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Diversified firms on dynamical supply chain cope with financial crisis better

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ABSTRACT

To investigate whether diversification within a supply chain can help middlemen firms survive prolonged financial crises, we simulated an extension of the dynamical supply chain network model by Mizgier et al. (2012) under normal and crisis economic conditions. In these simulations, firms in the middle of the supply chain are allowed to (i) forward vertically integrate by buying over one of its customers, (ii) backward vertically integrate by buying over one of its suppliers, or (iii) horizontally merge with a competitor to pool capital and resources. We extracted from these simulations the lifetime distributions of undiversified firms, and of firms adopting the three diversification strategies described above. We then compare the average lifetimes and the rates at which the midsections and tails of the cumulative lifetime distributions decay for these four types of firms. Based on these comparisons, we found that forward vertical integration most effectively extends the lifetimes of middlemen firms during a financial crisis, but also makes them less resilient to sudden economic downturns. In contrast, backward vertically integrated firms most successfully weather such downturns.

1. Introduction

In the recent global financial crisis, many big firms with long histories went bankrupt through exposure to toxic CDO assets. These included Bear Stearns, JP Morgan, Fannie Mae, Freddy Mac, Lehman Brothers. Others, like General Motors and Chevrolet, went the way of dinosaurs from the ensuing slowdown. While news of these giants going under occupied our consciousness, the demise of many more smaller firms went largely unreported.

According to the American Bankruptcy Institute (2010), the number of business bankruptcy filings in the US in 2009 reached 16 014 new bankruptcy filings in the second quarter, the highest since 1994. In total, bankruptcy filings increased from 43 546 in 2008 to 60 837 in 2009. Along with the increased rate of bankruptcies, the US Bureau of Labor Statistics (2010) reported that the annual unemployment rate greatly increased from 5.8% in 2008 to 9.3% in 2009 with no change for the better in 2010 (9.6%).

This loss of employment due to firms folding adds stress to society. If the number of bankruptcies can be minimized, either through government support during the crisis, or through better management practices, it might be possible to reduce the number of job losses. Surely this would be a desirable economic and social outcome.

To achieve this goal, we must first understand that firms are not islands, but are interconnected players within ever changing supply chains regularly stressed by economic downturns (Reinhart and Rogoff, 2008). Da Cruz and Lind (2012) showed that in a network of interconnected banks (suppliers of liquidity), failure of a single bank spreads through its neighbors and leads to financial instability of the entire system. Contrary to the beliefs of regulators, the authors showed that increasing capital requirement does not necessarily lead to higher stability of a realistic financial system. In fact, a lot of research has been done on understanding complex dynamics of such networks, including those of supply chains (see Section 2.1). Within this body of work, a significant amount of effort has also been put into predicting financial crisis and detecting bubbles (Johansen and Sornette, 2001; Sornette and Anderson, 2002; Johansen, 2004). In this paper, we put one (supply chain network dynamics) and one (financial crisis) together, and ask if we can get three (means for firms on a supply chain to alleviate the impact of economic downturn).

The best way to discover supply chain management practices that would help firms weather financial crises would be to mine historical data on their long-term viability. For example, we can

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look into a complete registry of firms within a given industry, to see when they were registered and deregistered. From firms living through one or more financial crises, we then identify the anomalously long-lived ones to do careful case studies.

In particular, we suspect that some of the long-lived firms might have benefitted from diversification. To identify diversified firms, we would need data on their proprietors or boards of directors, because diversified firms frequently share the same proprietors or directors, or have these coming from the same extended families. Unfortunately, data down to these levels of details are hard to acquire, because they are captured by different agencies, and can in some countries be considered too sensitive to be released for academic research. Depending on the country, the proportion of diversified firms may also be small, making assurance of statistical significance difficult to achieve.

In the absence of real data, we settled for synthetic data generated by computer simulations, where there are no issues of data sensitivity or identification of diversified firms. We can also run large numbers of simulations to ensure that our conclusions are statistically significant. However, for simulated outcomes to be plausible, the model used must be sufficiently realistic. This is why we choose to work with the dynamical supply chain model of Mizgier et al. (2012), which is an adaptation of the dynamical supply chain model of Weisbuch and Battiston (2007).

