Supply Chain Disruptions and the Role of Information Asymmetry

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Abstract

My research examines how firm operational decisions influence and are influenced by firm value. In particular, I focus on these relationships in the context of low probability, high impact disruptions. Over the last several years, companies have faced rising levels of risk and volatility that affect their operations and supply chains. Some recent examples include the unrest in the Middle East, global financial shocks, volcano-related transportation disruptions in Europe, oil price volatility, and natural disasters. As a result, supply chain executives increasingly have a dual mission – to systematically address extreme risks such as hurricanes, epidemics, earthquakes or port closings, and to manage conventional risks, such as forecast errors, sourcing problems, and transportation breakdowns. In an environment where extreme risks are difficult to predict and have a variable impact on the firm, there is no panacea that will fully insulate the company and its operations. With my research I intend to provide firms with meaningful insights on how to manage this uncertainty by measuring and mitigating the level of risk in their operations. My dissertation focuses on one important aspect of this issue – how information asymmetry between the firm and its investors may lead managers within the firm to take actions which increase rather than decrease the firm's exposure to low probability, high impact disruptions.

In the first chapter, I examine the role of information asymmetry in inducing managerial decisions that contribute to supply chain disruptions. I use signaling game theory to develop a stylized model of a capacity investment decision by the firm's management. I integrate the Newsvendor Model, a canonical capacity planning tool, into the signaling game in order to tie the results directly to common operations management decision settings. In the model, the manager has private information about the firm's operations and may take a suboptimal capacity decision in order to signal her private information to an uninformed investor, and thereby influence the short-term stock price of the firm. Distinguishing features of the analysis are that: (i) I allow the capacity decision to be either in discrete increments or continuous, and (ii) I allow beliefs to be refined based on either the Undefeated refinement or the Intuitive Criterion

refinement. Previous research has shown that under continuous decision choices and the Intuitive Criterion refinement, information asymmetry gives rise to the least cost separating equilibrium, in which a low quality firm chooses its optimal capacity and a high quality firm over-invests in order to signal its quality to investors. I build on this research by showing the existence of pooling outcomes in which low quality firms over-invest and high quality firms under-invest so as to provide identical signals to investors. The pooling equilibrium is practically appealing because it yields a Pareto improvement compared to the least cost separating equilibrium. Such an outcome makes clear, however, that managers may knowingly under-invest in capacity.

If management engages in such myopic decision-making, then some portion of supply chain disruptions may be self-inflicted. This has direct implications for how to effectively mitigate disruptions. For instance, proper consideration should be given to the development of managerial incentive schemes to ensure they aren't inducing such undesirable outcomes. To gain some insight on when such myopic decision making can be expected, I run a numerical analysis consisting of approximately 1.5 million scenarios based on the inputs in our model. Feeding the results of this numerical analysis into an empirical model, I show that the parameters of the Newsvendor Model have a significant influence on the likelihood of myopic decision making, and that the magnitude and direction of this influence is highly sensitive to which assumptions are relaxed. Finally, I provide evidence from executive interviews that support the results of our model.

This analysis is important because it provides a tractable model to analyze myopic behavior in a common operations management setting. It is relevant to my research because it shows that supply chain disruptions can be traced to management's purposeful actions, and the circumstances under which such behavior should be expected. It is also surprising because it reveals that the outcomes from the model are highly sensitive to two assumptions which have been widely employed in the literature – capacity choices with continuous support and the application of the Intuitive Criterion refinement.

In the second chapter, I present the results of a controlled experiment that analyzes whether the Intuitive Criterion refinement or the Undefeated refinement is a better predictor of decisions made under information asymmetry. Recall that chapter 1 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 established in the operations literature, the use of the Undefeated refinement has received less attention. Deciding which refinement to employ is central in analyses involving better informed decision makers that are called upon to make choices which may provide a costly yet informative signal to less informed parties. A challenge in such settings is how to handle the plethora of equilibrium outcomes that are often produced from the analysis. Researchers address this issue by using belief refinements, which pare the set of equilibrium outcomes by making assumptions on how the players in the game form their beliefs.

Both the Undefeated and Intuitive Criterion refinements are theoretically sound, and researchers are justified in adopting either approach on those grounds. Our experiment, however, is the first direct empirical evidence of whether individuals make decisions which are consistent with the Undefeated refinement compared to the Intuitive Criterion refinement. I examine this issue in a setting central to operations management – a capacity investment decision. I find that the Undefeated refinement is a much better predictor of individual choices and that these results stand up when greater complexity is added to the game. The proportion of subjects making choices consistent with the Intuitive Criterion, however, is relatively low and reduces further as the complexity of the game increases.

A common criticism of complex experiments is that the subjects may not understand the game, and this lack of understanding governs their behavior. I address this by running practice rounds to acclimate the subjects to the game, having subjects change roles during the game, and requiring subjects to define their strategies before playing each round in the game. I also ask subjects to rate their understanding of the game before they are paid. I show that individuals making decisions which are consistent with the Undefeated refinement report a higher understanding of the game and earn more money from the game.

These results provide strong support that decisions are made consistent with the Undefeated refinement rather than the Intuitive Criterion refinement. This is surprising because the Undefeated refinement has not been applied in our field, and yet it is more predictive of actual decision making. It is also important because, as I show in both chapters 1 and 2, the results generated by the Undefeated refinement can often be materially different compared to those generated by the Intuitive Criterion refinement. For instance, the Undefeated refinement is far more likely to predict a pooling equilibrium such that managers at superior firms commit to lower capacity levels while managers at inferior firms commit to higher capacity levels. This ties to the theme of my research because it demonstrates that superior firms can expose themselves to potential disruption by building out less than the optimal level of capacity.

In the final chapter, I examine whether managers exercise significant discretion in disclosing supply chain disruptions to investors. A major challenge in empirical research on supply chain disruptions is the possibility that selection issues prevent the identification of material, disruptive events. It is not clear whether managerial disclosure of such events is influenced by the expected impact of the event on the firm's share price, nor is it clear whether this impact would differ if managers were more forthcoming. I empirically examine these issues using a sample of over 500 disruption announcements collected from company press releases. I take advantage of an exogenous regulatory shock, the enforcement date of new corporate disclosure rules, to identify whether managers were previously exercising significant discretion in deciding whether or not to reveal material disruptions affecting the firm. I find that after the regulatory change, managers disclosed far more material disruptive events, indicating that they had previously been suppressing their release. I also find that there is a significant amelioration in the average impact of disruptions on firm value after managers improve their disclosure practices. Finally, I show that disruptions attributed to the firm's internal operations are far more damaging to firm value than those attributed to environmental factors, and this difference persists after disclosure is improved.

The impact of disruptions on firm value can vary widely. My findings are important for managers and investors alike because they help identify the types of disruptions and the firm characteristics that contribute disproportionately to the most damaging announcements. Countermeasures to mitigate the risk of disruptions have a cost, and insights into the types of disruptions that represent the greatest risk to company value will help managers assess whether the company is investing appropriately to mitigate the most material risks.

Contents

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Listing of figures

To my amazing wife, Melissa. ILY, IWY, INY. And to my wonderful children. Kisses, Hugs and Head Bumps.

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Signaling to Partially Informed Investors in the Newsvendor Model

1.1 Introduction

We investigate the effect on a firm's capacity decisions of short-term objectives (*short-termism*) and asymmetric information between the firm and its equity holders. 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 (Holmström 1999, Narayanan 1985). Although myopic decision making is decried as damaging the long-term value and competitiveness of firms, it is widely acknowledged to occur. For example, Barton (2011) argues that the "mania over quarterly earnings consumes extraordinary amounts of senior [managers'] time and attention," and expresses dismay at "quarterly capitalism" (in which firms are unduly influenced by short-term market pressures). 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 et al. (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 important to operations management because managers generally prefer operational manipulations over accounting manipulations to meet performance benchmarks (Bruns and Merchant 1990, Graham et al. 2005). Furthermore, evidence of myopic decision making is found in many operational settings, including manipulating inventory levels (Thomas and Zhang 2002), modifying production schedules (Roychowdhury 2006), and postponing or eliminating maintenance, new projects, and R&D expenditures (Bushee 1998, Roychowdhury 2006). Other recent empirical studies provide evidence that such behaviour harms long term performance (Cohen and Zarowin 2010, Holden and Lundstrum 2009, Zhao et al. 2012).

