders and to meet forecasted next week orders.

Experimental Settings

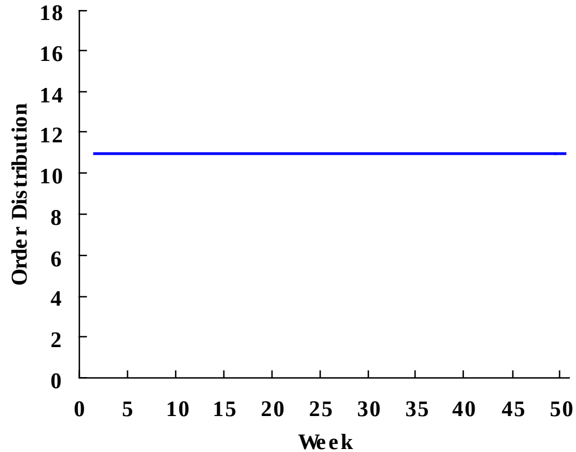
- Treatment variables
  - **The number of firms** in a supply chain (two or four firms)
  - **The length of delay** in ordering and shipping between firms (1 week or 3 weeks)
  - Customer's **order distribution**



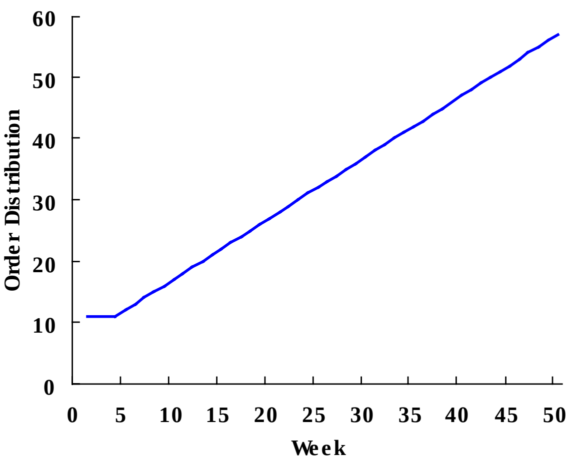
T1: Up Step



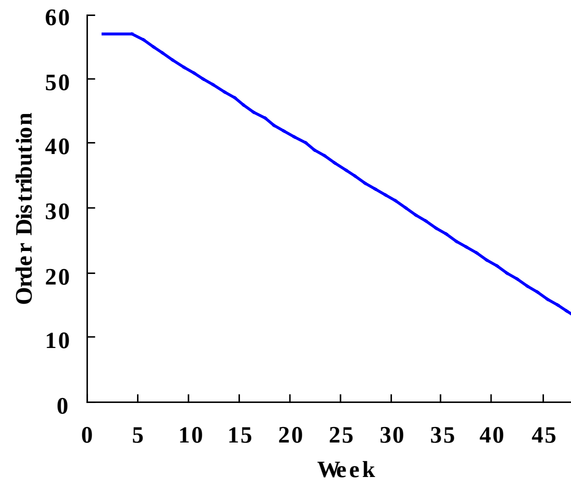
T2: Down Step



TC: Constant

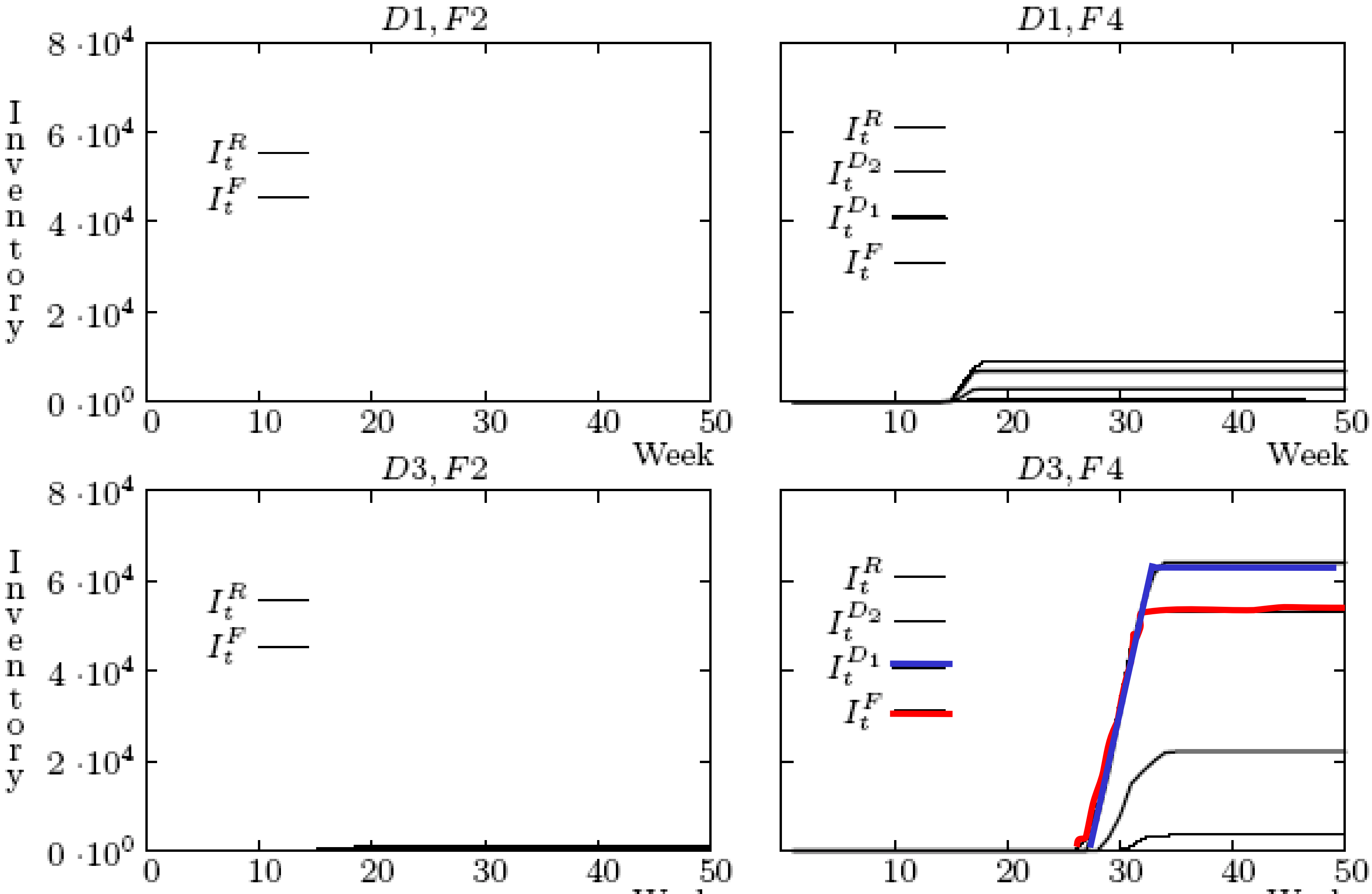


T5: Up

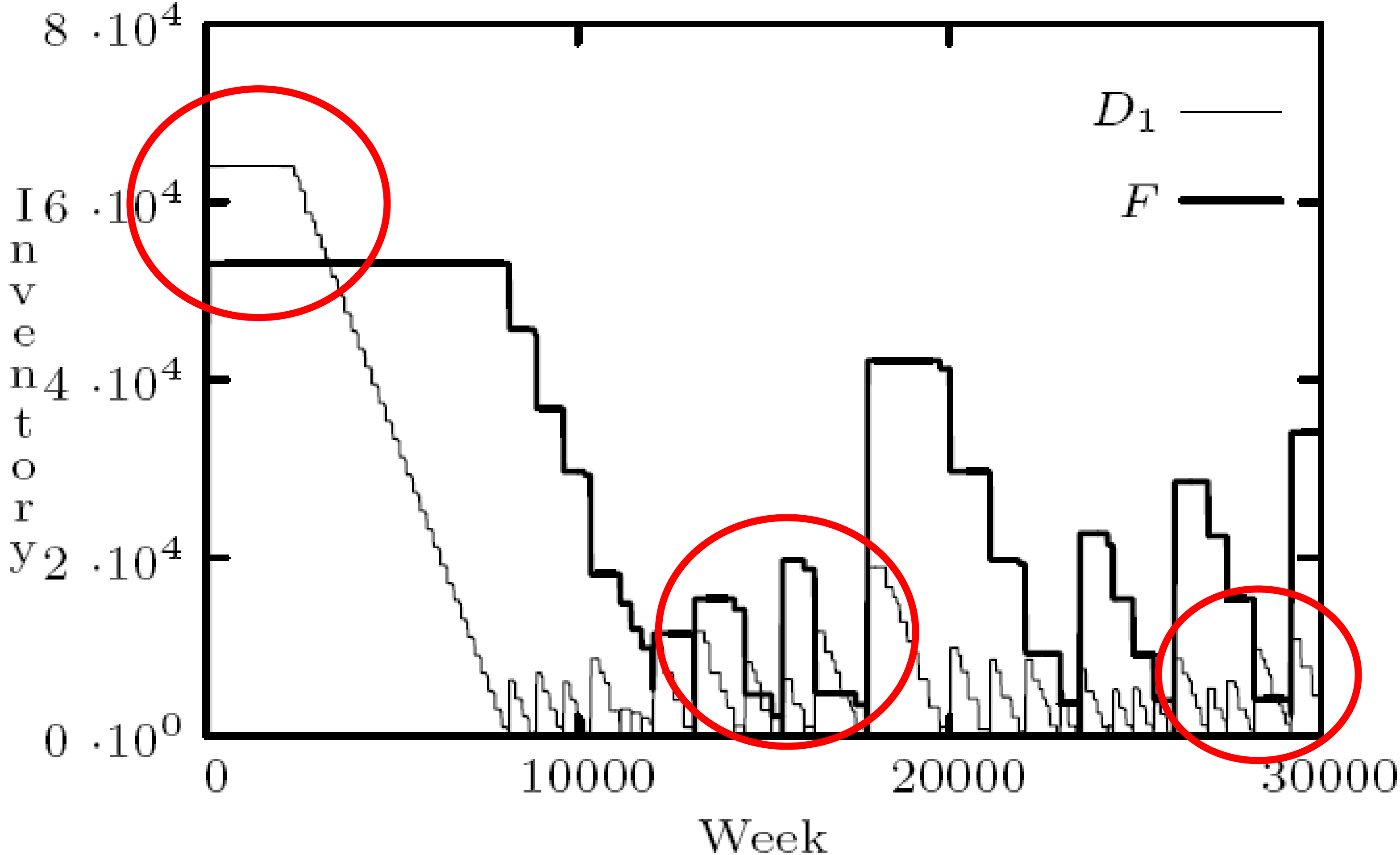


T6: Down

A Counterexample in (W,L5,TC) Case



Simulation Result with Longer Weeks: (D3, F4, TC) Case



The counterexample for the bullwhip effect does not disappear in the long run

Descriptive Statistics of Inventory Level: (D3, F4, TC) Case

	Mean	Standard Deviation
Factory	22397.8	25574.6
	∧	∧
Distributor	26082.4	30521.1
Whole seller	8774.9	10545.9
Retailer	1389.3	1758.1

