



International supply chain agility

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Tradeoffs between flexibility and uncertainty

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Abstract *Firms operating in an international environment face a host of uncertainties that make it difficult to meet deadlines reliably. To be reliable in an uncertain and changing environment, firms must be able to quickly respond to changes. The ability to do this in a useful time frame is called agility. Unfortunately, measures taken to increase agility often lead to increases in complexity, which works against agility. We propose a theoretical construct linking elements of uncertainty with aspects of agility, pointing out the two-edged nature of the requisite capabilities. We illustrate our points with examples from five case studies.*

Firm-level responses to an uncertain international environment

Supply chain agility

The Agility Forum has defined “agility” as the ability of an organization to thrive in a continuously changing, unpredictable business environment. Simply put, an agile firm has designed its organization, processes and products such that it can respond to changes in a useful time frame (Agility Forum, 1994).

Despite the obvious benefits of agility, firms that operate in complex environments such as international markets, face challenges in implementing the measures necessary to increase their agility. These challenges stem from the expense associated with the complex operations and management structures necessary to support the desired attributes. For example, it may be difficult for an intercontinentally operating firm that ships components or products by sea to serve niche markets with individualized goods. Moreover, it may be difficult for this firm to promptly react to changes in demand. Hence, unless the firm is willing to significantly increase its administrative and logistics costs (e.g. for coordinating all parts of its value and supply chains), it may be forced to take counter-agile actions in order to remain competitive, and limit its vulnerability in the marketplace.

In an international environment, the supply chain often is the part of a firm that is most severely affected by changes. The firm’s international supply chain

frequently limits performance along many traits usually associated with agility. For example, it may be hard to adjust the structure or geographical set-up of a supply chain to react to changes in the manufacturing or political environment if the firm has plants in more than one continent. In such cases, supply chain agility may quickly become the limiting factor of a firm's overall agility.

To define the term "supply chain agility", we first discuss the terms agility and supply chain. Two concepts inherent to the definition of agility are:

- (1) speed; and
- (2) flexibility.

In the context of this paper, speed is a measure of the time it takes to ship or receive a good. Flexibility is the degree to which the firm is able to adjust the time in which it can ship or receive goods. Flexibility may be broken down into two capabilities:

- (1) the promptness with; and
- (2) the degree to which a firm can adjust its supply chain speed, destinations, and volumes.

The supply chain may be broken down into three basic segments:

- (1) sourcing;
- (2) manufacturing; and
- (3) delivery.

The combination of these supply chain segments on the one hand and speed and delivery on the other hand leads to the definition of supply chain agility (see Figure 1). In particular, the degree to which a firm's supply chain is agile is determined by how its physical components (i.e. sourcing, manufacturing and delivery) are configured to incorporate speed and flexibility. As the levels of speed and, more importantly, flexibility increase, the level of supply chain

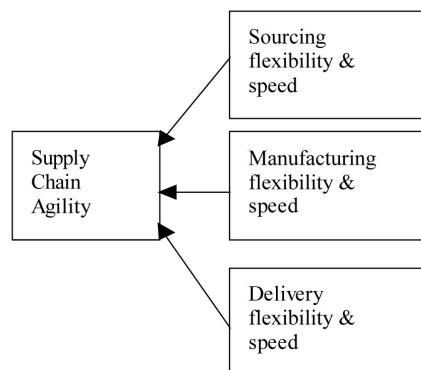


Figure 1.
Supply chain agility

agility increases. The firm can, to a certain degree, make up deficiencies in the speed or flexibility of one of the supply chain parts by excelling in the other two. For example, the delivery part of the supply chain may be inherently inflexible, such as is found in sea transportation (i.e. the speed is low). Supply chain agility may be increased if the firm is able to compensate for this shortcoming by setting up its inbound logistics (i.e. sourcing) or manufacturing operations to be fast or flexible. As the speed in outbound logistics is inflexible, speed and flexibility in manufacturing and sourcing could help compensate for the slow outbound transportation.

If a deficiency is serious enough to limit supply chain agility, the firm becomes vulnerable to competitors and customers. Two types of vulnerability exist:

- (1) internal vulnerability; and
- (2) external vulnerability.