Prior theoretical research in economics and operations has shown that, under standard assumptions commonly used in the signaling game literature, the resulting unique perfect Bayesian equilibrium (PBE) is the least cost separating PBE in which a high quality firm *over-invests* 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 and Stole 1993, Lai et al. 2012). Our paper analyzes a signaling game between a manager of a firm and an equity holder of the firm. The firm can be one of two types with respect to its demand distribution - a low type or a high type. The type or quality of the firm is revealed to the manager but not to the equity holder due to information asymmetry between them. The manager has short-term objectives tied to the current stock price of the firm and makes a capacity investment decision using the newsvendor model. The equity holder uses the manager's capacity decision as a signal of the quality of the firm and determines its stock price. We use this model to (i) identify conditions in which the firm over-invests or under-invests in capacity compared to its optimal long term solution, and (ii) evaluate the role of the newsvendor model parameters in affecting the type of equilibrium and the level of investment.

Our contribution is to build on the existing research by considering two alternative assumptions. 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, p.41). Second, we examine the impact of refining out-of-equilibrium (OOE) beliefs using the Undefeated refinement. We do so in order to address known concerns about the Intuitive Criterion, including that a high quality firm is presumed to choose the separating capacity investment at all costs even if the probability that it is a low quality firm approaches zero (Bolton and Dewatripont 2005, Kreps and Sobel 1992), the equity holder's beliefs are not fully updated by the application of the Intuitive Criterion (Mailath et al. 1993, Salanie 2005), and the Intuitive Criterion may actually eliminate all PBE in the game, leaving a model with no predictive power. These points are discussed in Section 1.5.1.

We show the existence of pooling PBE, including situations in which a low type firm over-invests and a high type firm under-invests, when either or both of the above assumptions are relaxed. First, we show that when the capacity investment choice is discrete, (1) pooling PBE exist, (2) in some cases separating PBE do not exist at all, and (3) in many cases, pooling PBE survive the Intuitive Criterion refinement. Second, when the Undefeated refinement is applied, we show that (4) if one or more pooling PBE exist then at least one survives the Undefeated refinement, and (5) if more than one PBE survives the Undefeated refinement, there is a unique lexicographically maximum sequential equilibrium (LMSE) from this set of PBE. In other words, the alternative refinement process predicts the existence of a unique pooling PBE in identical situations in which the Intuitive Criterion refinement predicts the least cost separating PBE. Therefore, it becomes important to examine the validity of differing predictions of these methods. A rich set of outcomes emerges from our model, such as a high quality firm under-invests while a low quality firm invests optimally, a high quality firm under-invests while a low quality firm over-invests, both high and low quality firm types invest optimally, a high quality firm invests optimally while a low quality firm over-invests, and a high quality firm over-invests while a low-quality firm invests optimally.

One limitation of our paper is that discrete support for the decision variable and the inequalities in the signaling game framework prevent us from getting a closed form solution or comparative statics. Despite this, our paper makes a valuable contribution because discrete choices are important in operations management and we are able to show that they produce a different equilibrium result. We examine our theoretical results through an exhaustive numerical analysis and evidence from practitioners. Our numerical analysis shows that the existence of a pooling PBE is not a pathological phenomenon. Depending on which combination of assumptions are relaxed, a pooling PBE uniquely survives refinement in 12% to 42% of the examined scenarios. The numerical analysis enhances the predictions of the theoretical model by showing that there is a sharp difference between the outcomes from the two competing refinements. We confirm the reasonableness of our results in practical settings through interviews with executives. Our interview with the current Chairman of Clarins Group shows that high type firms can face significant pressure from investors to under-invest in capacity due to information asymmetry and short-term market demands. On the other hand, our interview with the former CEO of Arrow Electronics in the context of B2B e-commerce shows that low type firms can over-invest in capacity when facing information asymmetry and short-term market demands. Our result also captures the phenomenon found empirically in Bushee (1998), Graham et al. (2005), Roychowdhury (2006) and others in which firms *under-invest* in long term projects.

1.2 Literature Review

Signaling game theory has been utilized to study a wide range of topics involving information asymmetry, such as consumer purchases (Debo and Veeraraghavan 2010, Milgrom and Roberts 1986), competitive entry (Aghion and Bolton 1987, Anand and Goyal 2009), new product introductions (Lariviere and Padmanabhan 1997), franchising (Desai and Srinivasan 1995), channel stuffing (Lai et al. 2011), supply chain coordination (Cachon and Lariviere 2001, İşlegen and Plambeck 2007, Özer and Wei 2006), and capital project and capacity investments (Bebchuk and Stole 1993, Lai et al. 2012). Our paper applies this theory to the operations-finance interface wherein not only information asymmetry but also short-termism occurs, leading to a distortion of managerial decisions. We build on the broad signaling game literature by considering alternative assumptions that are widely acknowledged but have not been utilized in the operations-finance literature.

Our paper is closest to Bebchuk and Stole (1993), Lai et al. (2012), and Lai et al. (2011), which examine signaling games between managers and investors under information asymmetry and short-termism. Bebchuk and Stole (1993) model an informed firm which uses its continuous capacity investment decision to signal the expected return on its capital project to outside investors. They show the existence of a separating equilibrium in which the firm over-invests if it faces a more profitable project. Lai et al. (2012) extend the model of Bebchuk and Stole (1993) by investigating the effect of supply chain contracts on the equilibrium outcome. They show that a firm facing a superior demand distribution will separate by over stocking relative to its long run optimal stocking quantity, but a menu of buy-back contracts can restore efficiency to the supply chain. Lai et al. (2011) show that in order to improve short-term valuation, a firm may utilize channel stuffing to inflate its reported sales in the first period and signal higher demand in the second period. A semi-pooling PBE may result because the amount of channel stuffing is limited by available inventory such that for certain levels of demand, some firm types do not have enough inventory to separate. These papers differ from our paper by assuming that the signal, i.e., the capacity or stocking decision, has continuous support, and the participants in the game refine their beliefs using the Intuitive Criterion refinement or logic that is consistent with the same.

Much of the broader operations management literature utilizing signaling game theory emphasizes separating PBE outcomes over pooling PBE outcomes. Cachon and Lariviere (2001), Özer and Wei (2006) and İşlegen and Plambeck (2007) acknowledge that pooling PBE may exist, but focus their analyses on investigating the least cost separating PBE such that the sender of the signal can credibly reveal her type. Bebchuk and Stole (1993) also do not consider any pooling PBE and instead focus exclusively on market beliefs which support the separating PBE. However, ignoring pooling PBE outcomes precludes a full analysis of when the proposed separating PBE is likely to be the only PBE to survive refinement. Other research papers use assumptions under which pooling PBE outcomes do not survive refinement, i.e., that the participants in the game refine their beliefs using the Intuitive Criterion refinement (or logic that is consistent with the same), the signal has continuous and infinite support, and there are two types of the informed player. These papers include Lai et al. (2012), Desai and Srinivasan (1995) studying a model of an informed franchisee using royalties and franchising fees to signal the quality of demand to an uninformed franchisor, and Lariviere and Padmanabhan (1997) modeling an informed manufacturer using wholesale prices and slotting fees to signal the quality of demand to an uninformed retailer.

There are more intricate signaling models in which pooling PBE are possible, such as those with complex signals or more than two players. For instance, Debo and Veeraraghavan (2010) explore how firms may use two signals of quality, prices and congestion, to attract uninformed consumers. The cost of the congestion signal differs between the firm types, but the price signal has equal cost to both firm types in a pooling equilibrium. The authors find that in some circumstances both firm types will select the same price signal. For instance, if the low-quality firm type has a faster service rate than the high-quality firm type, pooling on price may ensue since a low-quality firm can mimic the high-quality firm type by slowing service (increasing congestion) and raising prices. Anand and Goyal (2009) investigate a signaling game with three players – an incumbent firm, an entrant firm and a common supplier. The incumbent has superior information compared to the entrant concerning the quality of its demand.

We build on and contribute to the operations management-finance literature by showing that, under discrete decision choices and/or undefeated refinement, the commonly recognized least cost separating equilibrium may not occur. Instead, a pooling PBE outcome occurs. This outcome is beneficial to firms and investors because it is Pareto improving compared to the least cost separating equilibrium. Our model reconciles with the abundant empirical evidence that firms often under-invest in capacity (Bushee 1998, Graham et al. 2005, Roychowdhury 2006). Moreover, we show that the newsvendor model parameters not only impact the likelihood that a pooling PBE uniquely survives refinement, but that this impact differs in both sign and magnitude depending on which refinement is employed.