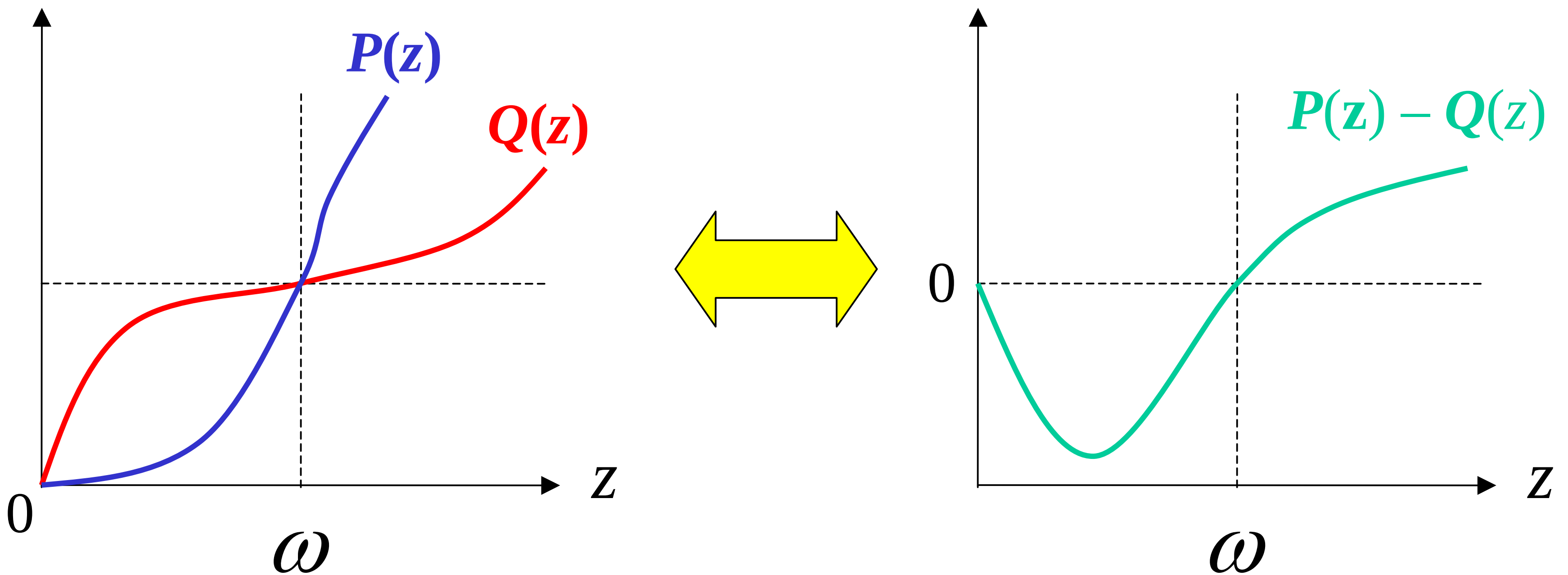
In Searching of Other Quantitative Definitions of the Bullwhip Effect

- **Descriptive statistics** do not take into account of frequency information of inventory level explicitly.
- We would like to compare other quantitative measurements which takes into account of **frequency information** more explicitly such as stochastic dominance

First-order Stochastic Dominance (FOSD)

Given two distributions P and Q, we say that P first-order stochastically dominates Q if for all $z \in [0, \omega]$

$$P(z) \leq Q(z)$$



Other Definitions of Stochastic Dominance

Hazard Rate Dominance (HRD)

P and Q are two distribution function with support $[0, \omega]$

$$\frac{p(x)}{1-P(x)} \le \frac{q(x)}{1-Q(x)} \iff \frac{p(x)}{1-P(x)} - \frac{q(x)}{1-Q(x)} \le 0$$

Reverse Hazard Rate Dominance (RHRD)

For all x

$$\frac{p(x)}{P(x)} \ge \frac{q(x)}{Q(x)} \iff \frac{p(x)}{P(x)} - \frac{q(x)}{Q(x)} \le 0$$

Likelihood ratio dominance (LRD)

For all $x < y$

$$\frac{p(x)}{q(x)} \ge \frac{p(y)}{q(y)} \iff \frac{p(x)}{q(x)} - \frac{p(y)}{q(y)} \le 0$$

Results of Identification by Stochastic Dominance

The length of delay	The number of firms	FOSD	HRD	RHRD	LRD
D1	F2	+	+	+	+
	F4	+	+	+	−
D3	F2	+	+	−	−
	F4	+	+	−	−

Note: Cells in red are the cases that are misidentified

Summary

- Evaluation by several statistical measures
  - Nonparametric measure such as stochastic dominance is not appropriate to identify the bullwhip effect quantitatively.
  - Descriptive statistics distinguished well between the case of the bullwhip effect and a counterexample.

Discussion

- Inventory strategy we adopt is very simple
  - It is, of course, worthwhile to run another series of experiments by introducing more sophisticated strategies.
- No capacity limit for inventory level for each firm
  - Incorporating such restrictions in our environment is also worth considering in the future research.