Internal vulnerability is a result of a lack of internal supply chain agility (Houlihan, 1987; Forrester, 1962). That is, the manufacturing segment of the supply chain. In this paper we focus on external vulnerability, i.e. the inbound and outbound logistics part of the supply chain, as it is a major factor determining the degree of agility of firms operating in international environments. The degree of external vulnerability is influenced by two related factors: complexity of sourcing and delivery and uncertainty in demand or forecasting (see Figure 2).

Dealing with vulnerability of the supply chain

To illustrate the effect of demand or forecasting uncertainty, consider the “bullwhip effect” (Lee *et al.*, 1997), illustrated by the following scenario. Firm S supplies components for final assembly to the factory F. Factory F estimates demand based on several factors, including past and current sales. In turn, supplier S forecasts its demand based on factory F’s orders. Naturally, there is an error in forecasted demand. The error, however, is greater in supplier S’s forecast than in factory F’s forecast. Moreover, the less accurate F’s forecast is,

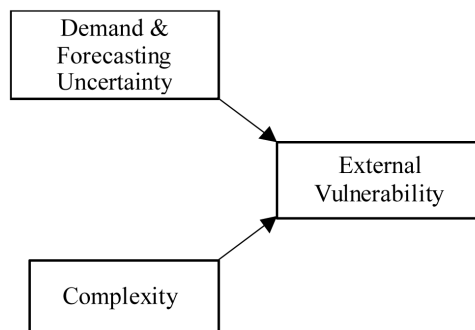


Figure 2.
External vulnerability of
the supply chain

the more inaccurate is S's forecast. Obviously, the more parties are involved in the supply chain, the greater the eventual impact of forecasting errors.

A typical response to uncertainty is to build flexibility into the supply chain. The firm's ability to adjust its supply chain to changes easily allows it to postpone delivery for some time. Postponing delivery results in more accurate data because a shorter forecasting horizon increases the reliability of information (see Van Hoek *et al.*, 1998; Weng and Parlar, 1995). The potential to increase flexibility, however, depends on environmental, organizational, and technical factors. For example, to take advantage of a postponement strategy, the firm must be able to exchange information frequently and reliably with its customers and outbound logistics partners. Moreover, its manufacturing operations must be organized so that orders can be filled in minimal time (e.g. short manufacturing lead times or sufficient inventory). Measures taken to increase flexibility, however, may be very costly. Most important, if these measures also necessitate an increase in complexity of management, coordination costs may drastically increase. This scenario is particularly relevant when the supply chain extends over multiple geographical regions or countries (Levy, 1992; Forrester, 1962).

International supply chains are complex, dynamic systems that are subject to large time-lags and variability in delivery. Complexity may arise from physical distances. Long distances usually increase transportation and order lead and the order lead times and (Stank, 1997) decrease the reliability of demand forecasts (Ho, 1992). This, in turn, increases the uncertainty with respect to production schedules, orders to suppliers, and the likelihood of meeting demand (Swenseth and Buffa, 1991). The firm has the choice of:

- (1) dealing with the resulting uncertainty;
- (2) implementing costly coordination mechanisms (i.e. increasing flexibility); or
- (3) limiting complexity by restructuring the supply chain.

Purpose of this paper

Supply chain agility is a crucial factor at the strategic level. Since successful supply chain management has become an order winner, the agility of the international supply chain may determine the survival of a firm (Vastag *et al.*, 1994); so delivery speed has become one of the main reasons for restructuring the manufacturing function (Colins, *et al.*, 1990). However, most research on agile manufacturing has overlooked supply chain management issues in general and logistics in particular (Vastag *et al.*, 1994). This is surprising considering that the integration of the supply chain into design and management decisions is critical to the success of a global, responsive manufacturing strategy (Fawcett, 1991). For example, the integration of the internal capabilities of firms, suppliers and customers can enhance manufacturing performance and the agility of an organization (Youssef, 1991a,

1992b) . Clearly, we need to investigate the limitations of supply chains to offer advice to firms on how to limit their vulnerability.