1.3 Model Setup

We analyze a signaling game with two players, N and E, and two time periods, 1 and 2. Player N is a newsvendor firm (she/her) and player E is an equity holder (he/him). Period 1 represents the short term and period 2 represents the long term. The players move sequentially under incomplete information. We focus on the relatively common scenario in which a firm's equity holder has less information than the firm concerning the *quality* of demand for the firm's product (Berle and Means 1932, Stein 1988). The firm can be of two types, τ_L and τ_H, that differ only in the probability distribution of demand. Let $g(\tau), \tau \in T = \{\tau_L, \tau_H\}$ be the probability by which nature chooses the type of the firm, and let $f_\tau(\cdot)$ and $F_\tau(\cdot)$ denote the probability density function and cumulative distribution function, respectively, of demand if the firm is type τ. We assume that f_τ is greater than 0 over an interval on $\Re^+$ and 0 elsewhere. The demand distribution for a τ_H type first order stochastically dominates (FOSD) the demand distribution for a τ_L type, i.e., $F_L(x) \geq F_H(x)$ for all $x \in \Re^+$ and $F_L(x) > F_H(x)$ for some x.

The firm seeks to maximize her expected utility by choosing a capacity investment η to serve random demand. She is a price-taker in her product market, and has a purchase cost c, selling price r, and salvage value s of unsold inventory; $r > c > s$. When we enforce the assumption that capacity has continuous support, then $\eta \in \Re^+$. When capacity has discrete support, we model that it is purchased in multiples of lot size Q, i.e., $\eta = nQ$ for some integer n. Discrete capacity investment levels reflect real-world constraints which firms often face when making capacity decisions. The fixed quantity may represent a container load, server, factory, or a production batch (Nahmias 2008). At one extreme, as Q becomes large, the model captures "all or nothing" investment decisions faced by the firm; at the opposite extreme as Q becomes small, the model results converge with those when $\eta \in \Re^+$ is assumed. We discuss the implications of the size of Q in Section 1.6. All the parameters in the model except the firm's type are common knowledge because they can be credibly communicated to the equity holder whereas the demand forecast cannot be.

The firm moves first. At the start of period 1, she receives a private signal about her type. Then she chooses a capacity investment η, which may convey information about her type to the equity holder. The equity holder observes the firm's capacity decision but not her type. He moves second by assigning a short-term valuation (i.e. a price) to the firm. Subsequently, in period 2, the demand is realized and the firm makes a profit or a loss. This time-line is supported by the classical lead time argument in the newsvendor model. To ease the exposition of the main points of our analysis, we assume that the firm is dissolved at the end of period 2 and its proceeds are distributed to the equity holder.

The equity holder's prior beliefs of the firm's type are $g(\tau)$. His posterior beliefs of the firm's type after seeing the firm's signal η are denoted as $\lambda(\tau)$. The price that the equity holder assigns to the firm after receiving signal η is $\rho(\eta) \in P(\eta)$. From this set of all possible prices, the set of the equity holder's pure-strategy best responses to signal η is represented as $P^*(T', \eta)$, where T' represents his posterior assessment of firm types, i.e., T' is a non-empty subset of T such that $\lambda(T') = 1$.

The firm's utility is a linear combination of the equity holder's valuation of the firm in period 1 and his expected valuation in period 2, weighted by α and $1-\alpha$ respectively, where $\alpha \in [0, 1]$. A larger value of α corresponds to a higher emphasis on short-term valuation and a correspondingly lower emphasis on the expected long-term valuation. Note that the actual valuation of the firm in period 2 will be identical to the firm's actual profit. The expected long-term valuation of the firm comes directly from the newsvendor model, $\pi(\tau, \eta) = E_\tau \left[r \min\{\eta, x\} + s(\eta - x)^+ - c\eta\right]$. Therefore, the firm maximizes the following utility function with respect to its discrete capacity decision:

$$U(\tau, \eta, \rho) = \alpha\rho(\eta) + (1-\alpha)\pi(\tau, \eta). \tag{1.1}$$

The equity holder operates in a perfectly competitive market and seeks to maximize his utility, which depends on his valuation error of the firm. To capture this, we adopt a utility function for the equity holder suggested in Gibbons (1992) that is of the form

$$V(\tau,\eta,\rho) = -[\pi(\tau,\eta) - \rho(\eta)]^2.$$

This utility function corresponds to the equity holding wanting to set a stock price such that his error is minimized. Instead of assuming a single equity holder with this utility function, we could have assumed that the firm's equity is traded in an efficient market comprised of many investors, which then determines the valuation. This alternative would lead to the same pricing function as the above utility function does, and thus, has no bearing on the results. Assuming a single equity holder enables us to model the actions of the equity holder more clearly.

The newsvendor model is commonly used as a framework for capacity and stocking decisions under demand uncertainty (Chod et al. 2010, Van Mieghem 2008). Thus, our model is generalizable to a wide range of project investment decisions that a firm may encounter, including plant expansions, capital expenditures, and contracting for production inputs. In addition, the information asymmetry in our model can be generalized beyond product demand to other situations such as the firm having better insight into the effectiveness of an emerging technology, its internal cost structure, the value of a new supply chain configuration, or the potential size of a new market.

1.3.1 Complete Information or No Short-termism

Under complete information, the firm's utility function in (1.1) simplifies to the newsvendor expected profit function. Let η_L^* denote the smallest capacity investment that maximizes the utility of a τ_L type when $\lambda(\tau_L) = 1$, and η_H^* denote the smallest capacity investment that maximizes the utility of a τ_H type when $\lambda(\tau_H) = 1$. Here and elsewhere, we consider the minimum over alternative solutions because in cases when η is discrete there could be two alternative optimal solutions for either firm type. Our results are unaffected if we instead use the alternative maximizers.

$$\eta_j^* = \min\left\{\eta : \arg\max_{\eta} \pi(\tau_j,\eta)\right\}, \qquad j = L, H.$$

The classical newsvendor result is also recovered when the firm's short-termism, α, is equal to zero. In this case, the firm's utility function is determined solely by its expected long-term valuation, which the firm again optimizes by a straight application of the newsvendor model.

While the classical newsvendor result is recovered when there is no information asymmetry or no short-termism, the motivation for the firm is different in the two cases. In the former, both players in the game have the same information, so there is nothing to be gained if the firm were to act in a way that was not in accordance with its type, even if the firm had an interest in its short-term valuation. In the latter case, regardless of whether there is information asymmetry, the firm has no interest in its short-term valuation and is motivated solely to optimize its long term valuation. Both information asymmetry and short-termism must be present in order for the firm to deviate from its long-term optimal capacity investment.

1.3.2 Incomplete Information *and* Short-termism

We show conditions under which pooling and separating PBE exist and the conditions under which these PBE survive refinement. We note that equilibrium capacity investments in our model cannot be expressed in closed-form formulas because they involve discrete variables and inequalities among utility functions. Therefore, we illustrate the theoretical results with numerical examples. According to Kreps and Sobel (1992), a pooling PBE is an equilibrium in which the firm chooses the same strategy regardless of its type, and a separating PBE is an equilibrium in which each type of firm chooses a different strategy. We apply the definition of a PBE derived from Fudenberg and Tirole (1991); please refer to Definition 1 in the Appendix. Intuitively, in a PBE, the equity holder maximizes his utility by setting a price that reflects his posterior beliefs formed after observing the firm's choice of capacity investment. The firm chooses a capacity investment while recognizing the implications of this choice on the equity holder's posterior beliefs. Neither player has an incentive to deviate from the equilibrium strategy.

Based on Definition 1, the equity holder's best response price function conditional on his posterior beliefs and the firm's capacity choice is found by solving $\arg\max_\rho \sum_\tau \lambda(\tau)V(\tau,\eta,\rho)$. This gives the price assigned by the equity holder as:

$$\rho^*(\eta|\lambda(\tau)) = \lambda(\tau_L)\pi(\tau_L,\eta) + \lambda(\tau_H)\pi(\tau_H,\eta), \tag{1.2}$$

which is a weighted average of the expected profits for each firm type based on the equity holder's posterior belief that the firm is in fact of that type. It is useful to distinguish among three specific valuations of the firm by the equity holder that lead to different capacity decisions. A *low* valuation occurs when the equity holder sets the posterior beliefs as $\lambda(\tau_L) = 1$, a *weighted* valuation occurs when the equity holder sets the posterior beliefs as $\lambda(\tau) = g(\tau)$ so they are equal to the prior beliefs, and a *high* valuation corresponds to $\lambda(\tau_H) = 1$. Note that the price is a function of both η and $\lambda(\cdot)$. We write the price as ρ^* when the posterior beliefs are clear from the context, and as $\rho(\eta|\lambda(\tau))$ when we refer to the price for a specific posterior belief.

