

Responding to the Lehman Wave: Sales Forecasting and Supply Management during the Credit Crisis

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Abstract

In this paper we analyze the strong dip in the manufacturing industry seen at the end of 2008 and provide evidence from various sources that it was caused by cumulative de-stocking, triggered by the bankruptcy of Lehman Brothers. This de-stocking created a giant dampened wave, the so-called Lehman wave. We model the Lehman Wave using system dynamics and validate the model using data from a number of business units and market segments of Royal DSM. We show that the model gives a very good prediction of sales development during the credit crisis. We provide insights into how these results can be used to improve sales forecasting and supply chain management during times of severe crises. We also show that the effects of the current financial crisis are far from over and suggest that our methods be used to predict sales during the year 2010.

1. Introduction

Until the summer of 2008, credit was abundantly available. Then the credit crisis made headlines and peaked in September 2008 with the bankruptcy of Lehman Brothers. This caused a shockwave throughout the (financial) world, and in some cases even panic. Both consumer and producer confidence dropped and consumers were hesitant to spend money, especially on large purchases. As a result, the automotive market went down sharply; other consumer markets dropped considerably less.

The credit crisis also resulted in a tightened focus on cash for all companies. “Cash=King” became the adage. This resulted in a strong reduction in investments and capital expenditure, as well as cost reductions. In turn, this resulted in a decline of the B2B markets, and this decline was stronger than that in the consumer markets. It also made companies eager to reduce their operating working capital, which they did mainly by reducing stocks.

At the same time, a different trend was visible. Up until the summer, commodity prices had been high. Oil, steel, and plastic were at record levels. As a result, the industry had been speculating on even higher prices and thus had been over-stocking. When commodity prices crashed in Q4 as a result of reduced demand, everybody wanted to reduce their over-priced stocks first (see Figure 1).

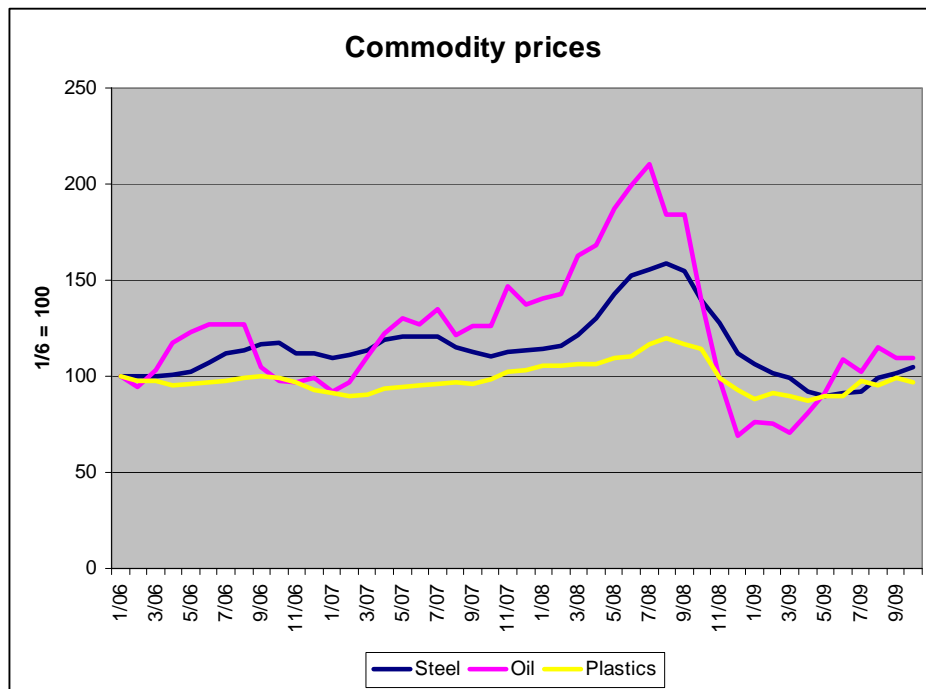


Figure 1. Commodity Prices for steel, oil, and plastics (source data: Bureau of Labor Statistics, 2009).

One of the business units of Royal DSM, a Life Sciences and Materials Sciences company headquartered in the Netherlands, is a producer of specialty resins for the coating industry. This unit saw a strong dip in its sales in the fourth quarter of 2008. Based on the knowledge that it has very long supply chains, the unit’s management drafted the hypothesis that the strong dip in demand for industrial products was caused by de-stocking, triggered by the bankruptcy of Lehman Brothers on September 15, 2008. It is fair to assume that the supply chain between this business unit and the end-customer could be as long as “250 days’ sales”. This means that it takes at least 250 days for a molecule to travel from DSM’s warehouse to the final consumer. To give an example: if such a 250-day supply chain decides to reduce its stocks by 12%, an amount of stock equal to 30 days’ sales (a whole month) is taken out of the chain, which for this DSM unit can result in either a business standstill for a whole month or a 33% decline during three months. Such a decrease does not take into account any dynamic behavior that may occur as a result of companies observing such substantial declines in sales. It is well-know from the literature (e.g., Forrester (1961), Sterman (1989), and Lee *et al.* (1997), Croson and Donohue (2006)), that decision makers typically overreact to short term sales information by erroneously updating their forecasts and by underestimating cumulative supply chain effects.

Extensive and simultaneous de-stocking throughout the supply chain has detrimental effects on this chain, especially for companies that are positioned upstream, such as DSM’s resins business unit. However, extensive de-stocking will at some moment need to lead to restocking, as in many markets consumer sales dropped only marginally compared to the losses amounting to dozens of percentage points that were reported in typical upstream industries such as the chemical industry.

In this paper, we will argue in the next Section why extensive de-stocking leads to a bullwhip in the supply chain: sales variance upstream in the supply chain is higher than downstream. We will show some anecdotal evidence from a variety of sources that sales indeed dropped substantially more with companies upstream in the supply chain. In Section 3, we will develop a system dynamics model in order to capture the decision making behavior, allowing us to predict the development of sales throughout the crisis. In Section 4, we validate the model using data from Royal DSM. In the last Section we will present our conclusions and make recommendations on how managers can act to gain a

competitive advantage out of the crisis by using this type of modeling. We also reflect on the way DSM has acted and which opportunities this has presented to them.