Unfortunately, the literature does not give helpful advice on how to deal with supply chain vulnerability either. While some research deals with complexity issues pertaining to general logistics, the results of that research are not always applicable to planning an agile international supply chain. Moreover, the literature does not give guidance on how much uncertainty can and complexity should be reduced. Or, in other words, what aspects of agility should a firm limit in order to reduce the complexity and uncertainty of its supply chain. Therefore, in this paper, we use case studies to show how firms have successfully made a tradeoff between vulnerability and supply chain agility. Then we illustrate how our concept can be used in judging the degree to which a firm should implement supply chain agility. Finally, we draw our conclusions from the concepts and experiences presented in this paper.

Limits on agility

Recall that uncertainty and complexity increase external vulnerability. That is, by decreasing uncertainty and complexity, a firm may lessen the potential harm to its operations and position in the market. However, in certain circumstances, the introduction of factors that increase supply chain agility may increase supply chain uncertainty and complexity. Examples of such circumstances are the extension of the supply chain over more geographic regions or political regions to serve niche markets and extending the number of internal and external cooperation partners.

In other words, as flexibility and complexity determine the external vulnerability of the supply chain, they essentially limit the degree of agility a firm can and should attempt to achieve. Thus, as external vulnerability increases, supply chain agility should decrease to limit complexity and uncertainty. We refer to the relationship between external vulnerability and supply chain agility as supply chain exposure (see Figure 3). Supply chain exposure indicates the degree to which an agile supply chain is “overextended” and, consequently, should be restructured, improved, or adjusted in length.

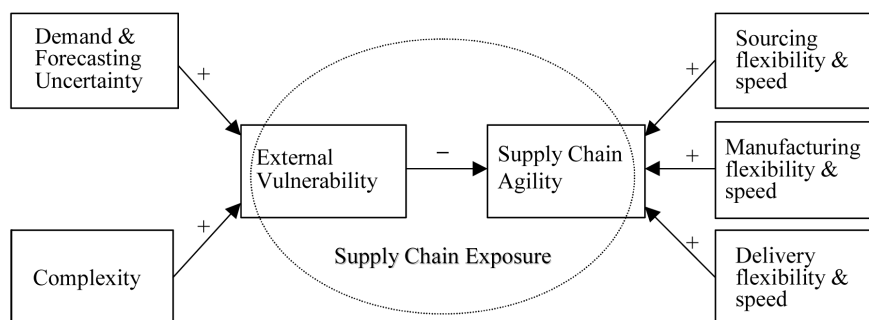


Figure 3.
The concept of supply
chain exposure

Factors of supply chain exposure

The degree of supply chain exposure depends on a number of factors. For example, a firm operating in developing countries may not have the information systems or road/rail/water connections it would need. Or, cross-border traffic may be subject to bureaucratic delays, just to name a few of the possible obstacles. The factors contributing to exposure can be categorized as follows.

- *Extent of geographic areas covered by the supply chain.* Specific geographic areas can have distinct transportation problems. For example, transporting goods across the Ural Mountains to Western Europe is best done by rail since the distances and mountains make it difficult to transport goods easily by truck. On the other hand, for moving goods from Southeast Asia to North America there are only two choices: via sea or air. Shipping by air is faster but more costly than shipping by sea. Even within an area such as North America, which has an excellent integrated road network, shipping goods by truck across the continent involves risks due to the road network's perpetual state of reconstruction and the continent's notoriously variable weather. Logistically difficult geographic regions and the number of regions covered by the supply chain increase uncertainty and supply chain exposure.
- *Political areas and borders crossed.* Each political area or border that a supply chain must cross can pose problems. On one hand, there is the issue of political instability within an area. This is defined as "events", or a series of events that can affect the physical assets, personnel, and operations of foreign firms (Jodice, 1984). (This is a mature area of study and there is a wealth of literature on this topic including Kelly (1983, Gould (1983), Kobrin (1982, 1983) and Grub (1993)). However, even in a politically stable environment, there is also the issue of border controls. For example, while the EU nations have eliminated border controls to allow smoother passage of goods, standardization of procedures and requirements has not been implemented in Eastern Europe. This contributes to increased complexity, uncertainty and supply chain exposure.
- *Number of transportation modes and their speed.* Intermodal transport adds complexity and delays to the supply chain. Although this process has been greatly simplified and speeded through the use of containers designed to be carried, for example, by ship, train, and truck, there are still delays and the potential for error. A particularly outstanding case of *de-facto* intermodal transport is the gage change necessary to allow railway cars to operate both in the former Soviet Union and its neighbors. In this case, the goods are not transferred between modes but a single mode is reconfigured with the inevitable delays, which was, interestingly enough, the purpose of changing the gage in the first place.