With this price function, the firm's utility in (1.1) can be rewritten as

$$U(\tau, \eta, \rho^*) = \begin{cases} (1 - a + a\lambda(\tau_L))\pi(\tau_L, \eta) + a\lambda(\tau_H)\pi(\tau_H, \eta) & \text{for } \tau = \tau_L, \\ a\lambda(\tau_L)\pi(\tau_L, \eta) + (1 - a + a\lambda(\tau_H))\pi(\tau_H, \eta) & \text{for } \tau = \tau_H. \end{cases} \quad (1.3)$$

As $\lambda(\tau_H)$ increases, first order stochastic dominance implies that $U(\tau, \eta, \rho^*)$ increases and the optimal capacity investment of the firm also increases regardless of her type.

Now consider the posterior beliefs of the equity holder. One challenge in analyzing a PBE is that the definition of a PBE does not fully characterize the posterior beliefs even as it defines the strategy profiles of players. According to Definition 1, the posterior beliefs are given by Bayes Rule at equilibrium points but are undefined on OOE belief paths because Bayes rule cannot be applied on OOE paths. For example, if there exists a pooling equilibrium in which the firm chooses capacity $\hat{\eta}$ regardless of its type, then the posterior beliefs of the equity holder *in equilibrium* will be equal to his prior beliefs, i.e., $\lambda(\tau) = g(\tau)$, but are undefined for all other choices of η.

Thus, the equity holder could, in theory, have any arbitrary OOE beliefs about the type of the newsvendor. The literature suggests many refinements of varying restrictiveness to determine OOE beliefs that are reasonable and any resulting equilibrium is hence justifiable. We apply strict dominance, which is a mild requirement that eliminates those signals for the first player that are strictly dominated with respect to all possible responses from the second player. In sections 1.5.1 and 1.5.2 we go on to apply the more restrictive Intuitive Criterion and Undefeated refinements.

Strict dominance is defined in Definition 2 in the Appendix. In words, equation (1.11) states that a signal is strictly dominated for a firm type if the best utility which that type could possibly achieve by sending that signal is strictly lower than the worst utility which that type could possibly achieve by sending some other signal. A PBE has reasonable beliefs if those beliefs do not put a positive probability on any type sending a signal that is strictly dominated. Applying strict dominance gives us a threshold capacity investment, η^s, such that the equity holder will be certain that the newsvendor is of type τ_H if and only if he observes a capacity investment equal to or greater than η^s. This result is stated in the following lemma. All proofs are in the online Appendix unless stated otherwise.

Lemma 1 *There exists a capacity investment η^s defined as*

$$\eta^s = \min\left\{\eta : \eta \geq \eta_H^* \ \ \& \ \ U(\tau_L, \eta, \rho(\eta|\lambda(\tau_H) = 1)) < U(\tau_L, \eta_L^*, \rho(\eta_L^*|\lambda(\tau_L) = 1))\right\}$$

such that the equity holder's reasonable beliefs are $\lambda(\tau_H) = 1$ if $\eta \geq \eta^s$ and $\lambda(\tau_H) < 1$ otherwise.

Intuitively, a τ_L type has no incentive to choose a capacity at or above η^s because she receives a lower utility under a *high* valuation than by choosing capacity η_L^* under a *low* valuation. As a result, if the firm chooses η^s, she must be a τ_H type and will therefore receive a *high* valuation. Thus, η^s represents the smallest quantity that a τ_H type will choose in order to separate, and is referred to as the least cost separating quantity. Note that $\eta^s \geq \eta_H^*$ because if a τ_H type can separate at a quantity less than η_H^* she will still choose η_H^* in order to optimize her utility under no information asymmetry. Moreover, any choice of $\eta > \eta^s$ is dominated for all firm types. No firm type has an incentive to send such a signal nor can they credibly threaten to send such a signal.

1.4 Existence of Pooling and Separating PBE

This section shows that both pooling and separating PBE exist when the firm's capacity decision is discrete. In the online Appendix, we show the analogous result when the capacity investment decision is a continuous variable. The next section builds on these results by showing which equilibria survive the Intuitive Criterion refinement or the Undefeated refinement. In order to simplify the exposition, we focus our analysis on situations in which neither the firm nor the equity holder pursues dominated strategies or makes mistakes in solving the respective utility maximization problems. In addition, we consider only pure strategies by the players.

1.4.1 Pooling PBE

Many combinations of capacity investment and posterior beliefs may lead to pooling equilibria. Let η^p be the smallest capacity investment that maximizes the expected utility of a τ_H type under the *weighted* valuation, i.e.,

$$\eta^p = \min\left\{\eta : \arg\max_{\eta} U(\tau_H, \eta, \rho(\eta|\lambda(\tau) = g(\tau)))\right\}. \tag{1.4}$$

This quantity is important because we later show that when there is a pooling equilibrium at η^p, it always survives under the Undefeated refinement criterion. Here again, we consider the minimum over alternative solutions because there can be two solutions when η is discrete. Our results are unaffected if we instead use the alternative maximizer.

Proposition 1 *When $\eta = nQ$ for $n \in \mathbb{Z}$ and capacity increment Q, there exists a pooling PBE in which the firm chooses capacity $\eta^p < \eta^s$ regardless of its type, the equity holder's response function ρ^* is given by (1.2), and equity holder's reasonable posterior beliefs are given by*

$$\lambda(\tau_L) = 1 - \lambda(\tau_H); \qquad \lambda(\tau_H) = \begin{cases} 0 & \eta < \eta^p, \\ g(\tau_H) & \eta^p \leq \eta < \eta^s, \\ 1 & \eta \geq \eta^s, \end{cases} \tag{1.5}$$

if the following two conditions hold:

$$U(\tau_L, \eta^p, \rho^*) \quad > \quad U(\tau_L, \eta_L^*, \rho^*), \tag{1.6}$$
$$U(\tau_H, \eta^p, \rho^*) \quad > \quad U(\tau_H, \eta^s, \rho^*), \tag{1.7}$$

Intuitively, this proposition indicates that for a pooling PBE to exist, both types must prefer the pooling outcome to their guaranteed outside option. This proposition follows from the construction of η^p and posterior beliefs (1.5). The proof of the proposition consists of verifying that η^p maximizes the firm's utility function under (1.5). Inequalities (1.6) and (1.7) are independent of one another and imply different requirements: (1.6) states that the utility derived by a τ_L type from choosing capacity η^p must be larger than the utility derived by a τ_L type choosing capacity η_L^*; (1.7) states that the utility derived by a τ_H type from choosing capacity η^p must be larger than the utility derived by a τ_H type choosing capacity η^s, which represents the least cost separating capacity investment. Note that as Q gets smaller then (1.6) will be violated only if (1.7) is violated (refer to Lemma 3 in the online Appendix for the intuition). Example 1 below illustrates the results of this proposition.

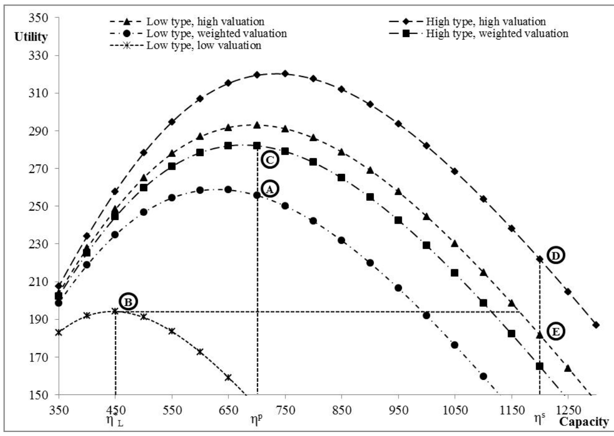
Example 1. Suppose that demand follows a log-normal distribution with log-scale parameters $\mu_L = 6.0$ and $\mu_H = 6.5$, and shape parameters $\sigma^2 = \sigma_L^2 = \sigma_H^2 = 0.15$, where $\sigma_L^2 = \sigma_H^2$ is required to maintain FOSD. In addition, $r = 1.00$, $c = 0.40$, $s = 0.00$, $Q = 50$, the extent of short-termism is $\alpha = 0.85$, and the probability that the firm is type τ_L is $g(\tau_L) = 0.25$. We find that $\eta_L^* = 450$, $\eta^p = 700$, $\eta_H^* = 750$ and $\eta^s = 1200$. Figure 1.4.1a displays the utility functions for a τ_L type under the *low*, *weighted* and *high* valuations, and for a τ_H type under the *weighted* and *high* valuations, with the solid points representing the achievable utilities for each type at feasible capacity investments that are multiples of Q.