2. The Lehman wave: a synchronized bullwhip

While the existence of the bullwhip effect has been extensively documented (e.g., Forrester (1961), Sterman (1989), and Lee *et al.* (1997), Croson and Donohue (2006)), there have been arguments about its existence in the overall economy or in supply chains encompassing numerous companies. Cachon *et al.* (2007) recently argued that no evidence of the existence of the bullwhip effect could be found. Fransoo and Wouters (2000) and Chen and Lee and (2009) argue that in order to observe the bullwhip effect it is crucial to measure it correctly. Both these papers argue that improper aggregation essentially takes away the opportunity to observe the bullwhip effect. In the beer distribution game (Sterman, 1989), the bullwhip effect is created by a single pulse. In Sterman's experiment, this single pulse is an increase in the demand level. In this paper, we study a single pulse by a synchronized decrease in the target inventory level along the entire supply chain.

We hypothesize that due to the bankruptcy of Lehman Brothers on September 15, 2008, a shock wave hit the international business community instantaneously. We have evidence of several companies, in anticipation of substantial shortages on the credit market, ordering preservation of cash wherever possible. The most obvious way to do this quickly is to reduce inventories.

Hypothesis 1: On September 15, 2008, or shortly following this date, most companies worldwide decided to reduce their target inventories.

A reduction of inventories under stable or slightly decreasing sales can only be achieved if purchases are reduced or postponed. As a consequence of the decision to reduce inventory, therefore, many companies substantially reduced their purchases of supplies or raw materials. Obviously, companies further upstream in the supply chain were hit more than companies downstream.

Hypothesis 2: During the 2008/2009 financial crisis, the sales decrease at companies further upstream was higher than the sales decrease further downstream.

Finally, we are interested in finding out to what extent the inventory decline can explain the sales decline experienced by companies upstream.

Hypothesis 3: The sales decline of companies further upstream in the supply chain is increasingly due to inventory reductions along the supply chain.

We have conducted four limited studies with different empirical material to investigate these hypotheses:

- telephone interviews in the supply chain downstream of DSM Resins in January 2009
- quarterly reported data by publicly listed companies
- aggregate data by US census
- cross-sectional survey data in a particular region of the Netherlands.

We will now briefly report on these studies and their main conclusions.

2.1 Supply chain investigation of DSM NeoResins+

In late 2008 and early 2009 there was no reliable public information available on inventories and sales across different echelons of the supply chain. As is common across most companies, DSM NeoResins+ collected sales information focusing on immediate customers only. Obviously market intelligence is

conducted on final markets, but at that time this information was used for purposes other than supply chain decision making.

Therefore, in January 2009 a series of telephone interviews were conducted to better understand the sales development in the supply chain downstream of DSM. Apart from information on actual sales, we also collected information on various items such as inventory levels, changes in inventory policies and actual inventory reductions. In addition, we asked questions about the supply chain structure, such as supply lead times and ordering frequencies.

We conducted a total of 50 telephone interviews across all levels of the supply chain. Then we grouped the responses into sets of companies depending on their position in the supply chain. Table 1 shows the results. They clearly show that further upstream, sales declined substantially more than downstream.

Table 1. Indicative sales decline across different supply chain levels based on telephone interviews in the resin supply chain.

<i>Level in supply chain</i>	<i>Percentage decline in sales observed during crisis (January 2009 vs January 2008)</i>
Retailer	Fairly stable
OEM	8%
Parts production	15%
Paint production	20%
Resin production	30%

We further concluded from the interviews that all companies had decided to destock. De-stocking percentages varied between 10 and 20%. No specific relationship between the percentage of de-stocking and the level of the supply chain could be discerned from the data.

2.2 Quarterly reported data by publicly listed companies

Publicly listed companies publish quarterly reports in which they list relevant information such as sales, purchases and inventories. While it has been shown that there are problems with the reliability of inventory data (see, e.g., Lai, 2009), patterns of sales and purchases show also that companies further upstream saw larger declines in sales than companies downstream. Figure 2 shows Sales and Purchases of Royal Philips Electronics.

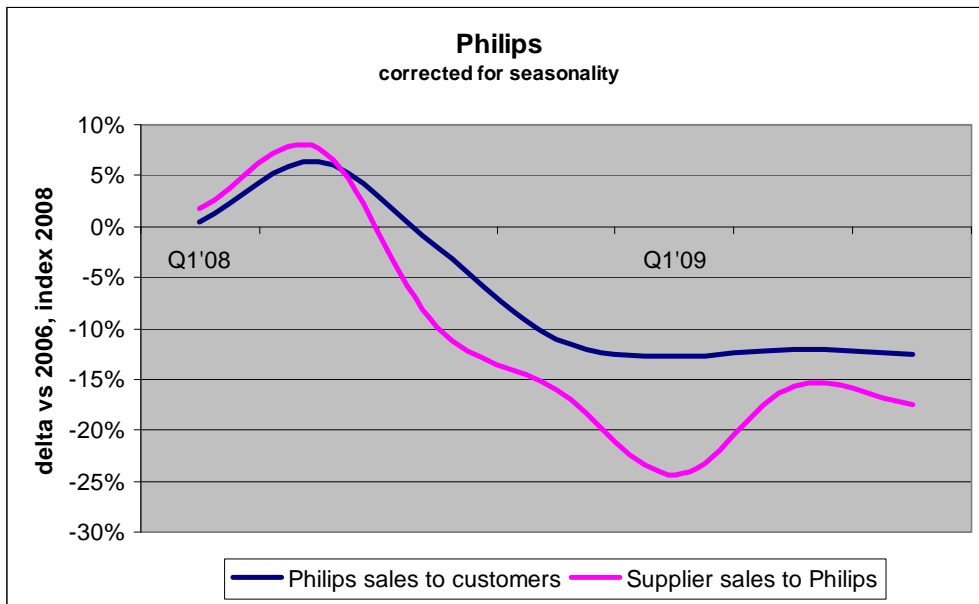


Figure 2. Philips sales and purchases (Based on data from Philips (2009), corrected for seasonality by taking the difference with same quarter, 2006 results)

While these data already show the general bullwhip effect occurring in 2007 and 2008, the data during the crisis period clearly show that where Philips’ sales dropped 20%, their purchases dropped more than 40%. Similar data can be observed in quarterly reports from other publicly listed companies. An analysis of a selected number of other publicly listed companies has been included in the Appendix.

2.3 Aggregate data

US Census collects data on sales based on a survey conducted monthly. Figure 2 shows US retail and US manufacturing sales between January 2007 and July 2009.

