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Supply Chain Disruptions and the Role of Information Asymmetry

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ABSTRACT

This research investigates how information asymmetry between the firm and its investors can influence supply chain disruptions. In such settings, these actors may be induced to take steps which exacerbate rather than ameliorate both the likelihood and impact of disruptions. By better understanding these mechanisms, managers and investors alike are better armed to avoid the costly consequences.[]

Subject Areas: Disruptions, Finance-Operations Interface, and Information Asymmetry.

INTRODUCTION

My research examines how supply chain decisions influence and are influenced by information asymmetry between the firm and its investors. Over the last several years, companies have faced rising levels of risk and volatility that affect their operations and supply chains. As a result, supply chain executives are increasingly called upon to manage their operations under both steady and disrupted states. Disruption risks can take a variety of forms, ranging from conventional risks such as sourcing problems and transportation breakdowns, to extreme risks such as unrest in the Middle East, global financial shocks, and natural disasters. Large gaps remain in our understanding of the occurrence and impact of such disruptions. I seek to provide firms with meaningful insights on how to manage these risks by understanding an important yet neglected aspect of this issue – how information asymmetry between the firm and its investors may lead managers to take actions which increase rather than decrease the firm's exposure to supply chain disruptions.

MYOPIA IN SUPPLY CHAIN DECISIONS

Underinvestment in capacity can contribute to both the occurrence and magnitude of supply chain disruptions (Chopra & Sodhi, 2004; Sheffi, 2005). We investigate

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how short-term objectives (short-termism) and asymmetric information between the firm and its investors can induce managers to make such underinvestment decisions, thereby contributing to supply chain disruptions. Managers may exhibit short-termism for a variety of reasons, including a desire to raise capital in a secondary offering (Stein, 2003), to prevent takeovers (Stein, 1988), or to burnish their reputation and careers (Holmstrom, 1999). Although myopic decision making is decried as damaging the long-term value and competitiveness of firms, it is widely acknowledged to occur. For example, Rappaport (2004) acknowledges that "[t]o meet Wall Street expectations, managers make decisions to increase short-term earnings – even at the expense of long-term shareholder value." In a survey of over 400 financial executives, Graham, Harvey, and Rajgopal (2005) find that over 78% would give up economic value in order to hit a short-term earnings target and 55% would defer initiating a project with a very positive net present value. This phenomenon is particularly important to operations management because managers generally prefer operational manipulations over accounting manipulations to meet performance benchmarks (Bruns & Merchant, 1990; Graham et al., 2005).

We analyze such operational choices by using a signaling game to model the interaction between a manager of a firm and an equity holder of the firm (hereafter, the investor). To convey the primary insights from the model, we assume that the firm can be one of two types with respect to its demand distribution – a low type or a high type. This is captured by having the demand distribution for a high type first-order stochastically dominate the demand distribution for a low type. The firm's type is revealed to the manager but not to the investor due to information asymmetry between them. The manager, whose payoff is tied to both the firm's long-term performance and its current stock price, then makes a capacity investment decision using the newsvendor model. The capacity decision can be generalized to a variety of operational decisions, including purchasing commitments, inventory levels, plant size, or store openings. The investor uses the manager's capacity decision as a signal of the quality of the firm and determines its current stock price.

Prior theoretical research in economics and operations has shown that under similar modeling assumptions, the unique outcome, called a perfect Bayesian equilibrium (PBE), is the least cost separating PBE in which a high-quality firm overinvests in capacity compared to its long-term optimal choice in order to signal its type to the market, whereas a low-quality firm invests optimally (Bebchuk & Stole, 1993; Lai, Xiao, & Yang, 2012). However, this theoretical result is not supported by the empirical evidence which instead finds support that firms underinvest in capacity, including reduced inventory levels (Thomas & Zhang, 2002), production schedules (Roychowdhury, 2006), and maintenance, new projects, and R&D expenditures (Bushee, 1998; Roychowdhury, 2006). To develop a model that better aligns with practical decision making, we modify two common assumptions to reflect real-world operating constraints. First, we allow the firm's capacity decision to be discrete. Discreteness is a common characteristic of operational decisions, such as in sourcing, production, and distribution, due to the use of integer-capacitated resources (Nahmias, 2008). It is therefore important to determine the implications of discrete decisions in signaling games in operations. Second, we examine the impact of refining the investor's beliefs using the Undefeated refinement. This