Points B and E show that choosing capacity equal to or greater than η^s will provide a τ_L type with a lower expected utility under a *high* valuation than choosing capacity $\eta_L^* = 450$ under a *low* valuation. Therefore, under the definition of strict dominance, reasonable beliefs by the equity holder should place zero probability that a firm choosing capacity $\eta \geq \eta^s$ is a τ_L type.

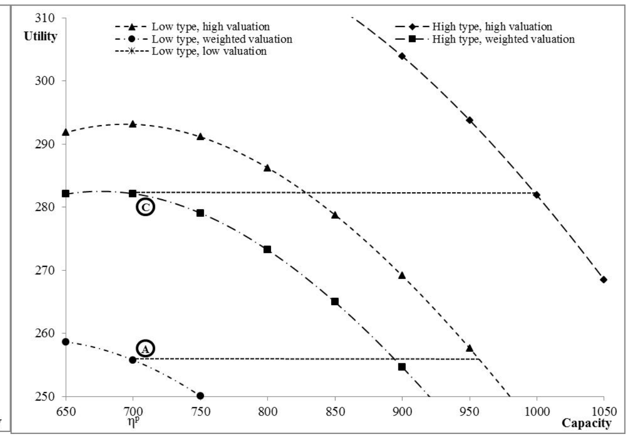
We apply the two conditions of Proposition 1. The relevant expected utilities are $U(\tau_L, \eta^p, \rho^*) = 255.8$, $U(\tau_L, \eta_L^*, \rho^*) = 194.2$, $U(\tau_H, \eta^p, \rho^*) = 282.1$ and $U(\tau_H, \eta^s, \rho^*) = 221.8$. Thus, both conditions are met and a pooling PBE exists at $\eta^p = 700$. The expected utilities are shown in Figure 1.4.1a by points labeled A, B, C and D, respectively. ■

Figure 1.4.1: Utility functions for a τ_L type under the low, weighted and high valuation, and for a τ_H type under the weighted and high valuation. The model parameters are: $\alpha = 0.85$, $g(\tau_L) = 0.25$, demand follows a log-normal distribution with log-scale parameters $\mu_L = 6.0$ and $\mu_H = 6.5$, shape parameters $\sigma^2 = 0.15$, $r = 1.00$, $c = 0.40$, $s = 0.00$, $Q = 50$.

(a) Firm utility functions showing a pooling PBE at $\eta^p = 700$.



(b) Firm utility functions showing that the pooling PBE at $\eta^p = 700$ survives the Intuitive Criterion refinement.



1.4.2 Multiple Pooling PBE

Other pooling PBE can be similarly constituted using different reasonable belief structures for the equity holder. Let η^{gp} be any capacity investment less than η^s. Corollary 1 (proof omitted) helps us determine all possible values of η^{gp} at which there will be a pooling PBE under reasonable beliefs.

Corollary 1 *When $\eta = nQ$ for $n \in \mathbb{Z}$ and capacity increment Q, there exists a pooling PBE in which the firm chooses capacity $\eta^{gp} < \eta^s$ regardless of its type, the equity holder's response function ρ^* is given by (1.2), and posterior beliefs which are reasonable under strict dominance are given by*

$$\lambda(\tau_L) = 1 - \lambda(\tau_H); \qquad \lambda(\tau_H) = \begin{cases} 0 & \eta < \eta^s \text{ and } \eta \neq \eta^{gp}, \\ g(\tau_H) & \eta = \eta^{gp}, \\ 1 & \eta \geq \eta^s, \end{cases} \tag{1.8}$$

if the following three conditions hold:

$$\begin{aligned} U(\tau_L, \eta^{gp}, \rho^*) &> U(\tau_L, \eta_L^*, \rho^*), \\ U(\tau_H, \eta^{gp}, \rho^*) &> U(\tau_H, \eta^s, \rho^*), \\ U(\tau_H, \eta^{gp}, \rho^*) &> \max_{\eta'} U(\tau_H, \eta', \rho(\eta'|\lambda(\tau_L) = 1)). \end{aligned}$$

Corollary 1 identifies all possible pooling PBE under reasonable beliefs since (1.8) represents the posterior beliefs that are most conducive to a pooling PBE under strict dominance. Other posterior beliefs may also support these pooling PBE. The first two conditions in the corollary are identical to those in Proposition 1 applied to η^{gp} instead of η^p. The third condition is new. It states that the utility derived by a τ_H type at η^{gp} must exceed the highest possible utility derived by a τ_H type under low valuation. This condition is not required in Proposition 1 because it is always met at η^p.

Example 1, continued. Using Corollary 1, all of the pooling PBE can be identified to be at $\eta^{gp} = 400$, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900 and 950. As noted earlier for this example, $\eta^s = 1200$. For each pooling PBE, $U(\tau_L, \eta^{gp}, \rho^*) > U(\tau_L, \eta_L^*, \rho^*) = 194.2$, $U(\tau_H, \eta^{gp}, \rho^*) > U(\tau_H, \eta^s, \rho^*) = 221.8$, and $U(\tau_H, \eta^{gp}, \rho^*) > U(\tau_H, \eta', \rho(\eta'|\lambda(\tau_L) = 1) = 204.2$, where $\eta' = 500$ maximizes the utility function for a τ_H type under *low* valuation. Thus, all the conditions of Corollary 1 are met. ■

We show in the online Appendix that pooling PBE exist if we assume that the capacity investment, η, has continuous support on $\Re^+$. Assuming continuous support allows us to simplify Proposition 1 and Corollary 1, which we restate in the online Appendix as Proposition 5 and Corollary 2.

1.4.3 Separating PBE

The least cost separating PBE has a τ_L type choosing $\eta = \eta_L^*$ and a τ_H type choosing η^s, which respectively represent their optimal capacity investment choices in a separating PBE under reasonable beliefs. We show in Proposition 2 that a separating PBE may not exist under discrete capacity choice. This result complements previous papers in the literature, which show that the least cost separating PBE always exists for continuous capacity investment levels.

Proposition 2 *The least cost separating PBE cannot exist under any reasonable belief structure unless:*

$$U(\tau_H, \eta^s, \rho^*) \geq \max_{\eta'} U(\tau_H, \eta', \rho(\eta'|\lambda(\tau_L) = 1)). \tag{1.9}$$

Intuitively, this proposition identifies that in some cases the least cost separating PBE is too expensive for a τ_H type. If (1.9) holds, then there will be a separating PBE under some reasonable belief structure, namely $\lambda(\tau_H) = 1$ for capacity investment $\eta \geq \eta^s$ and $\lambda(\tau_H) = 0$ for $\eta < \eta^s$. On the other hand, if (1.9) does not hold, then the maximum utility that a τ_H type can achieve by separating is strictly less than the utility that she could achieve by choosing the optimal capacity investment under the *low* valuation and therefore a τ_H type has no incentive to separate. Moreover, in this case, a pooling PBE under Corollary 1 will exist. Thus, the conditions in Corollary 1 and Proposition 2 cover all pure strategy PBE possibilities, but are not mutually exclusive or disjoint. Both the least cost separating PBE and potentially multiple pooling PBEs may exist for the same scenario but utilizing different OOE beliefs. The resulting multiplicity of equilibria motivates the discussion on refinements in Section 1.5.

Example 1, continued. Applying Proposition 2, a least cost separating PBE exists in which a τ_H type chooses capacity $\eta^s = 1200$ and a τ_L type chooses capacity $\eta_L^* = 450$. The relevant utilities to check for the existence of the least cost separating PBE are $U(\tau_H, \eta^s, \rho^*) = 221.8$ and $U(\tau_H, \eta', \rho(\eta'|\lambda(\tau_L) = 1)) = 204.2$, where $\eta' = 500$ maximizes the utility function for a τ_H type under *low* valuation. Thus, we have multiple potential equilibria in this example. ■

Example 2. In this example, a separating PBE does not exist. Let the log-scale parameter for a τ_H type be $\mu_H = 6.25$ while all other parameters are as in Example 1. We have $\eta_L^* = 450$, $\eta_H^* = \eta^p = 550$, and $\eta^s = 850$. A τ_H type obtains an expected utility of 199.7 by choosing capacity η^s under the *high* valuation. Under *low* valuation, the utility of a τ_H type is maximized by choosing capacity 450 and is equal to 200.4. Thus, by Proposition 2, the firm will choose not to separate. Instead, multiple pooling PBE exist under Corollary 1, namely at $\eta = 400, 450, 500, 550, 600, 650$ and 700. ■

1.5 Refinement of Out-of-Equilibrium Beliefs

Refining OOE beliefs can reduce the number of predicted PBE outcomes in a signaling game. This is useful because having multiple potential PBE outcomes is less informative in many settings than having just a few or even one predicted outcome. In Section 1.5.1, we demonstrate the effect of discretizing the capacity choice on the outcome of the Intuitive Criterion refinement. In particular, one or more pooling PBE can survive refinement along with the least cost separating PBE (if it exists under Proposition 2), or no PBE may survive refinement. In section 1.5.2, we show that when the Undefeated refinement is applied and at least one pooling PBE exists under Corollary 1 or Corollary 2, then at least one of these pooling PBE will survive refinement, but the least cost separating PBE will not. Thus, that section demonstrates the effect of relaxing the Intuitive Criterion refinement under both continuous and discrete capacity choices.