At equilibrium, the Mizgier, Wagner and Hołyst (MWH) model has few large bottom level suppliers and few large top level customers, but many small and medium sized firms in the middle of the supply chain. This proliferation of middlemen has been observed in many supply chains, in particular by Popp (2000) in the apparels industry. From an ecological perspective, middlemen firms evolve naturally during good times in a sophisticated economy, filling the niche of specialized firms producing a small number of products highly efficiently. However, because of their specialization, these middlemen firms are also most susceptible to sudden changes in the economic climate and conditions.

In this paper, we will provide a short overview of the agent-based supply chain modeling literature in Section 2. In Section 3, we will describe how we extend the MWH model by allowing middlemen firms to diversify, either by (i) buying over one of their suppliers, or (ii) buying over one of their customers, or (iii) merging with a competitor. We then report our findings in Section 4, and discuss their implications in Section 5. Finally, we conclude in Section 6.

2. Literature

2.1. Supply chain modeling

A supply chain is a network organized according to production relationships. By buying goods from and selling goods to each other, firms bring products or services from raw material-supplier to end-customers (Committee on Supply Chain Integration, 2000). In today′s competitive and ever changing markets, effective management of the supply chain is essential for minimizing inventory and logistic costs (Julka et al., 2002a,b).

Beside using stochastic processes, discrete events, linear and nonlinear programming and game theory (Ambrosino and Scutella, 2005; Wang et al., 2014; Larsen and Thorstenson, 2014; Feng et al., 2014; Chen and Grewal, 2013), there are empirical studies on identifying key variables of successful supply chain strategies (Roh et al., 2014). Also agent-based modeling (ABM) found its way into supporting and analyzing business decisions in recent years (Swaminathan et al., 1998; Julka et al., 2002a,b; Chatfield et al., 2009).

In the growing literature on supply chain modeling and simulations, we also find papers dealing with uncertainties (Yu and Li, 2000; Santoso et al., 2005) and dynamic changes (Ahn and Lee, 2004; Akanle and Zhang, 2008; Anosike and Zhang, 2009; Almeder et al., 2009).

Our study is based on the recent paper by Mizgier et al. (2012). Incorporating supply chain features defined by Melo and Nickel (2009), Mizgier, Wagner and Hołyst worked with a multi-stage supply chain network with single commodity and multi-period observations. Their model is an extension of the static supply chain network model of Weisbuch and Battiston (2007), whereby the network structure is allowed to continuously evolve under economically realistic rules. They are interested in how stochastic fluctuations in local processes can impact the global economic behavior of the supply chain, and observed that collective bankruptcies lead to emergent network structures.

2.2. Merger and acquisitions

The exact term for merger is merger by horizontal integration or horizontal merger. We speak of horizontal integration if a firm is taken over by, or merged with a competitor at the same level of the supply chain (Hill and Jones, 2009).

The usual corporate motives for merger and acquisitions are two-fold. The first, economic motivation is to improve internal efficiencies through the economy of scale. The second, strategic motivation is to enhance external relations by product growth or geographical expansion. Through mergers, competing firms pool their capitals and market shares, to leap frog over leading competitors (Chapman, 2002; Bodolica and Spraggon, 2009; DeYoung et al., 2009).

The diversification we model in this paper is more commonly referred to as vertical integration. Vertical integration means the expansion of the production program to products of the previous, next, both or all levels of the supply chain. The expansion of products to the next level is called forward vertical integration. A firm can achieve this by setting up the capabilities to make products at the next level, or by buying over its own customers. In contrast, backward vertical integration means that production capabilities are extended to the previous level.

In spite of the successes of many of the world′s largest and highly diversified conglomerates, which include IBM, Hewlett-Packard, General Electric, Wesfarmers, Bidvest, or ITC Limited and Mitsubishi, management experts now consider diversification ‘old-fashioned’ and ‘no-go’. Instead, they champion outsourcing peripheral functions, so that modern firms can focus on their core businesses (Hill and Jones, 2009). Why is diversification perceived as poor management practice in the modern business world? One reason might be the lack of positive evidences that diversification improves profits, growth, and market shares, which are what managers are interested in Mueller (2003). Another reason might be the need for a diversifying firm to acquire foreign managerial and technical practices, which may impede the business from being run efficiently (Stahl and Voigt, 2005).