refinement is based on Pareto optimization logic, which may be more consistent with operational decision making (Schmidt & Buell, 2014), and it addresses known concerns about the Intuitive Criterion (Mailath, Okuno-Fujiwara, & Postlewaite, 1993).

A rich set of outcomes emerges from the model when either of these assumptions is modified. Many of these outcomes have not been well studied in the academic literature and yet they have clear implications for supply chain coordination and contracting. These outcomes include a high-quality firm underinvests while a low-quality firm overinvests, a high-quality firm underinvests while a low-quality firm invests optimally, a high-quality firm invests optimally while a low-quality firm overinvests, both high- and low-quality firms invest optimally, and a high-quality firm overinvests while a low-quality firm invests optimally. Our results are significant because they can explain the existing empirical evidence for underinvestment. Our model therefore provides a basis to analyze this behavior in practice. We confirm the reasonableness of these results in practical settings through interviews with executives at two firms – Clarins Group and Arrow Electronics.

To better understand capacity choices in this context, we also provide analytical results on how the model parameters influence the likelihood of a pooling PBE (which typically involves a high type firm underinvesting) under continuous support and the Undefeated refinement. In particular, we study the impact of changes in short term-ism (α), the prior belief that the firm is a low type (g), and the critical fractile (ϕ). We show that when the capacity decision has continuous support on the positive real line and the Undefeated refinement is applied, then an increase in g decreases the likelihood of a pooling PBE, and an increase in either α or ϕ increases the likelihood of a pooling PBE. Thus, we observe that the model parameters can have a diverse impact on capacity decisions.

We augment the analytical results with an extensive numerical analysis that includes discrete support and the Intuitive Criterion refinement. Because we employ a large number of parameters and many scenarios, we apply regression analysis to assess the effects of newsvendor parameters on the occurrence of pooling equilibriums. While these regression results cannot be generalized beyond the numerical analysis, they do allow us to efficiently examine and compare all of the combinations of the assumption relaxations that we have proposed.

We use a logit model to estimate the impact of the model parameters on the likelihood of a pooling PBE. We observe that the existence of a pooling PBE is not a pathological phenomenon. Across the 218,880 scenarios, which use continuous support and the Undefeated refinement, a pooling PBE exists and survives refinement 37% of the time. This percentage is 12% for the 656,640 scenarios which use discrete support and the Intuitive Criterion, and 42% for the 656,640 scenarios which use discrete support and the Undefeated refinement. Furthermore, the likelihood of a pooling equilibrium increases in price and salvage value under Undefeated refinement and decreases in price and salvage value under Intuitive Criterion refinement. This contrast is valuable for future research because it can be used to empirically test which refinement is more representative of real data. We also find that the probability of a pooling PBE increases in short-termism

α, decreases in the prior probability of a firm being low type g, and increases in the capacity increment Q.

If management engages in myopic decision making, then some portion of supply chain disruptions may be self-inflicted. With this research, we cast light on the drivers behind such outcomes. Despite a host of empirical and theoretical literature in other fields which indicates that managers do behave myopically, this concept has not been well integrated into supply chain management models. As a result, little is known about when such behavior is more or less likely and what form it may take. We strengthen the current operations management literature by showing: (i) that the real-world and operations-relevant constraints of discrete investment levels and Pareto optimization decision rules yield dramatically different outcomes compared to stylized economic models and (ii) that the newsvendor model parameters play an important and counterintuitive role in these outcomes. In so doing, we are able to explain a broad set of firm investment decisions and reconcile with empirical studies which have found that firms underinvest in capacity.

