Reduction of the Bullwhip Effect in Supply Chains through Speculation

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Summary. Agent-based simulations show that some kinds of speculators are able to stabilize the price in a market and to make this market more efficient. Instead of a single market, we consider a supply chain comprising a sequence of three markets in order to check that such speculators can also stabilize a supply chain. Specifically, we verify if these speculators reduce the price fluctuations caused by a phenomenon called the bullwhip effect, which is the amplification of order variability in supply chains. Our simulations show that speculation reduces such price fluctuations, even if price bubbles may appear. Another point is that the speculators we consider lose money in reducing these fluctuations while all the other agents would get richer and richer when the equilibrium is achieved in every market of the supply chain.

1 Introduction

Empirical evidence shows that orders in a supply chain are more variable for raw material producers than the initial demand addressed by end-customers to retailers. This phenomenon of amplification of order variability is known as the bullwhip effect [3]. The problem with the bullwhip effect is not only its essence itself, i.e., demand becomes more variable along the supply chain, but also the fact that it makes demand less predictable. Both increased variability and unpredictability cause important financial costs due to higher inventory levels and agility reduction. As an insight into the importance of these inefficiencies, Carlsson and Fullér [1] claim that the bullwhip effect would cost 100-200 MFIM (17-34 million euros) per year to the Finnish forest products industry, which has a total turnover of more than 100 BFIM (17 billion euros). The solution most often proposed to the bullwhip effect is information sharing [9], but other proposed solutions have included: EDLP (Every Day Low Pricing) policy or the allocation of sales based on past sales [3]. See [6] for a literature review of known causes with their solutions. In this paper, we study whether the presence of speculators could serve as another solution, which seems to be an approach never investigated before. More generally, we investigate interactions between related markets.

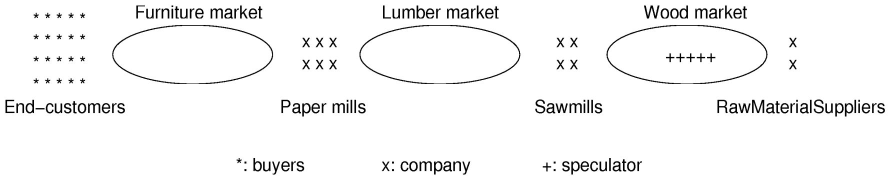


Fig. 1. Supply chain structure.

To this end, we see our supply chain as a sequence of markets, then we apply approaches stabilizing a single market to stabilize our supply chain. Steiglitz and his colleagues [5, 10, 11] provide us with such market-stabilizing approaches. In fact, they analysed the behaviour of a quite general market in which they noted that the presence of speculators (agents who simply try to buy low and sell high) are beneficial to all agents[1]. Specifically, adding the two considered kinds of speculators stabilizes the price of the only considered good[2], and this stabilization *"results in an overall increase in market efficiency and fluidity, in the sense that individual production decisions are more closely matched to skill, and the numeraire is more easily converted into accumulated wealth"* [10, p. 3]. In this paper, we study whether one of these same two kinds of speculators also stabilizes supply chains, in order to have a new solution to the bullwhip effect. Our concern deals with neither the reason for speculation (e.g. is speculation either an irrational behaviour, a rational behaviour due to asymmetric information, or a rational behaviour due to different degrees of risk aversion [4]) nor its potentially harmful consequences (e.g., bubbles, crashes and continued high trading volume [7]), but we only focus on the potential benefits of the aforementioned type of speculators for a supply chain.

This paper is organized as follows. Section 2 presents the simulation model. Then, Section 3 outlines the results obtained with this model. Section 4 presents how our speculators behave in a reproduction of their original environment proposed in [10, 11]. Section 5 discusses our approach.

2 Simulation model

2.1 Overview of the model

We have implemented our supply chain as three inter-linked marketplaces along which a single type of product is traded. As shown in Figure 1, these marketplaces are linked by companies, that is, paper mills and sawmills buy in one market and sell in another. To be precise we use the settings outlined in Figure 1, that is, 25 end-

[1] Kaldor [2] presents a defence of speculation in terms of economic stability.