3. Model

3.1. The model scheme

In the MWH model (Fig. 1) we assume five stages in the network from stage 0 (the consumers) to stage 4 (the raw material suppliers). We further assume that there are 50 firms in each stage, so that there are a total of $N=250$ firms. A firm in stage s and a firm in stage $s+1$ are connected by a link, if the former places orders to, and receives goods from the latter. So, a firm in

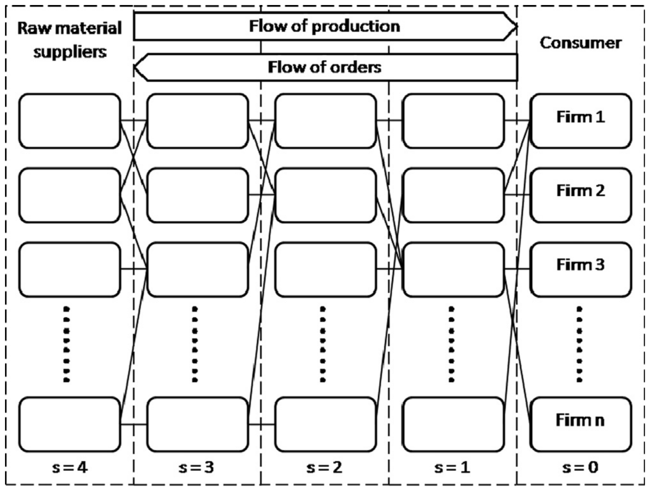

Fig. 1. Schematic diagram of the MWH supply chain. See Section 3.1 for description.

stage s is the customer of the firm in stage $s+1$, or firm in stage $s+1$ is the supplier to the firm in stage s. Firms within the same stage are not connected.

The following qualitative features have been incorporated to make the MHW model realistic.

3.1.1. Price dispersion and dynamics

In real markets, different sellers assign different prices to the same goods. To model this price dispersion, we follow MWH to assign random sales prices drawn from a log-normal distribution:

$$f(x,\mu,\sigma)=\frac{1}{x\sqrt{2\pi}}\sigma \exp\left[\frac{-\ln^2\left(\frac{x}{\mu}\right)}{2\sigma^2}\right], \tag{1}$$

for $x>0$ where $\mu=1$ is the expected value, and $\sigma=0.01$ the standard deviation of $\ln x$, to firms at the start of the simulation. We then further include mark-ups of 0.5, 0.4, 0.3, 0.2, 0.1 to the unit sales prices for $s=0, 1, 2, 3, 4$. Here, the mark-up—a function of stages—reflects the fact that raw materials have a lower retail price than produced goods. In the real world the shape of the mark-up function can be convex, linear or concave depending on the industry. Since we are not simulating the supply chain of any industry specifically, we chose to use a linear mark-up function. In the MWH model the unit sales price $p_{s,i}(t)$ of a firm i in stage s at time t is given by

$$p_{s,i}(t)=c_{s,i}(t)+\lambda+\frac{l}{2}P, \tag{2}$$

where $c_{s,i}(t)$ is the unit cost of production, $\lambda=0.002$ is the capital interest rate, $l=5$ is the number of stages in the supply chain and $P=0.05$ is the failure probability. This price dynamics ensures that firm i not only breaks even, but also adds on a marginal reserve to deal with rare production shortfalls.

For our study, we simplified the price dynamics, such that firm i in stage s of the supply chain will raise their unit sales price $p_{s,i}(t)$ to the unit cost when their profit becomes negative. Otherwise, $p_{s,i}(t)$ remains constant. We feel that this price dynamics is also economically reasonable, because when prices are marked up, firms have immense resistance to reducing them.

3.1.2. Network configuration

Because of the price dispersion, it is only reasonable for firms to constantly search for the cheapest suppliers. To assign these links between firms in our supply chain model we use the MWH linking algorithm: at each time step starting from stage 0 we randomly choose one firm A in stage s and then randomly choose three firms of the stage $s+1$. We then link the cheapest firm B of the three in $s+1$ with A in s only if the sales price of B is lower than the sales price A adopts for its products, such that there is potential to profit from the difference. This algorithm is repeated until linkages are established in the last stages. We start the network without any edges and begin connecting the vertices by using this linking algorithm.