Speed is usually inversely proportional to the cost and volume of products that can be shipped. For example, as the firm moves from sea to rail to truck to air, the speed of transport and its cost increase while the total volume of goods that can be transported decreases. Slow modes of transportation coupled with long distances contribute to a low flexibility and, hence, increase uncertainty and supply chain exposure.

- *Technical infrastructure and its degree of use.* Some countries lack the technical and communications infrastructure to allow firms to operate efficiently. For example, in many developing countries, the telecommunications infrastructure limits the ability of firms to exchange information via voice, fax, or computer. This constrains the standard operating procedures of most firms by decreasing flexibility and increasing uncertainty. Hence, the more primitive the technical infrastructure, the greater the supply chain exposure. The degree of use recognizes that, although a technical infrastructure may be in place, the actual extent of use of the infrastructure by firms in a particular area or industry can limit the ability of a firm to exploit the potential of the infrastructure. In this case, it is often necessary for an influential firm in an industry to insist that its suppliers adopt procedures such as EDI in order to “get the ball rolling.”
- *Random occurrences.* Some events are beyond control, such as earthquakes, floods, avalanches, etc. Other random occurrences can be foreseen but not avoided. For example, if a firm moves goods from Southeast Asia to North America by sea, the typhoon season always affects transport times since ships must avoid the storms. Therefore, a long distance covered with a mode that is subject to “acts of God” increases uncertainty and, thus, supply chain exposure.

It should also be noted that the factors mentioned in this list interact with each other. For example, in general, the greater the geographic extent of the supply chain, the more the chain is vulnerable to random occurrences. If the chain crosses a wide body of water, intermodal transport will be used. The use of a telecommunications infrastructure can mitigate the effects of random occurrences and political instability by, for example, providing advance notice of bad weather, road closings, and political unrest.

From this list it becomes clear that, with an increase in a firm’s supply chain exposure, it becomes more likely that the supply chain is a limiting factor of the firm’s strategy and operations.

Expressing the degree of exposure

To estimate the degree of exposure, a simple system can be used, as shown in Table I. In that table, the above factors are rated and added to arrive at a total measure for supply chain exposure. Note that the rating system shown is only an example and may be modified to suit a firm’s specific needs and circumstances.

Table I.
Measure of supply
chain exposure

Exposure factor	Geographic area covered by supply chain	Transport modes used	Political areas and borders	Technical infrastructure	Environmental issues	Risk of supply chain exposure
Degree of exposure	Difficult	4 Slow	4 Many	4 Bad	4 Serious	4 14-20
	Medium	2 Medium	2 Few	2 Fair	2 Some	2 7-13
	Easy	1 Fast	1 None	1 Good	1 Negligible	1 5-6

For example, if a firm's international supply chain covers a number of geographic areas extending over few political borders (ratings 4 and 2 respectively), it can use only slow modes of transport (e.g. long-haul sea freight, rating 4). If it is not coordinated by an IT system (rating 4), but does not have to deal with any serious environmental issues (rating 1), then the risk of supply chain exposure is in the high range. Consequently, if the firm wishes to increase its level of supply chain agility, measures should be taken to decrease external vulnerability. Since in most cases the geographic area, number of political borders, or environmental issues cannot be influenced by the firm, transport modes and technical infrastructure may need to be altered. For example, implementing at least a standard IT system would already decrease the overall exposure to the medium level.

To illustrate the concept of supply chain exposure, in the following section, we present cases that show how firms have dealt with the complexities involved in international supply chains. The first four cases point out how firms successfully exchange agility for reduced complexity in order to reduce their supply chain exposure. The last case illustrates how excessive supply chain exposure can have negative consequences for a firm's operations.