EVIDENCE ON DECISIONS UNDER INFORMATION ASYMMETRY

To extend the insights from the model described in the previous section, we conduct a controlled experiment that analyzes whether the Undefeated refinement or Intuitive Criterion refinement is more predictive of subject behavior. The experimental setting examines how a manager of a firm (hereafter, the firm) and an investor of the firm interact in the presence of information asymmetry. Recall that the model in Section 2 considers the implications of both discrete capacity decisions and refining the participants' beliefs using the Undefeated refinement as opposed to the Intuitive Criterion refinement. While using discrete support for capacity choices is well justified in the operations literature, the use of the Undefeated refinement has received less attention. Both the Undefeated and Intuitive Criterion refinements are theoretically sound. This experiment, however, is the first direct empirical evidence of whether individuals make decisions which are consistent with the Undefeated refinement or the Intuitive Criterion refinement. We include the Intuitive Criterion refinement, which is based on equilibrium dominance logic, in our analysis because it is arguably the most commonly applied refinement approach in the literature.[i] Despite not being widely employed in the literature, we include the Undefeated refinement in our analysis because it is based on Pareto optimization logic, which we believe is more appropriate to describe decision outcomes in practical operations management settings. The choice of which refinement to employ is at the discretion of the researcher, underscoring the importance of the contribution we make in testing the practical validity of the different outcomes predicted by these refinement methods.

[i] Riley (2001) notes the "Intuitive Criterion has dominated the literature in the years since its introduction."

The assumptions reflected in our experiment[ii] are commonly used in the signaling game literature (Kreps & Sobel, 1992). Participants (N = 102, Median age = 21, 47% female) completed this experiment in a behavioral laboratory at a university on the American East Coast in exchange for $15.00 plus an average bonus of $14.26. Throughout the session, subjects engaged with one another anonymously, through a Web-based software application that was developed for this experiment.

A series of eight scenarios were presented during the experiment. Subjects considered each scenario from both the perspectives of a firm and an investor, resulting in a total of 16 rounds. The outcomes predicted by the Undefeated and Intuitive Criterion refinements differ for most scenarios. Our primary analysis evaluates the consistency of subjects' decisions with the predictions of the tested refinements and we find that participants are much more likely to make decisions that are predicted by the Undefeated refinement than by the Intuitive Criterion refinement. The predictive power of the Undefeated refinement across scenarios ranged from a low of 55.1% accuracy for Scenario 2 to a high of 81.8% accuracy for Scenario 1. In contrast, the predictive power of the Intuitive Criterion across scenarios ranged from a low of 12.0% accuracy for Scenario 4 to a high of 60.8% accuracy for Scenario 6. However, the Undefeated and Intuitive Criterion refinements predict the same outcome for Scenarios 2 and 6, so it is unclear which refinement is driving the results for those scenarios. If Scenarios 2 and 6 are excluded, the Intuitive Criterion refinement predicts the outcome of the experiment at most 16.7% of the time (Scenario 8). We test the predictive power of each refinement using one-sided binomial tests of the null hypothesis that each refinement has no predictive power. To test which refinement is more predictive, we perform a two-sided binomial test of the null hypothesis that neither refinement has predictive power. The Undefeated refinement is strongly predictive of subject behavior and the Intuitive Criterion refinement has no predictive power. The difference in the predictive power between the two refinements is both material and statistically significant.

We are also interested in the relationship between each subject's self-reported level of understanding of the game and the likelihood that their decisions are predicted by either refinement. We expect that in most managerial contexts, decision makers will have a high level of understanding with regard to their choices and their potential implications. As such, we are particularly interested in which refinement mechanism best predicts the behavior of decision makers with a high level of understanding. The results of our empirical estimation of the impact of subject understanding on whether their choices align with the prediction of each refinement. Subjects reporting a high level of understanding of the game were more likely to make choices consistent with the Undefeated refinement than subjects reporting a low level of understanding of the game. Subjects reporting a low level of understanding of the game were more likely to make choices consistent with the Intuitive Criterion refinement than subjects reporting a high level of understanding of the game.