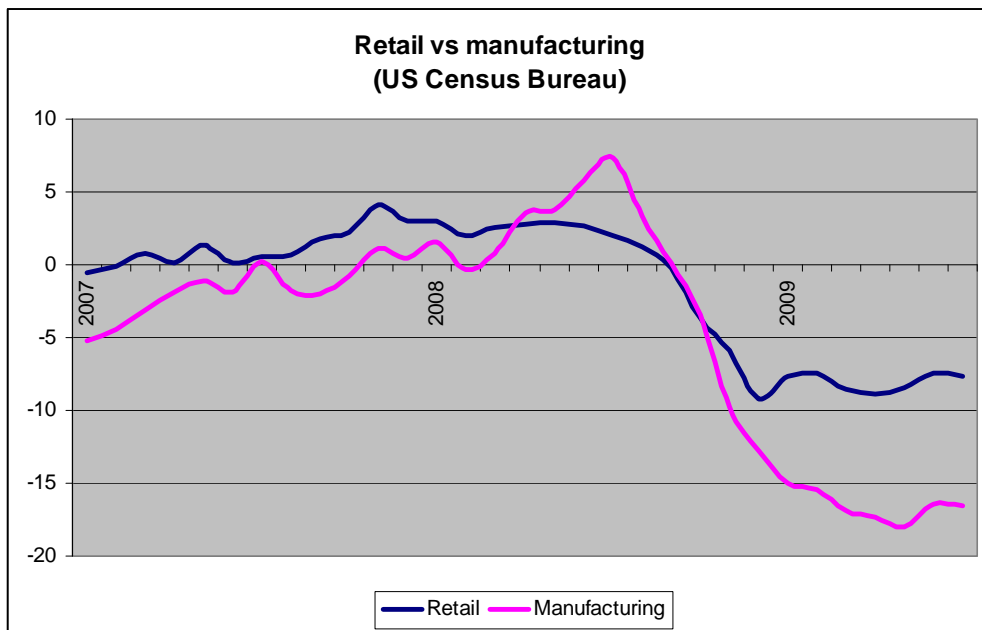


Figure 3. US retail and manufacturing sales (Source: US Census, downloaded 27 October 2009; seasonally adjusted, average of 2008 = 0)

The data in Figure 3 clearly shows that while retail sales dropped about 12% from September 2008 to the deepest point during the crisis, manufacturing sales dropped almost 30% in that period. The shapes of the curves are also different, with manufacturing sales showing a steeper decline extending over a prolonged period. We will further discuss this when presenting our model in Section 3.

2.4 Cross sectional survey data

In October 2009, we delivered a set of questions to the business survey of the newspaper *Brabants Dagblad*. Their area covers Noord-Brabant, a relatively highly industrialized region in the South of the Netherlands with about two million inhabitants. The survey was sent to about 500 companies in the manufacturing, wholesale, or retail industry, across all segments. We received a total of 125 usable responses to the specific questions we submitted.

We requested the companies to indicate what their position is in the supply chain (how many echelons from the consumer market), what their largest decrease in sales had been during the crisis, and what their sales level was at the time of the survey (October 2009). Figure 4 shows the results (Note: not all differences are significant).

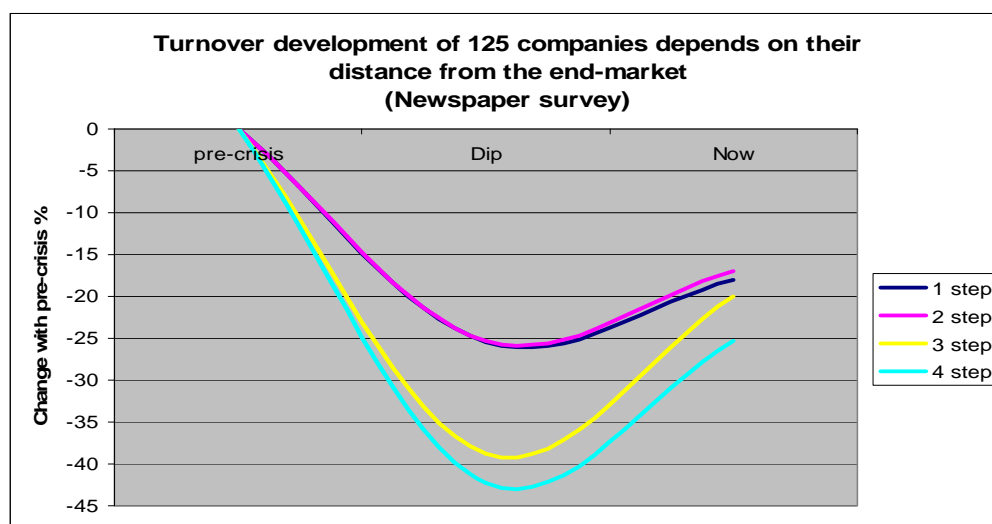


Figure 4. Revenues of 125 companies, dependent on the number of echelons from the consumer market.

2.5 Conclusions from empirical data

Empirical data from a wide variety of sources clearly provides supportive evidence for Hypothesis 2: *During the 2008/2009 financial crisis, the sales decrease at companies further upstream was higher than the sales decrease further downstream.* Furthermore, we have some evidence that inventories were depleted across the resin supply chain. As discussed above, inventory reductions across the supply chain can explain the phenomenon described in hypothesis 2. The pulse of simultaneous inventory reductions could have caused the substantial declines in sales experienced by many companies, with companies upstream in the supply chain experiencing a stronger decline. We will denote the resulting wave as the *Lehman wave*.

In the next Section, we will model the pulse and the resulting behavior in the supply chain. This will allow us to make the relationship between de-stocking and sales decline more explicit. We will validate our model using data from a variety of supply chains across a number of business units of Royal DSM. Our model and results will provide further evidence for Hypotheses 1 and 3.

3. Modeling the Lehman Wave using system dynamics

Inventory depletion along the supply chain following the credit crisis was largely caused by de-stocking. The first-order cumulative effect can be computed in a straightforward manner, as follows: at level l (with 0 being the most downstream level), the inventory reduction is the sum of inventory reductions at level 0 to l .

This first order effect however does not take into account a second-order effect, namely decision makers in the supply chain responding to lower sales levels from their customers and adjusting sales forecasts. If sales forecasts are adjusted, decision makers will be inclined to further adjust their inventory levels. When the inventory level reaches the desired (target) inventory level, they will start ordering again, causing an increase in orders placed upstream and, again, forecasting updating.