Apart from searching for cheaper suppliers to maximize their profit, firms also hedge against risk by multi-sourcing. To keep a realistic number of links between firms we use the following MWH network configuration procedure. The probability of reconfiguration is

$$P_{\text{reconf}}=\tan h(k_{s,i}/a), \tag{3}$$

where $a=5$ can be interpreted as the typical number of links, and $k_{s,i}\geq 0$ is the number of suppliers the firm i in stage s has. The basic idea is, once firms find cheaper suppliers they can exchange their existing suppliers for these new and cheaper ones, instead of just adding a new supplier to its list of suppliers. The more suppliers a firm has the more likely will it switch to new ones. In contrast, firms with only a few suppliers are less likely to reconfigure their linkages since they face higher risks of production shortfalls during the reconfiguration in real life.

3.1.3. Production dynamics

In the MWH model the production function is linear in the firm′s working capital and orders of the consumers are limited by the production capacity. A consumer i in stage 0 places its order $Y_{0,i}(t)$, according to

$$Y_{0,i}(t)=mA_{0,i}(t), \tag{4}$$

where m is the technological proportionality coefficient and $A_{0,i}$ is the working capital of consumer i. We set $m=1$ when we start off our simulations in normal economic times, and change this coefficient to $m=0.5$ when the financial crisis starts. Following Weisbuch and Battiston (2007), the initial working capital of each firm is sampled from a uniform distribution $U(1.0, 1.1)$.

Orders are then evenly distributed between all its suppliers in stage 1. In stages $s\geq 1$ the sum of orders received by a firm i at time t is

$$Y^r_{s,i}(t)=\sum_{i'\in v}\frac{Y_{s-1,i'}}{k_{s-1,i'}}, \tag{5}$$

where v stands for the set of customers of i. The firm i then places an order that is equal to the minimum between its productions capacity given by Eq. (4) and $Y^r_{s,i}(t)$. As soon as the orders reach the raw material suppliers, the production process starts.

The delivered production

$$Y^d_{s,i}(t)=\varepsilon(t)\sum_{i'\in v'}Y^d_{s+1,i'}(t)\frac{Y_{s,i}(t)/k_{s,i}}{Y^r_{s+1,i'}(t)}, \tag{6}$$

is governed by a stochastic coefficient $\varepsilon(t)$, which takes on value $\varepsilon(t)=0$ with probability $P=0.05$ (no deliveries at all), and value $\varepsilon(t)=1$ with probability $1-P$. The introduction of this stochastic coefficient gives rise to production shortfalls that cascade through the supply chain and v' and v stand for the set of suppliers and set of customers of i, respectively. Eq. (6) basically states that the delivered production of a firm i in stage s depends on the products delivered by its suppliers in stage $s+1$. When there is a production shortfall, and i cannot complete the orders of all its customers, the amount delivered to each customer will be proportional to its order.

Beside the production process, the working capital of each firm has to be updated to reflect the profits and losses they make. The profit in the MWH model is

$$\Pi_{s,i} = p_{s,i}(t)Y^d_{s,i} - c_{s,i}(t)Y^d_{s,i} - \lambda A_{s,i}, \tag{7}$$

where $p_{s,i}(t)$ is the unit sales price at time t, $\lambda = 0.002$ is the constant interest rate for the capital, and $c_{s,i}(t)$ is the unit cost of production at time t, which is given by

$$c_{s,i}(t) = \frac{\sum_{i' \in v'} p_{s+1,i'}(t)Y^d_{s+1,i'}(t)/k_{s,i}}{Y^r_{s+1,i'}(t)}. \tag{8}$$

3.1.4. Costs of production

In the MWH model, the production cost of firms changes over time, to reflect changes in the labor market and technological innovations. In this paper, we are interested in simulating the response of the supply chain to sudden (and prolonged) financial crisis. As such, we neglect slow technological innovations or changes in the labor market.

3.1.5. Bankruptcies and recovery

In the MWH model, firms tap into their working capital to pay taxes and wages. Hence, if a firm's working capital is too low, the firm will go bankrupt. Bankrupt firms recover after fresh injection of capital a few time steps later, retaining all the old links to their customers and suppliers.

Instead of recovering the bankrupt firm, we replace it with a completely new firm after a few time steps. This new firm A will be initialized with new links to its suppliers and customers.