1.5.1 The Intuitive Criterion Refinement

The Intuitive Criterion refinement is applied by evaluating all possible OOE capacity investment levels for a particular PBE and identifying whether, compared to the PBE results, a capacity investment exists which *would not* provide a τ_L type with a higher utility using a *high* valuation but *would* provide a τ_H type with a higher utility using a *high* valuation. If such a capacity investment does exist then the PBE is eliminated. The least cost separating PBE, if it exists under Proposition 2, survives the Intuitive Criterion refinement by construction. The formal definition of the Intuitive Criterion refinement is developed in Cho and Kreps (1987) and provided in the Appendix using our notation. The following proposition gives the conditions for the pooling PBE at η^p to survive the Intuitive Criterion.

Proposition 3 *The pooling PBE identified in Proposition 1 will survive the Intuitive Criterion refinement if and only if there does not exist a capacity investment, η', for which both of the following conditions are true: (i) $U(\tau_L, \eta^p, \rho^*) > U(\tau_L, \eta', \rho(\eta'|\lambda(\tau_H) = 1))$ and (ii) $U(\tau_H, \eta^p, \rho^*) < U(\tau_H, \eta', \rho(\eta'|\lambda(\tau_H) = 1))$.*

In words, the first condition states that the utility for a τ_L type is greater at the pooling PBE involving η^p than at an alternative capacity investment, η', under a *high* valuation. The second condition states that the utility for a τ_H type is less at the pooling PBE involving η^p than at this alternative capacity investment, η', under a *high* valuation. If an alternative capacity investment, η', that meets both conditions does not exist then the equilibrium will survive the Intuitive Criterion refinement. By replacing η^p with η^{gp}, Proposition 3 can equivalently be used to test whether any of the pooling PBE identified by Corollary 1 also survives the Intuitive Criterion refinement.

Note that the conditions in Proposition 3 are always satisfied (i.e., an η' will always exist) for capacity decisions with continuous support. Therefore, no pooling PBE will survive the Intuitive Criterion refinement if the decision space is continuous in a game such as ours, i.e. a game with two types of the informed player and a single costly signal with infinite support (Cho and Kreps 1987, Mas-Colell et al. 1995). In contrast, Proposition 3 implies that multiple equilibria can survive the Intuitive Criterion refinement, including the least cost separating equilibrium and one or more pooling PBE, if the decision space is discrete. Thus, this refinement does not result in a unique prediction under discrete capacity choice.

We consider alternatives to this refinement method because the Intuitive Criterion may not be appropriate in all operations management settings. As noted by Bolton and Dewatripont (2005), "as plausible as the Cho-Kreps Intuitive Criterion may be, it does seem to predict implausible outcomes in some situations." Indeed, the application of certain belief-based refinements such as the Intuitive Criterion is unsettled in the game theory literature (Mailath et al. 1993, Riley 2001). One concern is that a τ_H type is presumed to choose the separating capacity investment, η^s, even if such a choice is Pareto-dominated by a pooling capacity investment. The Intuitive Criterion refinement does not eliminate the separating equilibrium even if the probability of the firm being a τ_L type approaches zero (Bolton and Dewatripont 2005, Kreps and Sobel 1992). This results in a discontinuity in the choice of capacity investment for a τ_H type (from η^s to η^*_H) when $g(\tau_L)$ goes from a value of $\varepsilon > 0$ to 0 (Mailath et al. 1993).

A second concern is that the Intuitive Criterion assumes that the participants in the game can communicate counterfactual information to other participants by way of "speeches," but these speeches are not explicitly modeled in the game (Salanie 2005). One implication of this is that the equity holder's beliefs, specifically their beliefs at the proposed OOE point, are not fully updated by the application of the Intuitive Criterion. This casts doubt on whether the deviation proposed by the Intuitive Criterion can actually be considered an unambiguous signal of the firm's type (Mailath et al. 1993).

A third concern is that when a least cost separating PBE does not exist (as in Proposition 2) then the Intuitive Criterion refinement may actually eliminate all PBE in the game. This eliminates any predictive power that would otherwise be provided from the analysis of the signaling game. Example 5, summarized in Table 1.5.1, shows such an outcome.

Example 1, continued. This example shows that multiple PBE survive the Intuitive Criterion refinement. The least cost separating PBE in which a τ_H type chooses capacity $\eta^s = 1200$ and a τ_L type chooses capacity $\eta^*_L = 450$ survives the Intuitive Criterion refinement by construction. Based on Proposition 3, the pooling PBEs at 700, 800, 900 and 950 also survive the Intuitive Criterion refinement. Figure 1.4.1b shows this in greater detail for the pooling PBE at $\eta^p = 700$. Compared to the pooling PBE at $\eta^p = 700$, a τ_L type is willing to invest in capacity up to 950 units in order to receive a *high* valuation, but a τ_H type is unwilling to invest in capacity more than 950 units in order to receive a *high* valuation in lieu of the *weighted* valuation. Therefore, as required by Proposition 3, there is no capacity investment to which a τ_H type is willing to deviate from η^p under a *high* valuation but a τ_L type is unwilling to deviate from η^p under a *high* valuation.

Example 3. This example illustrates the first criticism of the Intuitive Criterion refinement, namely that it may identify the least cost separating PBE as the unique surviving PBE even if another PBE is a Pareto improvement over it. Let demand follow a log-normal distribution with log-scale parameter μ_L = 6.0, μ_H = 6.75 and shape parameters $\sigma^2 = 0.4$, and the remaining model parameters be r = 1.00, c = 0.40, s = 0.30, α = 0.95, $g(\tau_L)$ = 0.05, and Q = 1. There are several pooling PBE, including one at $\eta^p = 1,648$, which results in expected utilities of 473.1 for a τ_H type, 457.5 for a τ_L type, and 0 for the equity holder. However, this pooling PBE is eliminated by the application of the Intuitive Criterion refinement. In fact, the only equilibrium that survives the Intuitive Criterion refinement is the least cost separating PBE in which a τ_H type chooses capacity $\eta^s = 4,781$ and a τ_L type chooses capacity $\eta^*_L = 792$. This separating PBE results in a utility of 249.6 for a τ_H type (a decrease of 47.2% compared to the pooling PBE at η^p), a utility of 230.5 for a τ_L type (a decrease of 49.6% compared to the pooling PBE at η^p) and a utility of 0 for the equity holder (so the equity holder is indifferent between the two equilibria). ■

1.5.2 The Undefeated Refinement

In light of the concerns raised about the Intuitive Criterion refinement, an alternative refinement process may be warranted in some circumstances. The Undefeated refinement is applied by iterating across all possible PBE in the model and identifying whether the beliefs used to support each PBE are reasonable given the other possible PBE and the preferences for each firm type among those PBE. PBE that rely on beliefs that are unreasonable in this regard are eliminated. The formal definition of the Undefeated refinement is developed in Mailath et al. (1993) and summarized in the Appendix using our notation.

The Undefeated refinement has been applied in the finance and economics literature (Fishman and Hagerty 2003, Gomes 2000, Spiegel and Spulber 1997, Taylor 1999) and it addresses many of the concerns raised about the Intuitive Criterion refinement. By construction the Undefeated refinement does not eliminate any PBE that is Pareto efficient, as is possible with the Intuitive Criterion refinement. In addition, unlike the Intuitive Criterion refinement, the Undefeated refinement does not rely on unmodeled "speeches" from the firm in order to convey additional information to the equity holder. Instead, the Undefeated refinement ensures that OOE beliefs are restricted only by other equilibria in the model. Finally, at least one PBE will survive the Undefeated refinement since it eliminates PBE by performing a Pareto comparison to other PBE.

Proposition 4 *If one or more pooling PBE exists under reasonable beliefs as in Corollary 1 or Corollary 2, then (i) at least one of those PBE will survive the Undefeated refinement, and (ii) the least cost separating PBE, if it exists, will not survive the Undefeated refinement.*

The intuition behind Proposition 4 is that at least one of the pooling PBE identified using Corollaries 1 or 2 will not be Pareto dominated by any other PBE. If the least cost separating equilibrium also exists under Proposition 2 then every pooling PBE that exists is by definition a Pareto improvement over the separating PBE. A corollary result to Proposition 4 is that the least cost separating PBE is the unique Undefeated PBE if and only if a pooling PBE does not exist under reasonable beliefs. Examples 1-5, summarized in Table 1.5.1, illustrate these possibilities.