Case studies

These cases illustrate the international supply chain issues faced by four companies. Four case studies stem from interviews with companies conducted in the spring of 1996. The other case study (Apple Corporation) is adapted from Levy (1992). The cases (as well as other interviews not detailed in this paper) pointed out two main problems faced by firms in Europe. First, accurate forecasting is the key issue in supply chain management in Europe. Second, firms face a difficult task of successfully developing a supply chain structure that will meet their needs for agility.

General Electric Lighting (GE)

When the Eastern European markets were opened, GE was one of the first Western firms to move in, buying 75 percent of the Hungarian lighting company Tungsram. After two years of ownership, Tungsram had reduced its employee rolls by 50 percent and was turning a profit. GE now uses the Hungarian plant to supply light bulbs to the European market. GE outsourced its European transportation requirements but retained control of warehousing. It centralized warehousing in a single facility in Metz, France, which has direct access to multi-modal links. Its transportation provider, Danzas, is responsible for preparing the load, providing transport papers, loading the trucks, and delivery receipts. While GE also uses regional transport contractors (e.g. Tanzal in Switzerland), these others must work with Danzas. Interestingly, GE has no computer links with Danzas. Instead, Danzas employees have offices in the GE facility to expedite information flow. As another method of "facilitating" communication, GE capital owns part of Danzas. This allows GE to have direct input into Danzas' operations.

The complexity issue with which GE had to deal concerned flexible delivery scheduling. Once GE had created its single warehouse out of facilities in Germany, Austria, France, Switzerland and the Benelux region, it realized that each affiliate had set up special delivery plans with local customers. This provided a key agility feature, namely individualized goods and services. However, meeting customized demands from one facility greatly complicated GE's operations. GE ran inefficiently or was not able to reliably meet delivery times. GE therefore decided to drop its just-in-time (JIT) delivery approach in favor of scheduled delivery. Customers can still change orders up to two days before delivery. However, the scheduled delivery allows GE to achieve a better utilization rate of its equipment and lower its transportation costs. It can also ship larger volumes with fewer workers.

In essence, as a first step, GE reduced complexity by consolidating warehouses and outsourcing logistics. This, however, left GE still vulnerable because of the forecast uncertainty. As a second step, uncertainty was decreased through increasing lead times and introducing a frozen time horizon of two weeks for orders. In return, GE's customers profited from more reliable order delivery. The tradeoff: a short lead time with maybe 80-85 percent delivery reliability for a longer lead time and 99 percent reliability. Such a method of balancing functional objectives is also suggested by Houlihan (1987). In conclusion, GE substantially decreased its external vulnerability while increasing the reliability of its delivery time, thus reducing the external exposure of its customers.

Hewlett Packard and Fraure Machette

Hewlett Packard (HP) developed an innovative approach to dealing with transportation uncertainties within Europe. HP centralized its manufacture of printers to one facility in Holland that supplies all of Europe and North Africa. The printers are designed so that all components that differ regionally (e.g. the power supply, cables, and manuals) are add-ons to the basic printers. This design allows HP to customize the goods once an order has been received by packaging the printer along with the appropriate set of add-ons (referred to as co-packaging).

Since logistics is not one of HP's core capabilities, the company outsources its transportation and distribution to Fraure Machette (FM), a French firm. All printers and components are shipped to FM's warehouse in Metz, France. FM's information system is tied into HP's system so that both firms know what orders are expected and the current levels of inventory. When HP receives an order, it "releases inventory" from FM's warehouse. FM co-packages the printers and the add-ons according to the order specifications and ships the product.

HP has reduced its supply chain exposure and decreased vulnerability by limiting uncertainty due to fluctuating requirements for transportation. Uncertainty was also reduced by designing the product appropriately so as to customize it only once individual orders arrive. This strategy is referred to as

postponement and is a crucial part of time-based competition within an international logistics structure (Hise, 1995). It is further interesting to note that recent research by Sutcliffe and Zaheer (1998) found that supplier uncertainty tended to drive firms to vertically integrate. HP was able to achieve the benefits of vertical integration without purchasing firms in the value chain. HP has also reduced its vulnerability by the decreasing complexity of its operations. Yet, HP has retained control of operations through the linkage to FM's information system.