3.2. Diversification and merger

We then extend the MWH model to allow firms on the middle level of our supply chain to diversify and merge. Diversification is implemented as follows:

- In backward vertical integration we choose randomly one firm $A$of stage $s=2$ and let it buy over one of its linked suppliers Bin stage $s=3$. After integration Astill places its orders in the usual way, whereas Bnow has an obligation to fulfill. In case B experiences a production shortfall, and cannot meet the demands of all its customers, it must first complete A's orders. Any remaining products are then proportionally delivered to the rest of the customers, based on the size of their orders.
- In forward vertical integration we again choose one firm Arandomly of stage $s=2$ and let it buy over one of its linked customers Cin stage $s=1$. After integration, A delivered its products in the same way as before, without giving priority to C, whereas C cancels its links to all other suppliers. That is to say, after integration C places orders only with A.

Besides comparing forward and backward vertical integration we also observe the outcome of the horizontal merger of firms. The algorithm for merging two firms is as follows:

- At stage $s=2$ we choose randomly two firms to merge. We combine their working capital and their linkages to both stages $s+1$ and $s-1$.

4. Results

We simulated the supply chain network under normal economic conditions and during a financial crisis. In both scenarios we allowed firms in the middle level of the supply chain to merge, and to diversify.

In each simulation we record the lifetimes of undiversified and diversified firms. Combining the records from a large number of

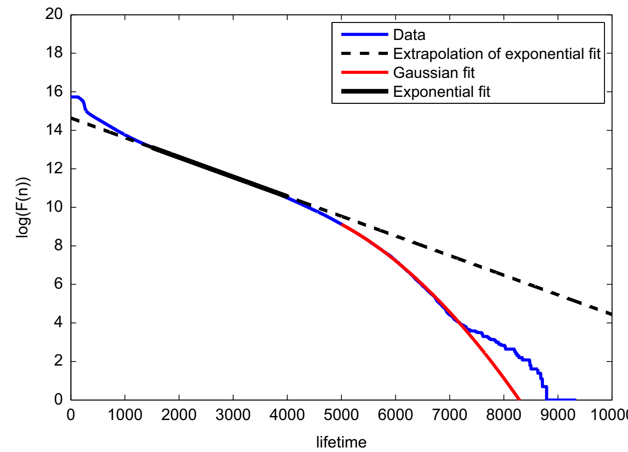

Fig. 2. Cumulative lifetime distributions of firms at stage 2 of the supply chain, accumulated over 10 000 simulations each of 10 000 time steps.

Table 1
Lifetime decay rates and average lifetimes of undiversified firms during normal and crisis times, where λ is the midsection decay rate, σ is the tail decay rate, and $\overline{n}$ is the average lifetime. The smaller λ or larger σ are, the slower the respective decays.

Supply chain stage	Normal times	Crisis
$s=0$	$\lambda_0 = (7.916 \pm 0.008) \times 10^{-4}$ $\overline{n}_0 = 590.7 \pm 2.6$	$\lambda_0 = (8.736 \pm 0.004) \times 10^{-4}$ $\overline{n}_0 = 701.9 \pm 2.9$
$s=1$	$\lambda_1 = (9.783 \pm 0.008) \times 10^{-4}$ $\sigma_1 = 2553 \pm 5$ $\overline{n}_1 = 624.7 \pm 2.6$	$\lambda_1 = (7.704 \pm 0.008) \times 10^{-4}$ $\sigma_1 = 2118 \pm 5$ $\overline{n}_1 = 714.8 \pm 3.2$
$s=2$	$\lambda_2 = (1.02 \pm 0.09) \times 10^{-3}$ $\sigma_2 = 1613 \pm 5$ $\overline{n}_2 = 563.8 \pm 1.9$	$\lambda_2 = (9.003 \pm 0.004) \times 10^{-4}$ $\sigma_2 = 1550 \pm 3$ $\overline{n}_2 = 595.5 \pm 2.1$
$s=3$	$\lambda_3 = (9.892 \pm 0.011) \times 10^{-4}$ $\sigma_3 = 1509 \pm 8$ $\overline{n}_3 = 470.5 \pm 1.7$	$\lambda_3 = (9.177 \pm 0.009) \times 10^{-4}$ $\sigma_3 = 1629 \pm 7$ $\overline{n}_3 = 458.1 \pm 3.3$
$s=4$	$\lambda_4 = (7.642 \pm 0.009) \times 10^{-4}$ $\sigma_4 = 1590 \pm 8$ $\overline{n}_4 = 296.1 \pm 0.9$	$\lambda_4 = (7.517 \pm 0.015) \times 10^{-4}$ $\sigma_4 = 1707 \pm 8$ $\overline{n}_4 = 298.7 \pm 1.0$