If multiple pooling PBE survive the Undefeated refinement, we apply the concept of lexicographically maximum sequential equilibrium (LMSE) to identify a unique PBE. According to Mailath et al. (1993), a PBE is a LMSE if among all PBE it maximizes the utility for a τ_H type and conditional on maximizing the utility for a τ_H type, it then maximizes the utility for a τ_L type. Using a LMSE to identify a unique PBE is intuitively appealing because typically a low-quality firm wishes to masquerade as a high-quality firm rather than the opposite, so resolving on a belief structure that supports such an outcome seems reasonable (Taylor 1999). The alternative would be to use a belief structure that increases the utility of a

τ_L type but decreases the utility of a τ_H type compared to the utilities achieved at the LMSE, which is more difficult to justify.

Due to the concavity of the utility functions, a unique LMSE will always exist among the PBE that survive the Undefeated refinement. If one of the pooling PBEs is at η^p, then this will be the unique PBE which is a LMSE since it maximizes the utility of a τ_H type and conditional on that, maximizes the utility of a τ_L type.

Example 1, continued. Of all the possible pooling and separating PBE, the pooling PBEs at $\eta = 650$ and 700 survive the Undefeated refinement but the least cost separating PBE does not, in accordance with Proposition 4. The pooling PBE at $\eta = 650$ yields a utility of 258.6 for a τ_L type and 282.0 for a τ_H type. Both firms receive a greater utility under this pooling PBE than under the pooling PBE at $\eta = 400, 450,$ $500, 550, 600, 750, 800, 850, 900$ and 950 or under the separating PBE. Therefore, each of these PBE are defeated by the pooling PBE at $\eta = 650$. Similarly, the pooling PBE at $\eta = 700$ yields a utility of 255.8 for a τ_L type and 282.1 for a τ_H type, and defeats the pooling PBE at $\eta = 400, 450, 500, 550, 750, 800, 850,$ 900 and 950 as well as the separating PBE. No other PBE defeats the pooling PBE at $\eta = 650$ or 700. The pooling PBE at $\eta = 700$ provides the maximum utility for a τ_H type and is therefore the unique PBE which is a LMSE. ■

Table 1.5.1 summarizes the results of Examples 1-3 and presents two additional examples illustrating various results of our paper. In Example 1, the least cost separating PBE and many pooling pooling equilibria survive the Intuitive Criterion refinement, and the pooling equilibrium at η^p is the unique LMSE prediction. In Example 2, a separating PBE does not exist, but multiple pooling PBE exist under Corollary 1. The pooling PBE at $\eta = 400, 450, 600$ and 700 survive the Intuitive Criterion refinement. The pooling PBE at $\eta = 550$ is the only PBE to survive the Undefeated refinement and it is a LMSE. Example 3, shown in Section 1.5.1, highlights the first criticism of the Intuitive Criterion refinement: although the pooling PBE at η^p is a Pareto improvement over the least cost separating PBE, the Intuitive Criterion implies that both types will instead choose the least cost separating equilibrium. The Undefeated refinement, on the other hand, eliminates the least cost separating PBE in favor of the pooling PBE at η^p.

Example 4 illustrates the significance of Corollary 1 by showing that *pooling at low* may occur and uniquely survive refinement, i.e., a τ_H type may choose the capacity level η_L^* which maximizes the utility of a τ_L type under *low* valuation. There is no pooling PBE at $\eta^p = 600$ units because (1.6) in Proposition 1 is violated (the utility of a τ_L type at η^p is 134.4 and at η_L^* is 134.7), so a τ_L type would prefer to separate than to choose capacity η^p. There is no separating PBE either, because Inequality (1.9) in Proposition 2 is violated ($\eta^s = 900$ and results in a utility of 146.5 for a τ_H type while her maximum utility under the *low* valuation is 147.5), so a τ_H type is unwilling to separate. Under Corollary 1, however, there is a pooling

Table 1.5.1: Examples illustrating the PBE that exist and survive refinement. In each example, $\mu_L = 6.00$, $c = 0.40$, and the other parameters are as listed. The first row in each example gives results for pooling PBE and the second row gives results for separating PBE. For instance, in Example 1, there are several pooling PBE at $\eta^{gp} = 400, 450, \ldots, 950$ and there is a separating PBE in which a τ_L type chooses $\eta = 450$ and a τ_H type chooses $\eta = 1200$. The latter survives the Intuitive Criterion but does not survive the Undefeated refinement.

Ex.	Model Parameters							PBE Capacities	PBE Capacities Surviving Refinement		
	μ_H	σ^2	r	s	Q	α	$g(\tau_L)$		Intuitive	Undefeated	LMSE
1	6.50	0.15	1.0	0.0	50	0.85	0.25	$400 \leq \eta^{gp} \leq 950$	700,800,900,950	650,700	700
								τ_L : 450, τ_H : 1200	Yes	No	No
2	6.25	0.15	1.0	0.0	50	0.85	0.25	$400 \leq \eta^{gp} \leq 700$	400,450,600,700	550	550
								None	-	-	-
3	6.75	0.40	1.0	0.3	1	0.95	0.05	$440 \leq \eta^{gp} \leq 4594$	*See Note*	$1616 \leq \eta^{gp} \leq 1648$	1648
								τ_L : 792, τ_H : 4781	Yes	No	No
4	6.25	0.15	0.8	0.2	100	0.60	0.75	500	None	500	500
								None	-	-	-
5	6.50	0.25	0.7	0.1	100	0.85	0.90	400	None	400	400
								None	-	-	-

Note: In Ex. 3, 635 pooling PBE survive the Intuitive Criterion. The surviving PBE are scattered between 3,360 and 4,594.

PBE at $\eta = 500$ (the utility of a τ_H type is 152.4 and of a τ_L type is 139.5). In fact, this is the unique PBE and survives the Intuitive Criterion and Undefeated refinements and it is the unique LMSE. It is interesting to note that a capacity investment at $\eta = 500$ maximizes the utility of a τ_L type under a *weighted* valuation, but it does not maximize the utility of a τ_H type under a *weighted* valuation. It also maximizes the utility of a τ_L type if there were no information asymmetry (i.e. under a *low* valuation). This counterintuitive result indicates that there are situations in which a τ_H type can benefit by adopting the preferred capacity investment of a τ_L type.

In Example 5, we highlight the third criticism of the Intuitive Criterion refinement mentioned in Section 1.5.1, namely that it may result in no PBE solution. There is no pooling PBE at $\eta^p = 500$ units because (1.6) in Proposition 1 is violated (the utility of a τ_L type at η^p is 83.8 and at η_L^* is 84.6), so a τ_L type would prefer to separate than to choose capacity η^p. There is no separating PBE either, because (1.9) in Proposition 2 is violated ($\eta^s = 1100$ and results in a utility of 87.4 for a τ_H type while her maximum utility under the *low* valuation is 88.7), so a τ_H type is unwilling to separate. Under Corollary 1, however, there is a pooling PBE at $\eta = 400$ (the utility of a τ_H type is 91.1 and of a τ_L type is 87.0). In fact, this PBE survives the Undefeated refinements and is the unique LMSE. It does not, however, survive the Intuitive Criterion.

1.6 Numerical Analysis

We conduct a numerical analysis to assess the likelihood of pooling PBE occurring and surviving refinement, and to determine the effect of the model parameters on this likelihood. We use the following setup. The firm faces a log-normal demand distribution regardless of its type. The log-scale parameter for a τ_L type is $\mu_L = 6.0$, and for a τ_H type is $\mu_H \in \{6.25, 6.50, 6.75\}$. The shape parameter takes values $\sigma^2 \in \{0.15, 0.25, 0.4\}$. The unit price (r) ranges from 0.65 to 1.00 in increments of 0.05, unit salvage value (s) ranges from 0.0 to 0.35 in increments of 0.05, and unit cost is fixed at $c = 0.4$. Short-termism (α) ranges from 0.05 to 1.00 in increments of 0.05, the equity holder's prior beliefs that the firm is type τ_L $(g(\tau_L))$ ranges from 0.05 to 0.95 in increments of 0.05, and the capacity investment is either continuous or discrete with $Q \in \{10, 50, 100\}$. We run 1,532,160 scenarios with these parameters. In these scenarios, we use Proposition 1 instead of Corollary 1 to check for the existence of pooling PBE, and thus restrict ourselves only to pooling PBE at $\eta = \eta^p$. This simplifies the analysis and makes it a conservative assessment of the likelihood of a pooling PBE because additional pooling PBE may exist under Corollary 1.