Clearly, operating a central warehouse contradicts the agility maxim of decentralized control. Speed and flexibility inherently suffer from a centralization of facilities. However, HP has maintained a certain level of agility by using FM as a potent logistics partner and linking its databases with FM's facilities. FM willingly accepts the uncertain demand for transportation. Transportation is its core capability and the company has ways of dealing with problems. FM can quickly staff up to meet unexpected demand by hiring temporary workers or by outsourcing to select carriers. FM and HP are now discussing moving beyond co-packing to a co-manufacturing arrangement in which FM would provide expanded final assembly capabilities for products.

Pioneer Hi-Bred

Pioneer Hi-Bred is one of the largest seed producers in the world. Even before Eastern European markets opened, it set up facilities in Eastern Europe so as to gain access to the "fertile" farming market. Pioneer Hi-Bred now has a facility in Budapest, Hungary, and is grappling with the supply chain issues specific to Eastern Europe. The main issue is the difficulty of transporting goods in Eastern Europe, where roadways, in many cases, are in bad condition, railways and railcars are not standardized to Western European gauges, the information systems and communications infrastructure is limited, and regulations change at each border. In addition, Pioneer Hi-Bred's product and yield is directly affected by the unpredictability of the weather.

To reduce complexity on the inbound logistics and production side, Pioneer Hi-Bred (PH) changed its operational structure. Usually, PH buys the land, grows the crops and then harvests and transports the goods itself. In Hungary, however, it contracted with farmers to grow and harvest the grain and to deliver the harvest to its storage facility. In return, PH signed contracts and guaranteed the farmers a minimum income regardless of the level of the harvest. PH uses its large capital resources to reduce the inescapable risk that farmers face of a poor harvest. Moreover, individual farmers provide their own transport. The obvious benefit to PH is that it does not need a complex inbound logistics system to bring in the harvest. However, while this setup significantly reduces PH's inbound transportation problems, PH does not have direct control over the farmers and some delays in harvest and transport must be accepted.

On the outbound logistics side, PH could not outsource transportation because no large transportation firm operated in its region. Instead, PH made a former local truck operator its director of transportation in Budapest. The

director knows the operators of all other small carriers personally. He can quickly hire those that are familiar with specific transportation routes (e.g. in the Czech Republic, Ukraine, Austria, etc.) and regulations. The knowledge of regulations is particularly important because they are not standardized. Moreover, due to the lack of an information systems infrastructure, most governments rely on paper records, thus significantly increasing the processing time at the borders.

In summary, PH reduced its vulnerability by decreasing the complexity of its inbound logistics. In addition, due to the local truckers' familiarity with the region and procedures, uncertainty in its outbound supply chain decreased. However, PH's supply chain agility is fairly low. It still cannot rely on guaranteed transport or delivery times. These limitations had to be accepted given the environment in which PH operates.

VAI

VAI is a large international producer of steel products. It recently expanded its production capabilities by setting up a joint venture with steel mills in the Ural Mountains of Russia. This operation is coordinated from VAI's offices in Austria. The joint venture allows VAI to deal with increased demand in steel while keeping costs fairly low. The supply chain agility is low, however, because of the uncertainty of transportation delivery times. VAI must organize transportation from the steel mills to the port of destination in Southeast Asia. The steel is first transported by rail from the Ural in Russia to Odessa on the Black Sea, then by ship to Southeast Asia.

VAI works with both Russian and Ukrainian freight forwarders. The main problem is the flow of information and reliability of transportation times. A three-week lead-time is required for the first sequence of the main transport plan. The first sequence includes the following steps:

- The mills order railway wagons through the Moscow Railway Mission.
- Odessa is informed that VAI wants rail capacity for 10,000 tons of pallets.
- Odessa informs Ukrainian Railway ministry of rail needs.
- Ukrainian Railway tells Russian Railway ministry of its needs.

The next step is to get railway confirmation from the freight forwarders and set up the sea transportation. All this must be done using telegrams since e-mail is non-existent and phone service is unreliable. To track the progress of shipments, VAI hires people to observe various points of the rail line. As each train passes by, the observer notes the apparent loads of the rail cars (in order to check for theft) and sends a telegram to VAI giving the train's location. This is the "information system."