simulations, we determine the cumulative distribution of lifetimes $F_s(n)$. It denotes the number of firms in stage $s=0$, 1, 2, 3, 4 with lifetimes at least n time steps long. Fig. 2 shows the typical behavior of the cumulative lifetime distribution. It decays exponentially for a while before accelerating to a Gaussian-like decay. To facilitative quantitative comparisons, we fit the midsection of all cumulative lifetime distributions to exponential decays and the tails of the cumulative lifetime distributions to Gaussians. We measure $F_s(n)$ instead of the lifetime distribution $f_s(n)$ (the number of firms in stage s with lifetime equal to n time steps) because the former is less noisy.

4.1. Undiversified firms

Table 1 shows lifetime decay rates and average lifetimes of undiversified firms during normal and crisis times at various stages s of the supply chain. Because the cumulative lifetime distribution of undiversified firms on $s=0$ shows an exponential decay that extends nearly all the way, we do not fit its tail to a Gaussian. Except for $s=0$, the midsections of these cumulative lifetime distributions all decay slower during a financial crisis. For $s=2$, 3, 4, these decays are only slightly slower, whereas for $s=1$, this decay is significantly slower. The midsection of the $s=0$ cumulative lifetime distribution decays significantly faster during a financial crisis. For $s=1$, 2, we find their Gaussian-like tails decaying faster during a financial crisis, whereas for $s=3$, 4, we

Table 2
Lifetime decay rates and average lifetimes of diversified middleman firms during crisis times, where λ is the midsection decay rate, σ is the tail decay rate, and $\overline{n}$ is the average lifetime. The smaller λ or larger σ are, the slower the respective decays.

Management strategy	**Diversified firms (crisis)**	**Undiversified firms (crisis)**
Forward vertical integration	$\lambda_f = (6.668 \pm 0.011) \times 10^{-4}$ $\sigma_f = 2148 \pm 12$ $\overline{n}_f = 1744 \pm 170$	$\lambda_2 = (9.003 \pm 0.004) \times 10^{-4}$ $\sigma_2 = 1550 \pm 3$ $\overline{n}_2 = 595.5 \pm 2.1$
Backward vertical integration	$\lambda_b = (6.315 \pm 0.013) \times 10^{-4}$ $\sigma_b = 1894 \pm 16$ $\overline{n}_b = 1474 \pm 69$	
Horizontal merger	$\lambda_m = (8.124 \pm 0.006) \times 10^{-4}$ $\sigma_m = 1021 \pm 7$ $\overline{n}_m = 932 \pm 52$	

Table 3
Lifetime decay rates and average lifetimes of diversified middleman firms during normal times, where λ is the midsection decay rate, σ is the tail decay rate, and $\overline{n}$ is the average lifetime. The smaller λ or larger σ are, the slower the respective decays.

Management strategy	**Diversified firms (normal times)**	**Undiversified firms (normal times)**
Forward vertical integration	$\lambda_f = (7.393 \pm 0.011) \times 10^{-4}$ $\sigma_f = 1765 \pm 13$ $\overline{n}_f = 1602 \pm 73$	$\lambda_2 = (1.02 \pm 0.09) \times 10^{-3}$ $\sigma_2 = 1613 \pm 5$ $\overline{n}_2 = 563.8 \pm 1.9$
Backward vertical integration	$\lambda_b = (7.263 \pm 0.013) \times 10^{-4}$ $\sigma_b = 4096 \pm 175$ $\overline{n}_b = 1671 \pm 68$	
Horizontal merger	$\lambda_m = (9.249 \pm 0.005) \times 10^{-4}$ $\sigma_m = 1152 \pm 14$ $\overline{n}_m = 1033 \pm 633$	

find their Gaussian-like tails decaying slower during a financial crisis.