The main decision that a decision maker takes is how much to order. For this, we assume a base stock policy, i.e., the decision maker orders products in order to reach the desired inventory level (base stock level). The base stock level is updated by the decision maker such that it essentially reflects the desired coverage of demand (in time units) multiplied by the expected demand per time unit. We have modeled the expected demand as the average realized demand over the past eight time units, in this case: weeks. This implies both forecast updating and base stock level updating, which is a rather simplistic way of modeling the decision making behavior in the supply chain. However, the model is fairly robust since only a few parameters need to be set based on estimates of the actual supply chain.

Apart from the decision making behavior, the supply chain also contains delays for delivering products. These represent the lead times in the supply chain.

We have captured this behavior in a system dynamics model (Forrester (1961), Sterman(2000)). System dynamics modeling allows us to build a simulation model in which we can easily extend this basic decision making behavior across an entire supply chain, and hence model the behavior of decision makers that are influenced by decision makers at other echelons in the supply chain. The mechanics of our system dynamics model of each of the echelons are depicted in Figure 5.

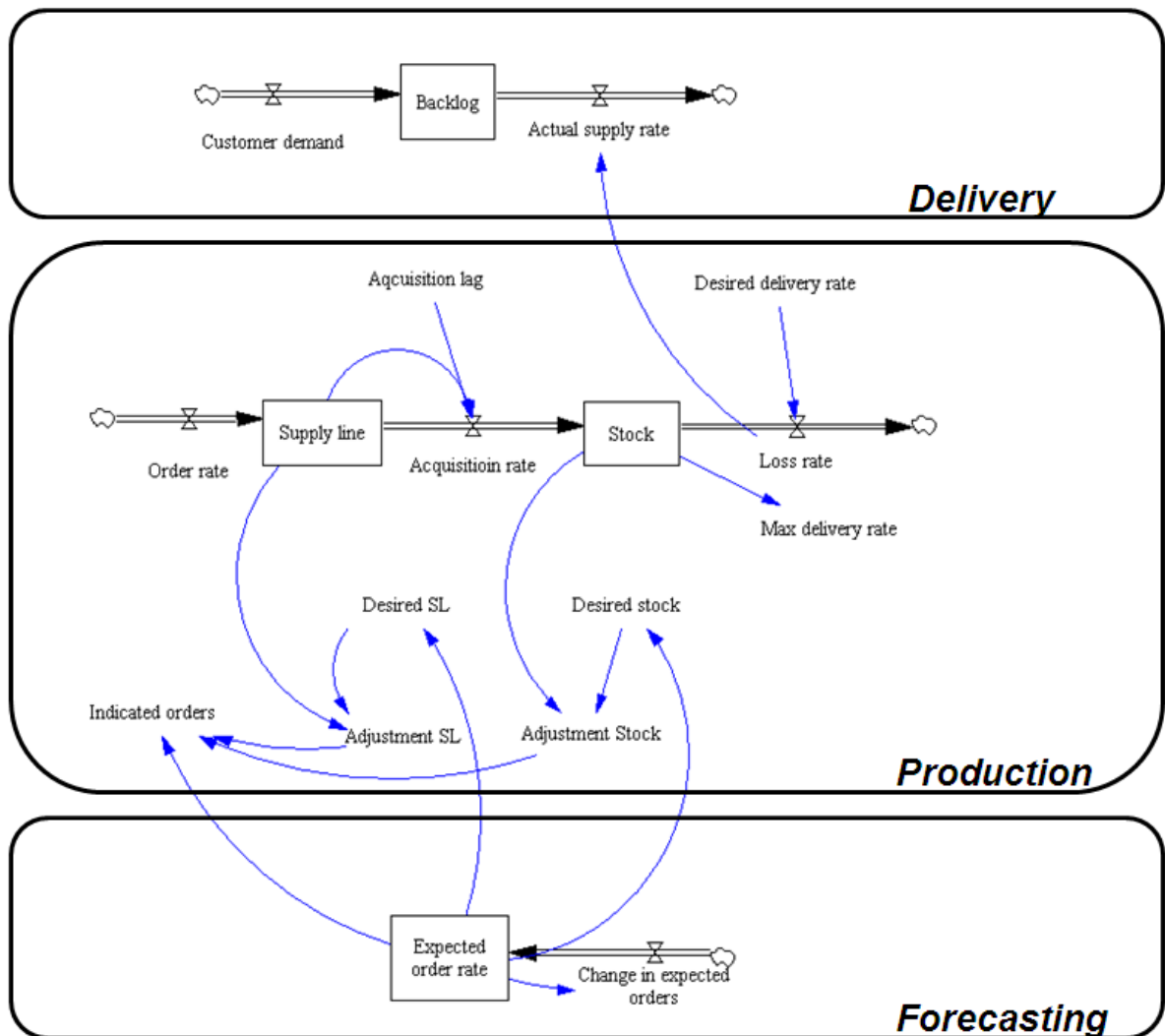


Figure 5. Single echelon system dynamics model

Using this single echelon model as a building block, we can now construct each arbitrary supply chain.

Apart from characterizing the parameters that determine the structure of the supply chain and its decision making as discussed above, we furthermore need to provide two types of additional input data for the model. These are the end market demand (realization and forecast) and the inventory reduction decision made at the various echelons in the supply chain. Both are exogenous to the model.

With this model, we ran a number of initial simulations to better understand the behavior along the supply chain. In Figure 6, we provide results of a sample run that demonstrates the bullwhip behavior occurring along the supply chain.