[ii]Two players, one costly signal, and two types of the informed player.

Finally, we evaluate whether subjects who make choices that are consistent with the Undefeated refinement or the Intuitive Criterion refinement earn a higher payoff. To the extent that behavior associated with one refinement methodology is rewarded by investors in our experimental market more than behavior consistent with the other, we would assert that an actual firm, helmed by actual decision makers, may have incentives to exhibit such behavior in practice. We find that subjects who make choices that are predicted by the Undefeated refinement are indeed rewarded by investors, receiving a payoff that is on average 27.5% higher than those making choices predicted by the Intuitive Criterion refinement. None of the choices available to the firm in any round are dominated by any other choice, so the firm is not guaranteed to make more money by making choices that conform to any particular refinement. Instead, the payoffs earned by the firm are in part determined by the actions, and hence the beliefs, of the investors in each round of the game. A higher payoff implies that investors are awarding higher valuations to firms when their choices are consistent with the Undefeated refinement.

Game theory has been used to shed light on a wide range of operations-relevant decisions, including supply chain coordination (Cachon & Lariviere, 2001; Ozer & Wei, 2006; Islegen & Plambeck, 2007), competitive entry (Anand & Goyal, 2009), new product introductions (Lariviere & Padmanabhan, 1997), channel stuffing (Lai, Debo, & Nan, 2011), and capital project and capacity investments (Lai et al., 2012). This research provides experimental evidence that subjects in such settings make decisions that are consistent with the Undefeated refinement, which to our knowledge has not been employed in the operations literature. This result is practically appealing because in general settings the outcomes predicted by the Undefeated refinement yield a Pareto improvement in payoffs over the outcomes predicted by the Intuitive Criterion refinement (a result which we confirm empirically). As revealed in Section 2, however, the Undefeated refinement often predicts underinvestment, which can contribute to the occurrence and magnitude of supply chain disruptions.

MANAGERIAL DISCRETION AND SUPPLY CHAIN DISRUPTIONS

There is abundant anecdotal and empirical evidence that supply chain disruptions negatively affect firm performance (Sheffi, 2005; Hendricks & Singhal, 2005a; Simchi-Levi, Kyratzoglou, & Vassiliadis, 2013). Given these costs, it is understandable that disruptions also negatively affect the firm's value. Developing an accurate assessment of the impact of operational disruptions on firm value is of practical importance because it informs managerial decisions on supply chain structure (Leone, 2006), mitigation investments (Foster, 2005; Bolgar, 2011), and supply chain insurance (Ellis, 2011; Reynolds, 2011). Prior studies show that companies lose in excess of 10% of their market value in the days surrounding the revelation of a disruption (Hendricks & Singhal, 2003; Hendricks & Singhal, 2005b; Sheffi, 2005; World Economic Forum, Accenture, 2013). These studies often rely on management revealing the occurrence of a disruption and on news outlets deciding that the disruption is sufficiently newsworthy to warrant coverage. However, management may choose not to reveal disruptions that damage firm

value, and this strategic behavior can distort the market's response to disruption announcements. Our research sheds light on these tangled relationships.