[2] In this model, agents exchange gold for food, consumes one unit of food per day, and produces gold and food. Production skills of gold and food are different from each other, specific to individuals and constant over a simulation.

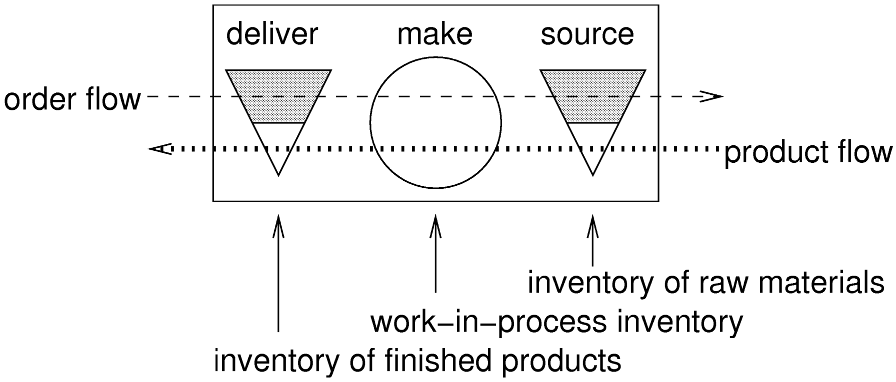


Fig. 2. Model of company.

customers buy furniture sold by 6 paper mills, which buy lumbers from 4 sawmills, which buy raw wood from 2 raw material suppliers. Figure 1 also shows that speculators buy and sell in the same market. We use the open-source JAVA Auction Simulator (JASA) [8] to implement each of the three marketplaces. Specifically, JASA provides several types of auctions (ascending auction, double auction, etc.) to represent each of our three markets, and, for the moment, we use a double auction for every marketplace. We have extended JASA to have our three inter-linked marketplaces so that, at every round, the furniture market is activated first (i.e., end-customers may place a bid shout while paper mills may place an ask shout, then the furniture auctioneer calculates the clearing price, and finally physical exchanges take place at that price), next the lumber market, then the wood market, and finally a new round starts with the furniture market.

Let us now outline the two types of agents in our model, namely, companies and speculators. As can be seen in Figure 2, the representation of companies complies with the first level of the model SCOR from the Supply Chain Council [12], that is, companies are made of three functions: (i) deliver is implemented as an inventory of finished products and a function to place ask shouts to sell products, (ii) make is the work-in-process inventory in which batches of items have to spend the production time before moving from the raw material inventory to the finished product inventory, and (iii) source is similar to deliver, except that its inventory contains raw materials and its function places bid shouts to buy products. Both asking and bidding functions depend on the capacity of their respective inventory. The asking function is the same as the bidding function to which we add a constant called $margin$ because products have to be sold at a higher price than what they were bought plus production cost. Basically, a company is thus represented by at least eleven parameters:

- 3 inventory capacities, i.e., one per inventory (but more when companies buy, sell and produce different types of products, which is not the case in this paper);
- 1 production rate (but more in general, when companies produce different types of products);

- 1 production cost called $margin$ (but more in general, when companies produce different types of products);
- 3 parameters of the bidding function, because we use an adaptation of Steiglitz and his colleagues' function [5, 10, 11] which has three parameters;
- 3 parameters of the asking strategy, for the same reason as for the bidding strategy.

For simplicity, transportation is supposed instantaneous, production rate and inventory capacities are the same among agents, and, for every agent, the bidding function uses the same parameters as the asking function. More precisely, *an agent is charaterized by the three parameters* of its bidding function (the asking function having the same parameters).