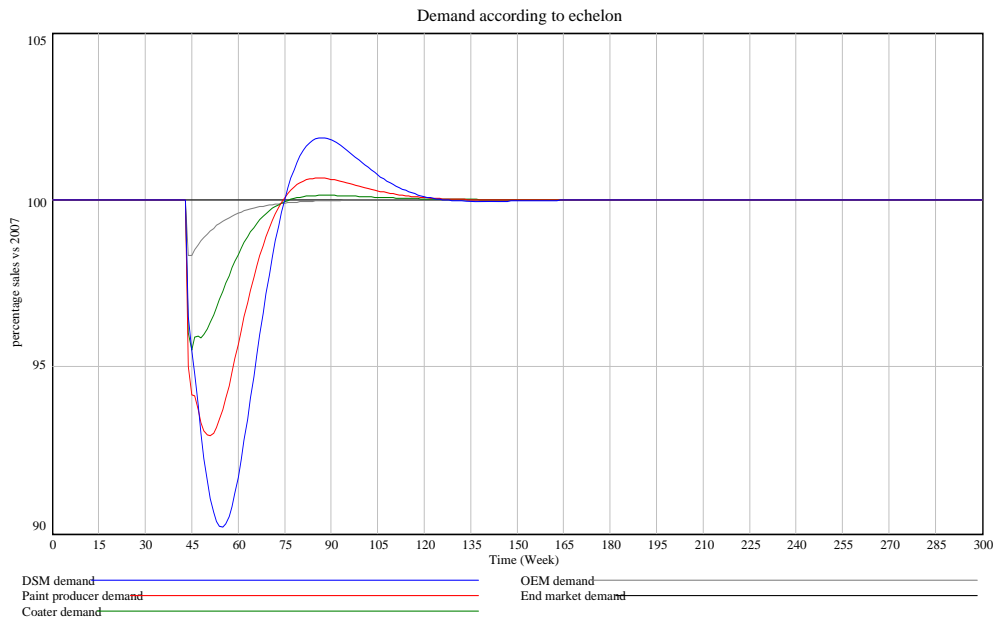


Figure 6. Sales level in a sample run of the 5-echelon resin supply chain under stable end market demand and a single inventory decrease across all supply chain echelons

In Figure 6, the horizontal axis is time in weeks, so in this case almost 6 years. The vertical axis represents the sales level. In this case 100% represents a situation of constant demand. The colors represent the various steps in the chain. Here we have entered a desired synchronous de-stocking of 10% in each echelon in week 44. This graph shows how the sales levels in the various echelons in a long supply chain respond to that. The cumulative nature of this response is clearly visible. The model also predicts an upward peak following the initial rapid decline of sales.

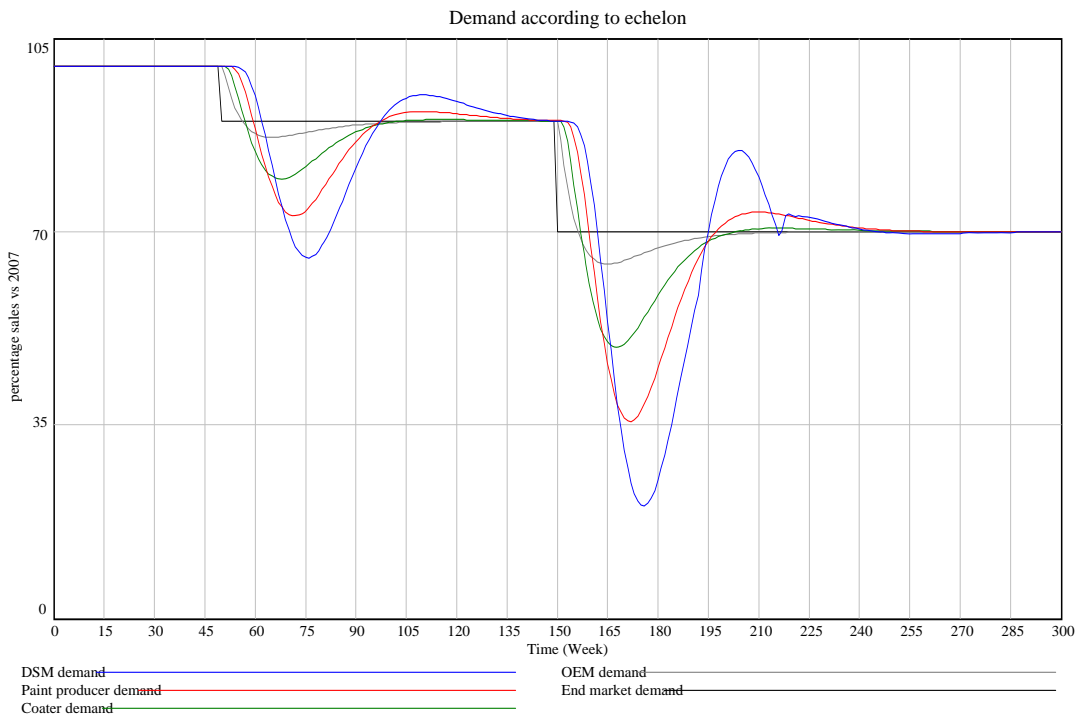


Figure 7. Sales level in a sample run of the 5-echelon resin supply chain under declining end market demand (in two pulse steps)

In Figure 7, the same model is used, with in black a sample end-market, including two instances of decline. This graph shows the cumulative response to market decline. It also shows that the wavelength of the curve does not depend on the amount of decline. While the model's sensitivity to the various parameters needs to be investigated more extensively and systematically, preliminary analysis has indicated that:

- The wavelength is primarily determined by the forecasting updating response times
- The depth of the trough and the height of the peak are primarily influenced by the length of the supply chain (cumulative lead time) and the total stock present in the supply chain (or the total amount of stock that is taken out of the supply chain due to the inventory reduction decision).

There are two types of de-stocking, which interact; we denote these as *active de-stocking* and *reactive de-stocking*, respectively. Active de-stocking is a conscious management decision to increase efficiency by setting sharper stock targets, either in volume or in stock turns. In the case of a company that is far removed from the end market, the combined decision of the echelons before them can easily result in the loss of 20 – 60 days of sales. Reactive de-stocking is the response by supply chain planners to lower stock levels if sales levels go down. This response is delayed over time. Both de-stocking actions interact and combine. In the model, active de-stocking constitutes a decrease in the desired inventory coverage (expressed in periods of demand). Reactive de-stocking is a result of forecast updating. When demand decreases, supply chain planners update their forecasts (as mentioned, we have used a simple moving average). Since the desired inventory level (base stock) is the product of the desired inventory coverage and the forecasted demand, a decrease in the forecast will lead to a decrease in stock. This is what we mean by reactive de-stocking.

Due to positive lead times, it takes some time before the actual inventory level reaches the desired inventory level. Once this has been reached, orders will start to increase again. This pattern interacts with patterns in end market sales. As a consequence, forecasts will be updated upward. Given the way that the base stock levels are updated, this implies that restocking will take place. In line with the terminology used above, we will denote this as *reactive restocking*. If end market sales do not increase, this will only lead to increased inventories, and will cause an upward peak.