We gain insight into this issue by taking advantage of a natural experiment – a change in U.S. securities regulations. Section 409 of the Sarbanes-Oxley Act of 2002, implemented during our sample period, requires management to more promptly disclose a wider variety of events that are material to the firm's financial condition. These regulations dramatically increased the number of non-operational events firms must disclose and shortened disclosure deadlines, forcing companies to streamline and formalize their disclosure practices generally, including developing more transparent decision rules, making investments in IT and other infrastructure, and increasing the awareness, visibility, and scrutiny of disclosures (McGee, Raskino, & Wood, 2004; Brown & Nasuti, 2005a, b; Kaarst-Brown & Kelly, 2005). Although the new disclosure requirements had little to do with operational disruptions, we argue that the improved disclosure processes implemented by firms were ultimately applied to all types of disclosures, including the disclosure of operational disruptions. Such formalization can change behavior by introducing greater rigor to disclosure decision making and removing managerial discretion. Importantly, for our analysis, the SEC did not change what constitutes a disclosable operational issue, nor did the SEC lower the threshold for what constitutes a material event (Securities and Exchange Commission, 2004). This distinction allows us to examine the impact of increased formalization of disclosure processes rather than changes to either the set of required operational disruption-specific disclosures or the threshold for what merits disclosure.

We identify disruptions by reviewing company press releases distributed via the PR Newswire and Business Wire. To generate our sample, we search the Factiva database of press releases from January 1, 1998, until December 31, 2011. We construct two samples – one sample to measure the likelihood that a firm makes a disruption announcement and one sample to measure the impact of the disruption announcement on the firm's stock price. We augment this with all quarters during the sample period in which these subject firms were publicly traded. The second sample is used to analyze the impact of increased disclosure on company valuation. We augment these announcements with quarterly earnings announcements one year before and one year after each disruption announcement.

From each announcement, we extract company identifying information, announcement date, earnings information (if provided), and whether the disruption is attributable to the firm's operations, its supply chain, or the environment. We link the information from the disruption and earnings announcements to analysts' expectations of firm earnings from the Institutional Brokers' Estimate System database, firm stock price information from the Center for Research in Security Prices database, and firm financial performance information from the Standard and Poor's Compustat database.

The unit of analysis to examine whether formal disclosure practices influence the likelihood that a firm announces an operational disruption is the firm-quarter. Our empirical estimation uses conditional fixed effects logistic regression with robust standard errors clustered by firm. We find that firms are significantly more likely to disclose disruptions after the enforcement date of Section 409. This implies that managers previously underreported disruptions and that this behavior

changed after adopting more formal disclosure processes. We examine several alternative mechanisms which may explain this result, including managers previously concealing operational disruptions, a lower threshold for materiality when it comes to required disclosures or an increase in management's awareness of disruptions when they occur. We find evidence that managers previously failed to reveal all disruptions and no empirical support for the alternative explanations.

We also evaluate whether formal disclosure practices change the market's response to disruption disclosures. The unit of analysis is the firm-announcement-date. Our empirical estimation uses ordinary least squares regression with firm-level fixed effects and robust standard errors clustered by firm. We find a significant improvement in the stock price impact of an operational disruption announcement once formal disclosure processes are adopted.

With this research, we show that the impact of disruptions on firm value has been exaggerated by informal disruption disclosure practices. While disruptions are damaging, a significant portion of this damage is due to information asymmetry between managers and investors rather than tangible value destruction. This is instructive as it provides evidence that a credible commitment by the firm to improve the disclosure of supply chain issues may alleviate the market's adverse reaction to disruption announcements.

CONTRIBUTIONS AND FUTURE RESEARCH

This research contributes to supply chain management practice and the academic literature in two ways. First, we show the conditions under which management acts strategically both in making operational decisions that lead to supply chain disruptions and in revealing such disruptions to investors. These insights give currency to the notion that disruptions are not entirely random occurrences, and it is therefore possible to take steps to better avoid them. Second, we highlight the particular importance of information asymmetry between the firm and its investors, and how the occurrence and impact of disruptions diminishes as this information asymmetry diminishes. While existing operations management theory and practice acknowledges the role of information asymmetry among supply chain participants, our research is among the first to examine the effect of information asymmetry with external investors, and how it has unintended consequences on supply chain decisions. Extensions to my dissertation research are already underway, including identifying whether privately held companies have different exposure profiles to supply chain disruptions compared to publicly traded companies, developing a better understanding of low-probability/high-impact supply chain disruptions, and the role of supply chain partners in ameliorating or aggravating the effects of such disruptions.

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