2.2 Details of the different types of companies

Whenever possible, we use the same parameters as presented by Steiglitz and Shapiro [11], e.g. the initial funds of all agents is 60 units, and the initial (source or deliver) inventory level is uniformly randomly distributed between 15 and 20 units. The initialisation of every parameter is the same for all the companies in all the results presented in this paper. In other words, we do not change the seed of the pseudo-random number generators, so that Agent 0 (an end-customer) always begins with 17 units in its source inventory while Agent 1 (another end-customer) always stars with 19 units. Because of our adaptation of Steiglitz *et al.*'s model [5, 10, 11] to supply chains, additional parameters are necessary. The main ones are as follows:

- *End-customers* consume 1 unit of furniture per week, which is similar to [11], except that only end-customers are consumers. In order to afford this furniture, end-customers produce 5 units of money per week. Conversely to Steiglitz *et al.*'s model [5, 10, 11], only end-customers produce money, and they produce that money every week without having to choose what to produce.
- *Manufacturers* (i.e. paper mills and sawmills) have a capacited make function. Every manufacturer can produce a batch of exactly 10 units every week. They produce a new batch of products whenever possible, that is, every week in which 10 items are available in their source inventory.
  Manufacturers have a parameter $margin$ in order to sell at a higher price than what they previously paid for the items to process. More precisely, when they place a ask shout, they add $margin$ to the price that Steiglitz et al.'s model [5, 10, 11] would normally choose[3]. Currently, sawmills have $margin = 2$ and paper mills $margin = 3$. We will see that this $margin$ moves up the equilibrium price in every market of the supply chain.
- *Raw material suppliers* are special manufacturers because they also produce 10 units every week, except that they do not need to buy components first. In fact,

[3] This is a first step. In future work, the sell price of finished products will depend on the buy price of its components, or at least, on the current price of these components.

raw material suppliers are the opposite from end-customers, that is, every end-customer is an infinite source of money and a product sink, while each raw material supplier is an infinite source of products and a money vacuum cleaner (but not a money sink).
As paper mills and sawmills, raw material suppliers have a $margin$ set to 1.

2.3 Details of the speculators

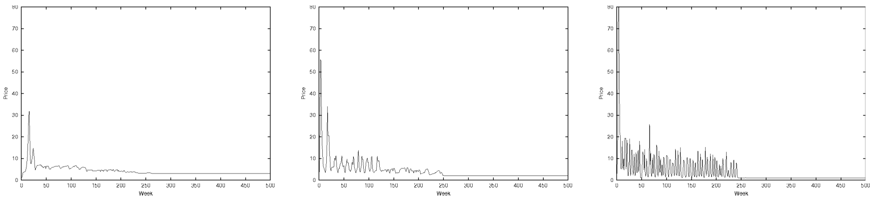
Conversely to companies, speculators buy and sell in the same market. We reimplemented the same two types of speculators as Steiglitz *et al.* [10, 11]. Like other agents, speculators have no inventory holding cost, and they do not look for selling items as soon as possible. All speculators own 60 units of money at the beginning, which is the same amount as the companies. We use the type of speculators called AVG (for average) which use a moving average to update their forecast of the price of the product. If we call P the actual price and $\hat{P}$ the forecasted price, then the forecast of the current price is $\hat{P}(t) = \beta.\hat{P}(t-1) + (1-\beta).P(t-1)$ for some coefficient $\beta \in (0,1)$. Then, a ask shout $P(t-1).(1+margin)$ for all the owned products is placed when $P(t-1) < \hat{P}.(1-margin)$, and a bid shout $P(t-1).(1-margin)$ for all affordables products when $P(t-1) > \hat{P}.(1+margin)$. As in [11], $\beta = 0.008$ and the $margin$ of the speculators is fixed at the beginning of a simulation by uniformly dividing the interval [0.0, 0.5].

3 Results

3.1 Reproduction of the bullwhip effect

Before studying how speculators may reduce the bullwhip effect, we first present how this phenomenon shows in our model. Figure 3 displays the price at which good are exchanged every week (in every subfigure, time is displayed between Week 0 and 500, and price between 0 and 80). Specifically, you can see in Figure 3(a) that the price of wood is more stable than the price of lumber in Figure 3(b) which is itself less variable than the price of wood in Figure 3(c). These three subfigures do not reflect the bullwhip effect itself but its consequence on price. Since the bullwhip effect is defined as the amplification of order variability, we should use the quantity requested in bid shouts to describe this effect. However, since all agents have the same form of utility function, we think the shape of the figures would be the same.