4. Validation using DSM data

The analysis in this Section is based on actual business segments of Royal DSM.¹

In this paper, we include the results of models for three market segments. For each of the segments, we will show three graphs:

- the output from the system dynamics model as discussed in Section 3. This shows the modeled sales of the specific DSM segment, based on the model, i.e. including the supply chain structure with lead times, the end market (forecast) demand, the reduction in the desired inventory coverage, and the replenishment rules. The model demand is shown using a solid blue line.
- the actual sales by the specific DSM segment (dashed yellow line)
- the three-month moving average sales by the specific DSM segment (solid yellow line).

Figure 8 provides the modeled and actual sales to customers that supply several echelons further down to the construction markets. We have modeled that from 1 October 2008 onwards all players in the supply chain decided to reduce their desired inventory coverage by 10%. The end market data are

¹ It should be noted that each segment is only a tiny fraction of DSM's total business. Many of DSM's segments do not see these effects at all because the end markets involved do not decline, the chain is short, or there is no de-stocking. Hence, DSM does not view these curves as an actual reliable forecast of total business development for DSM. The curves here mainly serve to illustrate the validity of the system dynamics model in specific market segments of selected business units of DSM.

based on the prediction by Euroconstruct in December 2008 that the market would decline 10% in 2009 and recover in 2010. The blue line is the calculated model curve, using only data available in February 2009. The yellow curve was made in October 2009 and shows the actual DSM sales, 3-month moving average, corrected for seasonal impact by taking the difference with 2007.

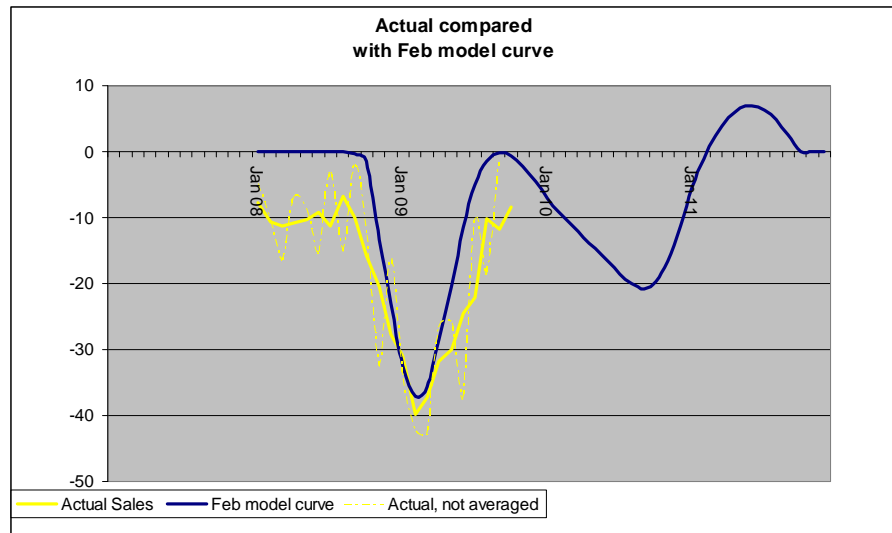


Figure 8. Modeled and actual sales curves in segment 1 supplying to construction market, based on construction market forecasts issued in December 2008

Note that the model accurately forecasts the timing of the trough in the sales curve in February 2009. The position of the trough is actually very robust to many of the parameters in the system, and is primarily a result of the structure and the decision making behavior in the supply chain. Furthermore, the depth of the trough has also been forecasted very well. Note that this depth is primarily dependent on the cumulative de-stocking (both active and reactive) and the decline in sales in the end market.

Later, it turned out that the construction market forecasts issued in December 2008 were too optimistic and an updated forecast was issued by Euroconstruct in June 2009. Figure 9 shows the same actual sales curves as Figure 8, but with an updated modeled sales curve, based on the updated construction market data. The updated modeled curve shows a stronger dip in 2009 and only little recovery in 2010 and 2011.

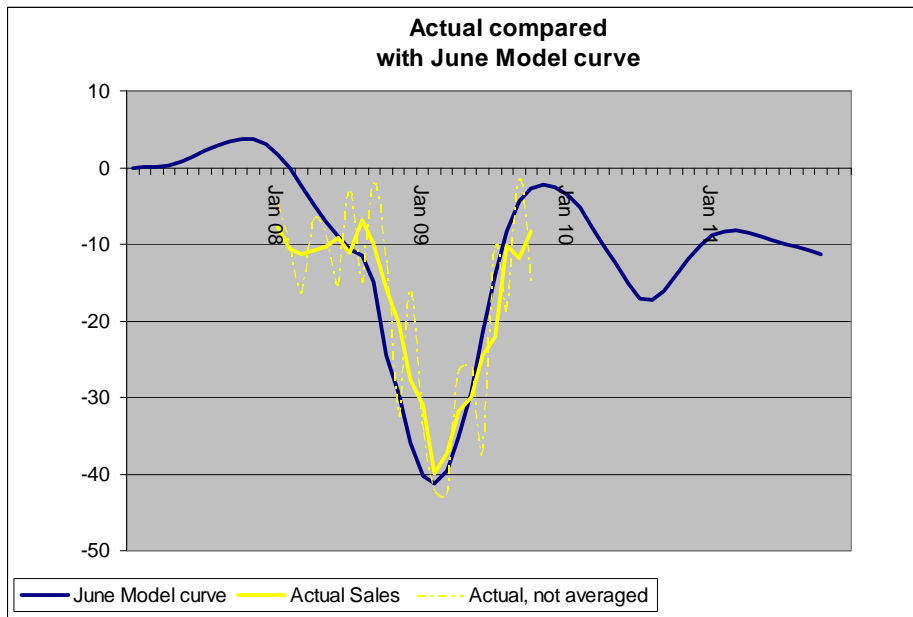


Figure 9. Modeled and actual sales curves in segment 1 supplying to construction market, based on construction market forecasts issued in the June 2009.

By considering the difference between Figure 8 and Figure 9, the impact of the updated end market data is made clear, and an even better fit of the modeled sales can be observed. Note that in neither case, the system dynamics model has been fitted to any of the actual DSM sales.