We also measured the average lifetimes, which received contributions from both the short-lived and long-lived ends of the lifetime distributions. We found that the average lifetimes of firms in stages $s=2$, 3, 4 of the supply chain remain more or less unchanged going from normal times to crisis times. In contrast, the average lifetimes for firms in stage $s=0$, 1 are significantly longer.

4.2. Diversified firms

Table 2 shows the comparison during crisis. Comparing the midsections of $F_s(n)$ of the undiversified, and diversified firms we find slower decays for the diversified firms. Instead of decaying at a rate of $\lambda = (9.003 \pm 0.004) \times 10^{-4}$ for the undiversified firms during a financial crisis, the midsections decay with $\lambda_m = (8.124 \pm 0.006) \times 10^{-4}$ (horizontal merger), $\lambda_f = (6.668 \pm 0.011) \times 10^{-4}$ (forward vertical integration), and $\lambda_b = (6.315 \pm 0.013) \times 10^{-4}$ (backward vertical integration). We also see the tail of $F_s(n)$ for horizontally merged middlemen firms decaying significantly faster than that for undiversified middlemen firms. The tails of $F_s(n)$ for the vertically integrated middlemen firms, on the other hand, decay significantly slower. During normal times, the midsections of $F_s(n)$ of diversified firms also decay slower compared to that seen for undiversified firms (see Table 3). Additionally, the tail of $F_s(n)$ for horizontally merged firms again decays faster, while the tails of $F_s(n)$ for vertically integrated firms decay slower than the tail of $F_s(n)$ of undiversified firms.

Another way to gauge the impact diversification has on the lifetimes of the middlemen firms is to compare the average lifetimes. Unlike the exponential decay constant λ of the intermediate lifetimes and the Gaussian standard deviation σ of the long lifetimes, the average lifetime also receives contributions from the short-lifetime end of the distribution. Here, we find that the average lifetime of undiversified firms is $\overline{n} = 595.5 \pm 2.1$, whereas those for forward vertical integration, backward vertical integration, and horizontal merger are $\overline{n}_f = 1744 \pm 170$, $\overline{n}_b = 1474 \pm 69$, and $\overline{n}_m = 932 \pm 52$, respectively. Hence, all three strategies increased the average lifetime.

Based on these results, we see that forward vertical integration most effectively slows down the decay in the midsection to tail of the cumulative lifetime distribution, producing the longest average lifetime overall.

4.3. Tagged comparison

Because the supply chain is highly heterogeneous, the environments of some middlemen firms may be better than others at the same level. A direct comparison of the lifetime distributions will not tell us how much longer a middlemen firm is expected to live, had it decided to diversify. Also, in the simulations reported thus far diversified firms lived out their lives entirely within normal or crisis conditions. It would be interesting to see what effects diversification has on middlemen firms living through the start of a financial crisis. We therefore use the following more precise method to compare the lifetimes of these firms.

For the tagged comparison we used ten different equilibrium supply chain networks. Starting from each of these ten equilibrium networks we ran 1000 tagged simulations. In each tagged simulation, we randomly pick and tag a firm from the middle stage of our supply chain. We then ran two parallel simulations of 10 000 time steps, with the first 2500 time steps under normal economic conditions, and the next 7500 time steps under crisis conditions. In one simulation our tagged middlemen was left undiversified. In the second simulation we allow the tagged middlemen to diversify.

Comparing the lifetime distributions of the tagged middlemen in the two simulations, we observe that backward vertical integration is the most effective strategy. It increases lifetime by 104 ± 79 time steps, whereas forward vertical integration is the least effective in helping middlemen firms survive a sudden downturn, as the lifetime decreases by 495 ± 227 time steps. Horizontal merger leaves average lifetime almost unchanged (-34 ± 96).

5. Discussions

5.1. Undiversified firms

The slower exponential decays in the midsections and slower Gaussian-like decays in the tails of the cumulative lifetime distributions for stages $s=1$, 2, 3, 4, and the longer average lifetimes for all stages during crisis times are surprising. We believe that the slower decays in the tails of the cumulative lifetime distributions can mean two things. Either the long-lived firms can live even longer during a crisis, because of the reduced competition from the smaller number of viable firms overall or the lifetimes of long-lived firms are not extended, but the crisis weeds off short-lived firms more effectively than it weeds off long-lived firms. The firms weeded off by the crisis pile up at the short-lived end of the cumulative lifetime distribution, thus flattening the long-lived tail of the distribution. We can distinguish which of these scenarios we are dealing with by performing the same kind of tagged comparison as we have done with diversified firms, but did not do it because our interest in this paper is to understand the advantages of diversification.