As previously said in Footnote 3, the price in one market has no direct impact on the price in another market. That is, a company may buy expensive components in order to produce then sell cheap products. We will implement in future work such a "price stream" in our model. At the moment, companies are only linked through a stream of orders/bids and a stream of products. However, Figure 3 shows that the interactions between these two streams is enough to create a bullwhip effect which causes greater price fluctuations in wood market than in furniture market.



(a) Furniture market (b) Lumber market (c) Wood market

Fig. 3. Amplification of price fluctuations in the supply chain without speculators (the three subfigures have the same scale)

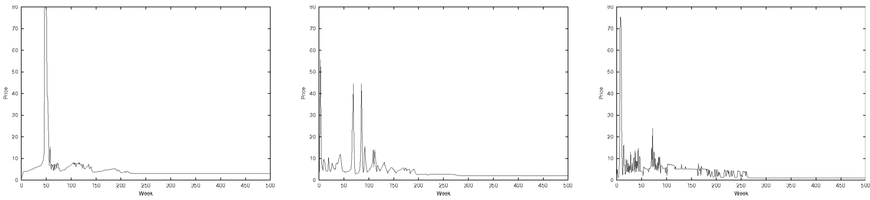
3.2 Impact of speculators on the price fluctuations caused by the bullwhip effect

Next, we add speculators in the lumber and wood markets. We do not add speculators in the furniture market because of the characteristics a good needs to possess to be speculated. In fact, according to Kaldor [2, p. 20], these “attributes are: (1) The good must be fully standardised, or capable of full standardisation; (2) It must be an article of general demand; (3) It must be durable; (4) It must be valuable in proportion to bulk.” As a consequence, raw materials, such as the lumbers and wood, are more likely to be speculated, conversely to finished products as furniture.

Figure 4 presents price fluctuations in every market when 5 speculators trade in the lumber and/or the wood markets (specifically, there are 5 wood speculators in the supply chain outcomes presented in Subfigures 4(a), 4(b) and 4(c), 5 lumber speculators in Subfigures 4(d), 4(e) and 4(f), and 5 lumber speculators and 5 wood speculators in Subfigures 4(g), 4(h) and 4(i)), and, similarly, Figure 5 shows price evolution when 25 speculators trade in the lumber and/or wood markets.

We can note that the price in the wood market stabilizes when wood speculators are added, because the price in Subfigures 4(c) and 5(c) is more stable than in Subfigure 3(c). Moreover, 25 speculators have a greater stabilising effect than only 5, because the price in Subfigures 5(c) is more stable than in Subfigures 4(c). When we compare these same two subfigures, we can also notice that 25 speculators allow the price to stabilise quicker than with only 5 speculators. The same conclusion may be drawn when speculators are only added to the lumber market (cf. Subfigures 3(b), 4(e) and 5(e)). Since this paper addresses the impact of speculators on the bullwhip effect, we can first conclude that the type of speculators we consider is able to *stabilise the price fluctuations caused by the bullwhip effect.*

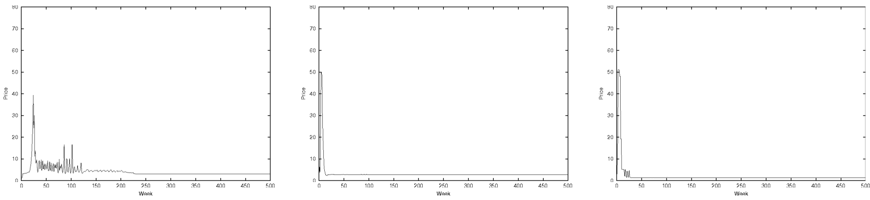
However, the smaller and shorter price fluctuations brought by speculators seem to be (sometimes) replaced by price bubbles of large amplitude. For instance, Subfigure 5(c) is much more stable than Subfigures 3(c), except that it has a single price bubble which is huge. Indeed, while no speculators lead to price fluctuations, too many speculators lead to price bubbles: there *seems to be an optimal number of*