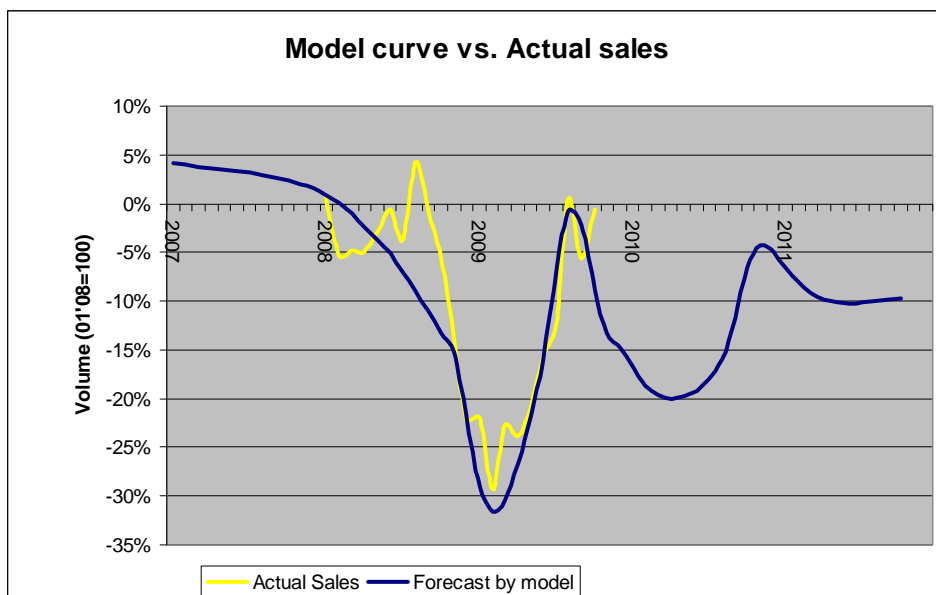


Figure 10. Modeled and actual sales curves in segment 2 supplying to construction market, based on construction market realizations issued by Eurostat in October 2009 and based on construction market forecasts issued by Euroconstruct in June 2009

Figure 10 shows market segment 2, which supplies into a different part of the construction markets via a different supply chain. The same de-stocking assumptions were made as in segment 1. The chain is shorter than in segment 1, which explains why the dip is less deep (less cumulative inventory in the supply chain and less reactive de-stocking due to forecast updating) and the peak is earlier and sharper. Figure 10 shows that the model predicts both the dip and the peak correctly.

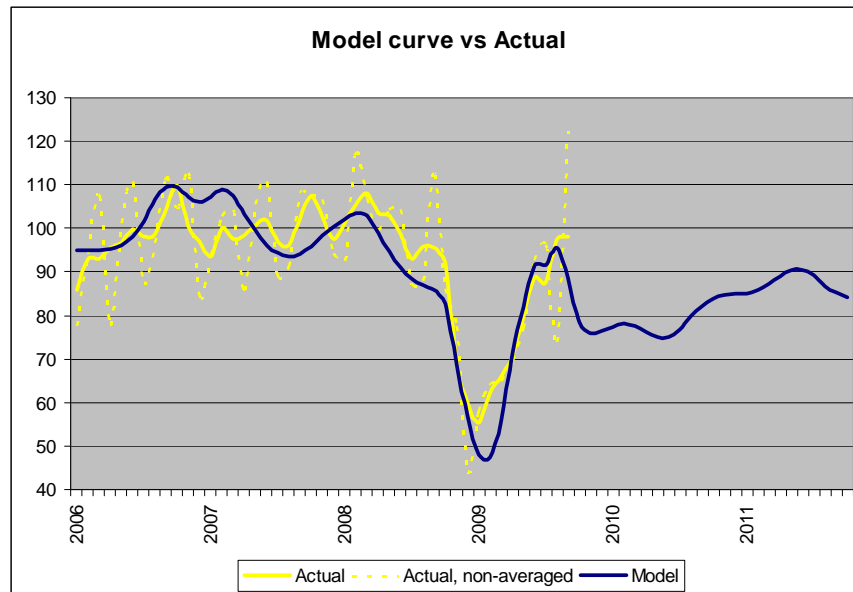


Figure 11. Modeled and actual sales curves in segment 3 supplying to furniture markets, based on market forecasts issued in June 2009.

Figure 11 shows market segment 3, which supplies to furniture producers. A small part of this segment follows the DIY end market, which is fairly stable; a second more substantial part is used in housing construction as described by the construction end markets; a third large part supplies the furniture supply chain, which ultimately also follows construction end markets. See Table 2 for the end market data and the shares that were used to construct end-market sales.

Table 2. End market segments in the furniture supply chain

<i>Supply chain</i>	<i>End-market</i>	<i>Share</i>
Retail DIY	DIY	5%
Residential & Non-residential construction	Construction	55%
Furniture OEM	Construction	40%

The same de-stocking assumptions were made as in segment 1. End market data are derived from a combination of Eurostat and Euroconstruct data (June 2009). Again, the model performs well in terms of the position and level of both the trough and the peak.

The model is able to predict reality because the economy as a whole is riding on a giant wave, caused by the bankruptcy of Lehman Brothers. We denote this wave as the Lehman wave. The Lehman wave is dampened, because all companies take time to respond to changes in demand. Like any other wave, the Lehman wave has a wavelength, which is determined by the medium in which it oscillates, in other words by the parameters of the supply chain. The amplitude of the Lehman wave is determined by the force of the pulse that caused it. So immediately after the Lehman wave had been triggered, its course was determined. The system dynamics model acts as an algorithm that accurately describes and predicts the Lehman wave.

5. Discussion, conclusions, and insights

In this paper, we have demonstrated how a relatively simple system dynamics model can explain the complete sales pattern across a number of business units and segments of a company relatively upstream in the supply chain. The model we have developed only uses the forecast of some crucial end markets, and structural characteristics of the supply chain. The model does not do any econometrical

model building or fitting, nor does it use any general market data for the customer segments that a company like DSM *directly* ships to.

A key element in the model is the assumption that all companies worldwide simultaneously decided to reduce their inventories following the collapse of Lehman Brothers on September 15, 2008. The collapse of Lehman Brothers cause a huge pulse in all supply chains worldwide. In a supply chain with a delay effect, a pulse causes a wave, the Lehman Wave. Similar to the bullwhip effect in supply chains, the amplitude of the Lehman Wave is larger for companies situated further upstream in the supply chain. The further upstream a company is situated in the supply chain, the less its sales decline can be explained by a sales decline in the end market, and the more it is due to de-stocking along the supply chain.

The insights provided in this paper provide a novel way of predicting how companies need to deal with market information and market intelligence when markets are not stable, such as during the current financial crisis. We suspect that the suggested behavior may also be true during less rampant times, when fluctuations in the overall economy drive inventory and forecasting decisions.