5.2. Diversified firms

Undiversified firms in stage $s=2$ of the supply chain live 595.5 ± 2.1 time steps on average during a financial crisis. While there are no real life evidence showing that diversification is good for the bottomline, it appears in our simulations at least that diversification helps increase the lifetimes of middlemen firms during a financial crisis. Comparing all three strategies, we see that forward vertical integration is the preferred diversification strategy. Of the two remaining diversification strategies, we find backward vertical integration to be significantly better than horizontal merger. In fact, horizontal merger is a poor strategy for middlemen firms which are already long-lived, because this strategy gives rise to a tail distribution decay that is faster than for undiversified firms.

Based on our simulations, forward and backward vertical integration are good diversification strategies even during normal times.

5.3. Tagged comparison

For middlemen firms living through the onset of a financial crisis, we find that horizontally merged firms do not live significantly longer than if they were not diversified. Backward vertically integrated firms, on the other hand, live significantly longer than if they were not diversified. Surprisingly, forward vertically integrated firms, which live longer than undiversified firms entirely within a crisis, fared extremely poorly if they were made to live through a sudden downturn.

We believe that the strategic implications of these observations are as follows. Even though forward vertical integration is also an acceptable diversification strategy during normal times (when backward vertical integration is the best diversification strategy), middlemen firms anticipating a sudden downturn should not forward vertically integrate. Instead, they should backward vertically integrate, because this diversification strategy best insures their survival through the downturn. After the downturn, the middlemen firm can then switch over to, or incorporate forward vertical integration (which is the best diversification strategy in crisis times).

As mentioned in Section 3, we are not simulating the supply chain of any specific industry. Therefore, we assume a linear increase of sales price mark-ups across the supply chain. When a linear mark-up function is used, the results show that forward vertical integration is favored during a financial crisis whereas backward vertical integration is preferable when firms live through sudden economic downturns. If we change the form of the mark-up function, we may end up favoring backward vertical integration during a crisis and forward vertical integration when facing a sudden downturn. However, we believe that a non-linear mark-up function will not affect our conclusion that diversification is favored over non-diversification during a financial crisis.

6. Conclusion

We extended the MWH model to investigate whether diversification within the same supply chain can help middlemen firms better cope with financial crises. To do this, we allowed middlemen firms to (a) buy over a customer (forward vertical integration), (b) buy over a supplier (backward vertical integration), or (c) merge with a competitor (horizontal merger). We then simulated order and production dynamics on the supply chain under normal economic conditions, and also under financial crisis conditions. By comparing the rates at which the midsections and tails of the cumulative lifetime distributions decay, and the average lifetimes, we found that forward vertical integration most effectively extends the lifetimes of middlemen firms. Horizontal merger was found to be the least effective strategy for ensuring a middlemen firm to survive a financial crisis.

We then performed parallel simulations of a tagged middlemen firm, which is undiversified in one simulation, and diversified in the other. Starting the simulations under normal economic conditions before switching over to crisis conditions, we found that backward vertical integration helps middlemen firms survive the downturn, while horizontal merger had no effect on the viability of these firms. We also found that forward vertical integration, a good diversification strategy under static economic conditions, made the middlemen firms more fragile towards sudden downturns.

While there have been many simulation studies on supply chain management, and many studies on how financial crises impact the economy on a whole, and individual firms, we are the first to use computer simulations of a realistic supply chain model as a tool to investigate the difference management strategies make in crisis situations, where viability, rather than profitability is the main concern.

In conclusion, we find that as far as middlemen firms are concerned, the main benefit of diversification is not to increase profits or lower operating costs. Instead, diversification helps middlemen firms more effectively manage the systemic risks they are exposed to, and help them survive longer in a competitive and uncertain business world. Moreover, our simulations point the way to dynamic diversification strategies that middlemen firms can adopt to cope with periodic economic downturns.

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