(a) Furniture market

(b) Lumber market with 0 lumber speculator

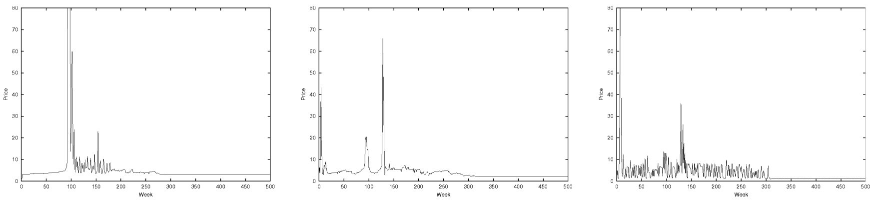
(c) Wood market with 5 wood speculators



(d) Furniture market

(e) Lumber market with 5 lumber speculators

(f) Wood market with 0 wood speculator



(g) Furniture market

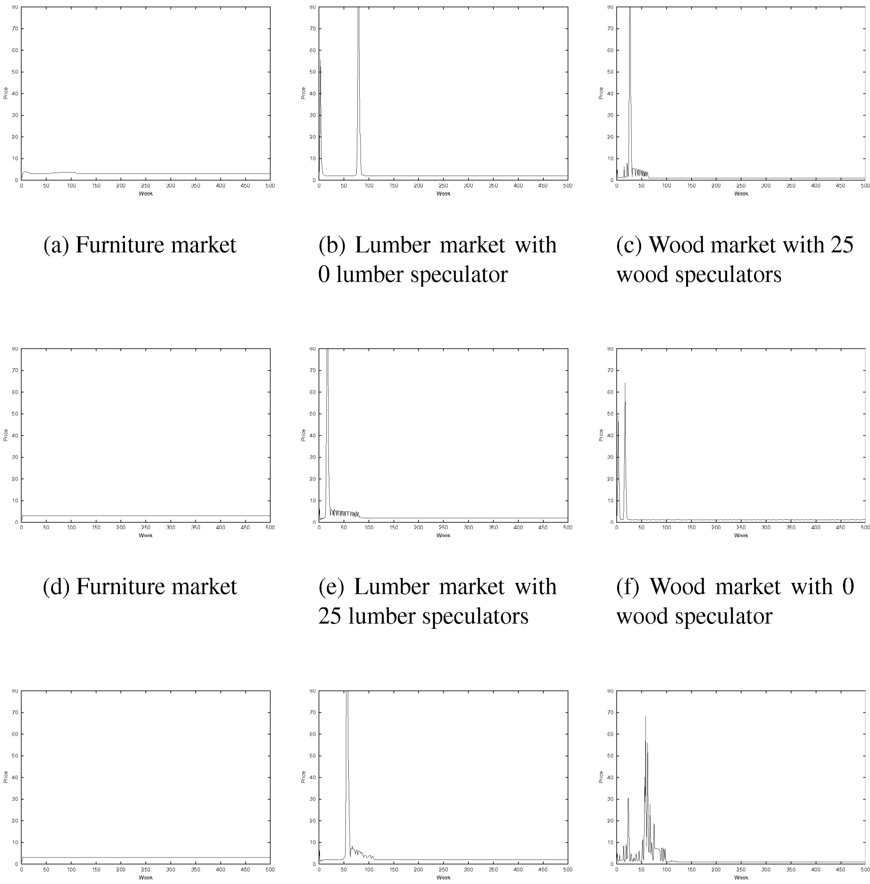
(h) Lumber market with 5 lumber speculators

(i) Wood market with 5 wood speculators

Fig. 4. Amplification of price fluctuations in the supply chain with 5 speculators (all subfigures have the same scale as Figure 3)

speculators for every market in the supply chain. The question is thus how many speculators to use and where. For example, Subfigures 4(d), 4(e) and 4(f) are the most stable among all the subfigures in Figures 3, 4 and 5, while they do not use the largest number of speculators. On the contrary, the graphs in Figure 5 are more stable than in Figure 4 (i.e., if you compare Subfigure 4(n) with Subfigure 5(n)), except that there are a few price bubbles of large amplitude.