For companies, the insights from our model suggest a number of important issues to take into account when making important supply chain decisions, such as shutting down or reopening factories and reducing or increasing inventory levels. First, we believe it is essential for companies to really know their end markets. Based on our discussions with many companies, it appears as though market intelligence at the tactical level tends to be focused on analyzing the markets for the products that a company makes (in our example: resins), rather than on the end markets where these products are consumed. At the strategic level, for instance for product development or technology strategies, analyses further downstream are made more often, but typically only looking at general data such as total market size rather than at time series of how markets develop. Second, our results also show it is important for any company to have an understanding of the general stockpiling or de-stocking policies occurring in the industry. There is a need for reliable and specific inventory statistics. In the US, US census collects such statistics, and potentially these could provide such insights. In Europe, inventory data are not collected and companies are in dire need of such data to help them make better decisions. Third, a relatively simple system dynamics tool helps to fairly accurately predict sales cycles. It pays to invest in developing such a model; if only because this requires market intelligence officers in a company to develop a real understanding of their supply chain structure.

At Royal DSM, so far the model has been used extensively in the waterborne resins business unit (DSM NeoResins+). The management has reflected on their handling of the crisis using the model as follows (reported in November 2009):

During the whole crisis an intense and constant communication flow was maintained in the company in which all 1250 colleagues were kept informed about the crisis and the measures that were being taken. The management set out on a quarterly road show, visiting 10 locations in different parts of the world, and addressing each of the employees. People were encouraged to stay calm and work together in cross-functional teams. Management letters, blogs, Q&A coffee meetings and various newsletters were issued to provide everybody the latest news in a very open way. The organization was asked to focus on only three things: Safety, the Customers and Cash is King. The employees were warned that economic growth would be slower in the years ahead of us, and that the crisis would be long, deep and W-shaped. The Key Accounts were approached and visited by the BU Director to see what DSM could do to support them in this difficult period.

The crisis was approached in three Alarm Phases. In each Phase the amount of cost reductions would become more severe, but only in Alarm Phase 3 would the cost cutting impact on the market oriented organization and thereby endanger our long term strategy. Crucial is that the knowledge about the Lehman wave gave the organization the determination to delay implementation of Alarm Phase 3 for as long as possible. In October 2008 we entered Alarm Phase 1: we decided to re-organize our non-

core business, while leaving our core segments intact. In our core production units only minor measures were taken, which could quickly be reversed when needed.

Since we knew that it is very hard to find the highly trained people we need in our complex technical environment, we ensured that all engineers and other key experts were kept on board and were dedicated to crisis related projects. We also realized that the market facing organization will be crucial in getting us out of the dip, so this organization was not touched. So most cost cutting was done in non-core business, in overheads and in expenses.

Because Royal DSM is a financially solid mother company, and because we could show the temporary nature of the sales dip, the DSM Managing Board decided that our Innovation program as well as our investment programs should be continued. We redirected part of our innovation to the markets stimulated by governmental incentive programs. In March we opened a new waterborne acrylic factory in Waalwijk (Netherlands) which gave us a large capacity expansion in one of our crucial product lines. When demand picked up, we benefited greatly from this abundant capacity. The investment for another factory, in Meppen (Germany), also continued and will come on stream at the end of 2009.

The insight from the Lehman wave was included in the Sales & Operations Planning (S&OP) process. We found that the sales forecast that is normally used for S&OP purposes was completely unreliable during the crisis, as our sales managers and our customers also didn't know what to expect. Instead, management made estimates about future demand based on considerations derived from the Lehman wave. The supply model partially changed from Made-to-Stock (MTS) to Made-to-Order (MTO) to create more flexibility.

In January 2009 it was decided to implement the first part of Alarm Phase 2, with closures of a site and reduction of some product lines. The second part of Alarm Phase 2, with further closures and dismissal of support staff, was postponed in the hope that business would recover as predicted. In the same hope, as from April 2009 we started in advance of market pick-up to rebuild the stocks which had been reduced the previous 6 months. The resulting stock position was not good enough to prevent all supply problems in the second half of the year, but the problems would have been much larger had we not started so early. For some crucial raw materials we covered the anticipated higher demand a year in advance and therefore could benefit from price as well as availability during the initial phase of demand pick-up in the market.

When we found in July-September 2009 that sales indeed recovered completely as forecasted by the model, the implementation of the second part of Alarm Phase 2 and Alarm Phase 3 was put further on hold.

During the crisis a downturn cannot be avoided, but the key was to be impacted less than the competition. We saw this crisis as a once-in-a-life time opportunity to improve market position and take a leadership position. In line with the overall strategy of Royal DSM, we believe that companies with long term vision and cash reserves, companies that stay the course, are in the best position to emerge from the crisis stronger. In a preliminary benchmark study we found that we have indeed done relatively well.”

Since the summer of 2009, the modeling effort at DSM has been extended to include other business units, and the Managing Board has mandated more extensive work to build comprehensive models to deal with future dynamics and economic cycles.

DSM's response can be summarized in the dos and don'ts as included in Table 3.

Table 3. General Dos and Don'ts

<i>Don't</i>	<i>Do</i>
Overreact	Flexibilize
Close factories	Communicate across the supply chain
Cut innovation	Make plans based on scenarios
Fire crucial people	Cut cost
Stop marketing communication	Continue M&A

A general question that remains is to what extent the theory put forward here can be extended to the world economy, beyond individual supply chains or companies. As discussed in Section 2.3, some of the aggregate data does suggest that the effect can also be observed at the aggregate level. Kuipers (2006) has conducted some initial work on how to better include stockpiling and de-stocking into econometric models of trade, but in general it appears that in economic theory inventories are seen as a correction to estimates rather than major causes of economic waves. A recent study by Van Leeuwe (2009), conducted at Rabobank and initiated on the basis of the insights presented in our paper, provides some initial econometric evidence that credit limitations had barely any direct impact on the economic downturn. However, indirectly (as a mediator on inventories), credit limitations have had considerable effect, with inventories explaining a substantial part of the decline in world trade. Further studies need to be conducted to better understand the aggregate behavior of the Lehman Wave. It is likely that more extensive inventory statistics would need to be collected. In any case, the appalling lack of aggregate reliable inventory data in Europe certainly does not facilitate such research.

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Appendix. Variance amplification based on publicly reported data
 (source: quarterly reports of respective companies)