Once the steel is at sea, the shipment is subject to the vagaries of the weather in the Indian and Pacific Oceans. Sea transport is outsourced. In order to have

bargaining power, VAI has bought shares in each of the shipping companies it uses.

Given its system, VAI cannot guarantee “quick” response or implement an agile supply chain. Therefore, it meets contracts on a monthly or quarterly basis. This decreases uncertainty (and vulnerability) for both itself and its customers.

Apple Computer Products, Inc.

To be able to better deal with production uncertainty, Apple moved its production facilities to Southeast Asia during the early 1990s. If demand increased, production facilities could quickly hire more workers at a lower cost than in the USA. Products could then be shipped via sea freight to warehouses in California.

However, Apple’s Powerbook Laptop generated extremely high and unanticipated initial demand. While Apple’s production facility was able to cope with this demand, delays in supply severely affected production and, thus, order response time. Because of the volume involved, the finished goods were shipped by sea which, due to the weather in the Pacific, affected transport times. Consequently, lost sales curbed the profits and increased market share Apple otherwise would have realized. In fact, based on simulations done by Levy (1992) (using Apple’s data as a baseline, with unstable demand being the only transient variable and 100 iterations of each simulation), Apple could, on average, expect a 25 percent probability that unfulfilled demand would exceed 10.4 percent over a 36 month period. In addition, there was a 10 percent probability that unfulfilled demand would exceed 13.6 percent. As Levy points out: “the question is how much risk a company is willing to bear.”

This case shows that, although Apple’s supply chain was not complex, the uncertainty involved in sea transportation made Apple’s supply chain vulnerable. At the same time, Apple’s supply chain agility was low because of the low speed and flexibility with which product could be brought to market.

Business implications

International supply chain exposure and tradeoffs in agility

The cases outline the tradeoffs firms face when developing an international supply chain. The successful firms focused on key aspects of their supply chain and did not attempt to provide every feature demanded of the agile firm. They managed their supply chain exposure by reducing uncertainty and complexity in the system and limiting agility to the extent that the degree of vulnerability became manageable.

Table II shows how the firms in our case studies are affected by supply chain exposure. As the supply chain exposure increases, firms accept that they may not be able to provide exact delivery times and immediate response. When exposure is not addressed, however, the firms risk failure.

Note that, according to Table II, VAI’s overall level of supply chain exposure is greater than that of Apple. However, VAI deals with this exposure by decreasing its supply chain flexibility (speed and flexibility) through meeting

		Exposure factor				Overall supply chain exposure
		Geographic area covered by supply chain	Transport modes used	Political areas and borders	Technical infrastructure	
GE	Western Europe	Truck	Fairly standard borders	Good infrastructure	Not a major factor	Low
Rating	1	1	1	1	1	5
HP	Europe and North Africa	Truck, rail, short-haul sea freight	Fairly standard borders	Good infrastructure	Can cause limits	Medium
Rating	2	2	2	1	2	9
PH	Eastern Europe	Truck, rail	Non-standard borders	Marginal infrastructure	Can have major effect on crop yields and harvests	Medium
Rating	2	1	4	2	4	13
VAI	Eastern Europe, Russia, Indian and Pacific Oceans, Southeast Asia	Rail, long-haul sea freight	Extremely non-standard borders	Minimal infrastructure	Can have major effects (mountain ranges, flash floods, hurricanes)	High
Rating	4	4	4	4	4	20
Apple	Southeast Asia, Pacific Ocean, North America	Truck, long-haul sea freight	Fairly standard	Good infrastructure	Can have major effects (hurricanes)	High
Rating	4	4	2	2	4	15

Table II.
Supply chain exposure

contracts on a monthly or even quarterly basis. In other words, customers know that, in order to obtain VAI's low priced steel, they need to accept fairly long order lead times. Therefore, the high level of exposure can be accepted. In contrast, Apple's customers are not willing to wait for weeks once they have decided to buy a laptop. Hence, Apple's exposure had been increased too much, decreasing its real supply chain agility to a point having a great affect on overall firm performance.