On the other hand, adding 5 wood speculators to Subfigure 4(f) destabilizes the wood market in Subfigure 4(i), which next destabilizes the lumber market in Sub-



(a) Furniture market

(b) Lumber market with 0 lumber speculator

(c) Wood market with 25 wood speculators

(d) Furniture market

(e) Lumber market with 25 lumber speculators

(f) Wood market with 0 wood speculator

(g) Furniture market

(h) Lumber market with 25 lumber speculators

(i) Wood market with 25 wood speculators

Fig. 5. Amplification of price fluctuations in the supply chain with 25 speculators (all subfigures have the same scale as Figure 3)

figure 4(h). This seems to confirm that our simulation model allows to make a *link among the stability of different markets*. That is, speculators first stabilize their market, then other markets. And also, speculators first create a price bubble in their market, which next destabilises another market.

Final, every market of the supply chain always reach its equilibrium price within 500 weeks. This equilibrium price is defined by the $margin$ of the company selling in the considered market. As a consequence, the equilibrium price is 1 in the wood market, 2 in the lumber market and 3 in the furniture market.

Supply chain level	0 lumber speculator & 0 wood speculator	
	μ	σ
End-customers	1,112.4	627.4
Paper mills	285.2	768.3
Sawmills	640.8	1,198.0
Raw material suppliers	18,793.0	592.2
Lumber speculators		
Wood speculators		

Supply chain level	0 lumber speculator & 5 wood speculators		5 lumber speculators & 0 wood speculator		5 lumber speculators & 5 wood speculators	
	μ	σ	μ	σ	μ	σ
End-customers	1,152.4	622.2	956.5	602.3	960.8	689.6
Paper mills	321.6	705.8	1,915.2	3,117.2	560.6	1,138.4
Sawmills	962.2	1,113.8	3,661.3	4,260.2	923.0	1,098.1
Raw material suppliers	17,702.3	38.8	9,718.6	33.1	19,206.0	421.4
Lumber speculators			96.6	49.0	0.2	3.7
Wood speculators	- 4.2	7.5			156.4	237.9

Supply chain level	0 lumber speculator & 25 wood speculators		25 lumber speculators & 0 wood speculator		25 lumber speculators & 25 wood speculators	
	μ	σ	μ	σ	μ	σ
End-customers	2,072.1	593.2	1,892.5	640.6	2,028.1	497.0
Paper mills	- 137.6	248.3	471.2	1,241.5	- 31.4	92.7
Sawmills	1,457.3	3,130.2	970.4	1,281.5	560.7	1,131.5
Raw material suppliers	7,273.0	86.6	8,626.9	366.7	9,434.1	277.1
Lumber speculators			- 4.2	8.3	- 3.7	9.4
Wood speculators	- 7.3	10.7			45.5	102.4

Fig. 6. Average funds and standard-deviation of funds between parentheses per level in the supply chain at Week 500.

3.3 Financial aspects of speculation in our supply chain model

Another important point is the financial impact of speculation on companies and the cost efficiency of speculators. The table in Figure 6 presents the average amount and the standard-deviation of the money owned by the companies in every level of the supply chain. Three points can be noticed in this table:

- *The money ends up with the raw material suppliers:* The end-customers produce money which is next transferred to the raw material producers through the paper mills and the sawmills (and possibly via the speculators). These latter companies do not retain much of the money which goes through them. Of course, if simulations were run for a longer duration, the paper mills and sawmills would earn more and more money since, at the equilibrium of every market, they sell at one unit of money more expensive than they buy. This benefit is allowed by the use of different $margin$, which, as we have already said, move up the equilibrium price. As a consequence, many paper mills and sawmills have a negative amount

of money in Week 500, but they would earn an infinite amount of money if the simulation was run forever. Nevertheless, they would still remain poorer than the raw material producers
- *The end-customers seem to produce money at a good rate:* In the considered first 500 weeks, producing 5 units of money per week seems to be the good rate because all end-customers have positive funds in Week 500. Since the equilibrium price of the furniture market is only 3 (because of the $margin$ of paper mills), end-customers, as the other companies, would therefore become richer and richer in infinite simulations.
- *Speculators are not cost efficient:* Our speculators never earn a large amount of money. For instance, they own a maximum average amount of 156.4 shared among 5 wood speculators, but the corresponding large standard-deviation of 237.9 indicates that several of these speculators have negative funds in Week 500. Yet, speculators, like all agents, start with 60 units of money.
  This remark about the poor cost efficiency of speculators is rather counter-intuitive! In addition, speculators are the only agents in our simulation which loose money. And this latter point would not change if simulations were longer, because all simulations end with a market at the equilibrium in which they cannot trade, thus, earn money.