Complexity versus supply chain agility

Clearly, complexity is a major factor influencing supply chain exposure and agility. Therefore, in this section, we address complexity again.

Increasingly, large multinational firms, in an effort to simultaneously provide local responsiveness and global integration, are developing complex, differentiated network structures (Nohrai and Ghoshal, 1997). Large manufacturing firms have even argued that they are “hostage to complexity” with regard to their supply chain structure (Davis, 1993). These statements support the model that a firm’s structure and management processes must grow increasingly complex to respond to a complex environment, as argued in traditional organization theory Ashby (1956), principle of requisite complexity).

Recall, however, that developing a more complex system is not always the answer. For example, if the timing of demand is not very stringent (as in VAI’s case), it may not be worth increasing the complexity of management or logistics. The cases illustrate that, regarding the complexity of international supply chain issues, firms opt to simplify systems to manage problems. Developing ever more complex logistics systems in order to meet all the criteria of an agile firm may increase the complexity of the problems being dealt with and may become inherently infeasible.

Figure 4 shows that, instead of developing progressively more complex logistics systems in order to increase agility, in reality, the law of diminishing returns applies. In other words, companies realize that they can not manage all eventualities, particularly in an international environment. Instead, by focussing on the most important and feasible aspects of an agile supply chain, they choose an “optimal” (i.e. realistic) level of complexity that reflects an adequate degree of supply chain agility. This focus also allows them to better deal with the uncertainty of their international business logistics environment.

Conclusions for academics and practitioners

Agility has become a major topic of research for academics. Two concepts inherent in most of the 12 attributes specifying an agile firm are speed and flexibility. Although the speed and flexibility of the supply chain affect a firm’s agility, the agile manufacturing literature has overlooked the issue of supply

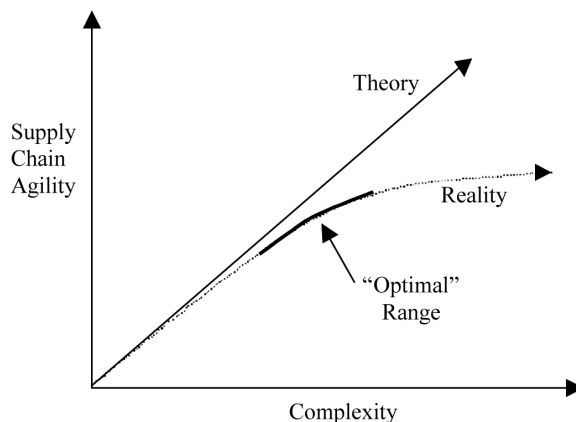


Figure 4.
Supply chain tradeoffs

chain management. In many cases, a firm's international supply chain may not be able to respond as quickly and reliably as the rest of the organization. While, in the ideal definition of an agile firm, all logistics problems could be dealt with directly, management must sometimes accept tradeoffs between external supply chain vulnerability (a result complex supply chains and uncertainty) and supply chain agility.

To establish the link between external vulnerability and supply chain agility, this paper introduces the concept of supply chain exposure. Exposure describes the degree to which an agile supply chain is "overextended" (i.e. vulnerable) and, consequently, should be restructured, improved, or adjusted. Our research finds that factors determining the degree of exposure include the number of geographic areas covered by the supply chain; the number of transportation modes used and their speed; the number of political areas and borders; the technical infrastructure; and environmental issues.

Clearly, as the exposure of the supply chain increases, agility should decrease. This is because uncertainty and complexity increase and, consequently, also the probability that the supply chain will have a negative impact on overall operations. From a practitioner's point of view this means that, in an international environment, businesses cannot be "all things to all people". With the help of case studies we show how some internationally operating firms have made distinct tradeoffs between agility on one side and complexity and uncertainty on the other side. Our analysis shows that firms should focus on key aspects of an agile supply chain and not strive to comply totally with the initial definition of agility. Moreover, even if a very high degree of supply chain agility is called for, complexity inherent in the organization of many international supply chains may make the realization of agility impossible. This approach, rather than a technically splendid optimization approach, reflects the realities of working in an international environment.

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