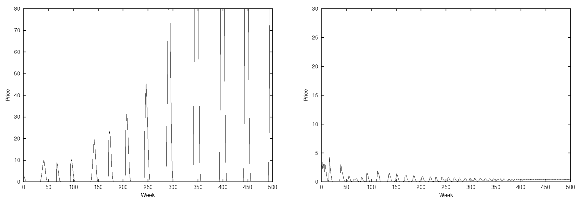
4 Related work

In this section, we outline our reproduction of Steiglitz and his colleagues' model [5, 10, 11]. As for our supply chain simulation, we use the parameters in [11]. More precisely, the speculators used here are exactly the same as those used in our supply chain, and the trading agents share most of their code (in particular, their bidding strategy and their valuation policy) with our supply chain agents.

Figure 7 shows that the speculators are as efficient in stabilising the price in our supply chain as in a single market. Subfigures 7(a) and 7(b) show that the speculators have a stabilising effect, and the table in Subfigure 7(c) that the speculators lose money when they trade (they all begin with 60 units of money and, on average, end up with a negative amount). As in our supply chain simulation, traders should pay the speculators to bring stability. Speculation does not seem to increase greatly the average welfare of traders (i.e the average final amount of money only increases from 616.4 to 664.0, which is not significant since only one simulation run is considered), but money is much better shared between the traders (i.e. the standard-deviation of final funds decreases by two orders of magnitude from 1,395.7 to 67.6).

5 Discussion

Since speculators lose money when they stabilize the supply chain, then companies should pay them for their service of stabilisation. The question is then who should pay for this stability? Since price stability can be seen as a common good (or, at



(a) 0 speculator (b) 25 speculators

Agent type	0 speculator		25 speculators	
	μ	σ	μ	σ
Traders	616.4	1,395.7	664.0	67.6
Speculators			- 3.5	4.6

(c) Average and standard-deviation of funds at Week 500.

Fig. 7. Reproduction of Steiglitz *et al.*'s experiments [5, 10, 11] (all subfigures have the same scale as Figure 3).

least, serice), a prisonner's dilemma may occur, that is, everyone would like money be given to speculators, but nobody wishes to pay because all companies prefer all other companies pay but not themselves.

Another point to consider is the second type of speculators proposed by Steiglitz *et al.* [10, 11], namely DER speculators (for derivatives). These speculators estimate the second derivative of the price slope. They sell when the slope of the price is increasing and buy when the slope is decreasing. Perhaps these agents can both stabilize our supply chain and be cost efficient.

6 Conclusion

This paper has proposed to use some sort of speculators to reduce the bullwhip effect, which is the amplification of order variability in a supply chain. Reducing this effect is important because it costs money to the companies due to higher inventory levels and because the bullwhip decreases supply chain agility. To our knowledge, using speculators as a solution to the bullwhip effect is a new approach. We have explored this idea by means of a computer simulation of a supply chain, in order to quantify the impacts of speculation on the price fluctuations caused by the bullwhip effect.

This is still a preliminary work, but three conclusions can be drawn. The first one is that adding a few speculators stabilizes the price in the market of the supply chain in which they are introduced. The second conclusion is that price bubbles may appear, and this seems occur when too many speculators are used. Finally, our speculators are not cost efficient and lose their initial level of money to an amount near zero.

As future work, we intend to run more experiments to confirm the conclusions in this paper. We also plan to compare different types of speculation (financial vs. stock) and study the potential benefits of futures contracts in supply chains. An application of these ideas concerns the effective control of online marketplaces, such as those emerging for scientific and commercial computational resources known as the GRID. If the presence of speculators in markets is shown to reduce the bullwhip effect, then designers of GRID distribution chains may engineer their systems to include artificial speculators.[4]

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