We are particularly interested in demonstrating the impact of the newsvendor model parameters on the existence of a pooling PBE. In the newsvendor model, increasing either the cost of underage or the cost of overage vertically translates the expected profit function with the amount of the translation increasing as capacity increases (refer to Lemma 2). This increases the utility from the various utility functions at each capacity level, and increases the skewness of the utility functions. The Undefeated refinement relies upon Pareto optimization across alternatives, making it sensitive to increases in utility. The Intuitive Criterion refinement utilizes non-equilibrium preferences that are sensitive to the skewness of the utility functions. This implies that the impact of increasing price or salvage value on the likelihood of a pooling PBE will differ depending on whether the Undefeated or the Intuitive Criterion refinement is asserted. We seek to clearly reveal this behavior in our numerical analysis.

Since we have a large number of parameters and many scenarios, we apply regression analysis to assess the effects of newsvendor parameters on the occurrence of pooling equilibria. While these regression results cannot be generalized beyond the numerical analysis, it allows us to efficiently examine and compare all of the combinations of the assumption relaxations that we have proposed. We separate the analysis into three situations: continuous support with the Undefeated refinement, discrete support with the Intuitive Criterion refinement, and discrete support with the Undefeated refinement. A logit model is used with a binary dependent variable, *Pooling PBE*, which is equal to 1 when a pooling PBE at η^p exists and survives refinement, and 0 otherwise. The explanatory variables consist of the price (*Price*), the salvage value (*Salvage*), the scale parameter of a τ_H type (*ScaleHigh*), the shape parameter (*Shape*), the prior beliefs of the equity holder (*PriorLow*), short-termism (*ShortTermism*), and the capacity increment (*CapacityIncrement*). Since the regression model is an approximation, we employ quadratic and interaction terms for price and salvage value to model non-linearity. These variables are mean-centered to aid in the interpretation of the quadratic and interaction terms, but mean-centering does not affect the marginal impact of the variables in the model. Our primary specification is:

$$
\begin{aligned}
Pooling\ PBE_i = & \alpha + \beta_1 \cdot Price_i + \beta_2 \cdot Salvage_i + \beta_3 \cdot Price_i^2 + \beta_4 \cdot Salvage_i^2 + \\
& \beta_5 \cdot Price_i \times Salvage_i + \beta_6 \cdot ScaleHigh_i + \beta_7 \cdot Shape_i + \\
& \beta_8 \cdot PriorLow_i + \beta_9 \cdot ShortTermism_i + \beta_{10} \cdot CapacityIncrement_i + \varepsilon_i,
\end{aligned}
\tag{1.10}
$$

where i identifies the scenario from the numerical analysis. We evaluate alternative specifications and the primary inferences are similar. Due to space constraints, we present estimates for a subset of those specifications.

Table 1.7.1 shows the results of the logit regressions. Columns 1 and 2 present estimation results for continuous support and the Undefeated refinement, which is addressed by 218,880 scenarios in the numerical analysis, Columns 3 and 4 present results for discrete support and the Intuitive Criterion refinement (656,640 scenarios), and Columns 5 and 6 for discrete support and the Undefeated refinement (656,640 scenarios). Columns 1, 3 and 5 exclude the square and interaction terms while Columns 2, 4 and 6 include those terms. Likelihood ratio tests indicate that the models in Columns 2, 4 and 6 provide a better fit than Columns 1, 3 and 5, respectively. We discuss the results in Column 2, 4 and 6, which subsume the inferences from column 1, 3, and 5.

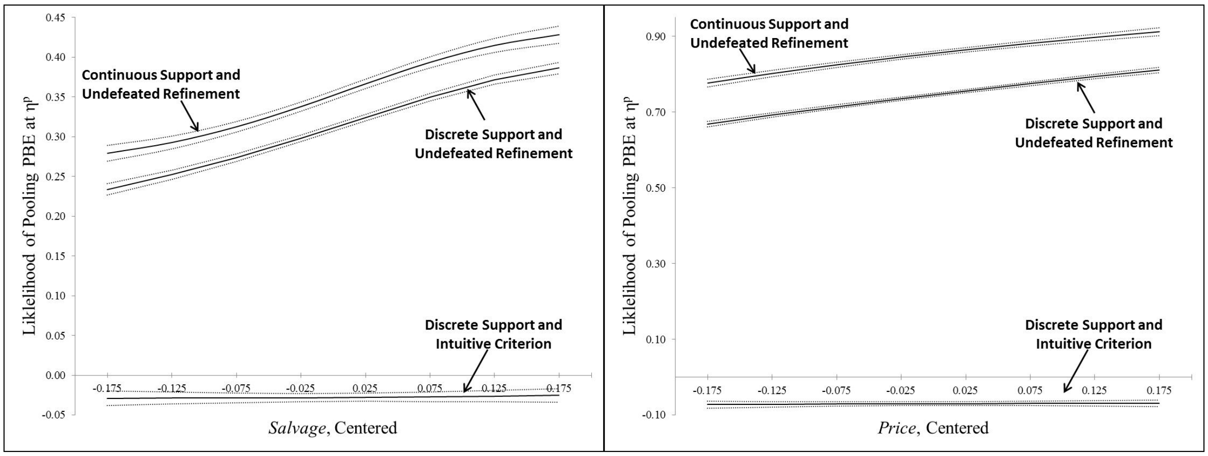
The main inferences from this analysis are as follows. We observe that the existence of a pooling PBE is not a pathological phenomenon. Across the 218,880 scenarios which use continuous support and the Undefeated refinement, a pooling PBE exists and survives refinement 37% of the time. This percentage 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. The pseudo R-square of the logit model is higher than 80% under Undefeated refinement and higher than 52% under Intuitive Criterion refinement. The newsvendor parameters have contrasting effects on the probability of occurrence of a pooling PBE under Undefeated and Intuitive Criterion refinements. Specifically, 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 because it can be used empirically to test which refinement is more representative of real data. Similar to price and salvage value, σ^2 has different effects on the likelihood of pooling equilibria under the Undefeated and Intuitive Criterion refinements. With respect to the remaining parameters, the probability of a pooling equilibrium increases in short-termism α, decreases in the prior probability of a firm being low type $g(\tau_L)$, increases in μ_H, and increases in the capacity increment Q.

We discuss some of the effects in detail. Changing price is equivalent to changing the cost of underage $r - c$. Figure 1.6.1a displays the average marginal effect of *Price* over the examined range of values of *Salvage*. We construct this figure because the marginal effect of *Price* depends on linear, quadratic and

Figure 1.6.1: Average marginal effects of *Price* and *Salvage* on the likelihood of a pooling PBE at η^p, with 95% confidence intervals. In both graphs, the top line shows the impact under continuous support and the Undefeated refinement using the regression results in Column 2 of Table 1.7.1, the middle line shows the impact under discrete support and the Undefeated refinement (Column 6), and the bottom line shows the impact under discrete support and the Intuitive Criterion refinement (Column 4).

(a) The average marginal effect of *Price* across a range of values of *Salvage*.

(b) The average marginal effect of *Salvage* across a range of values of *Price*.



interaction terms. In the graph, we average the discrete change in probability for each value of *Salvage* across the observed values of *Price*. The figure makes it clear that, under continuous support and the Undefeated refinement, increasing *Price* increases the likelihood that a pooling PBE at η^p exists and survives refinement, and moreover, the marginal effect of *Price* increases with *Salvage*. At the other extreme, under discrete support and the Intuitive Criterion refinement, increasing *Price* decreases the likelihood that a pooling PBE at η^p exists and survives refinement, and the marginal effect of *Price* does not vary materially with *Salvage*.

This result can be explained as follows. An increase in *Price* has three partially offsetting effects on the likelihood of a pooling PBE. First, η^s increases (based on Lemma 1), making it more costly for a τ_H type to separate and increasing the likelihood of a pooling PBE due to the effect of η^s on Inequality 1.7 of Proposition 1. Second, a τ_H type receives a higher utility from separating, decreasing the likelihood of a pooling PBE. Third, a τ_H type receives a higher utility from pooling, increasing the likelihood of a pooling PBE. These effects can be derived by noting that: (1) an increase in r increases the expected profit for both firm types, but more so for a τ_H type since $\frac{\partial \pi(\tau_H,\eta)}{\partial r} \geq \frac{\partial \pi(\tau_L,\eta)}{\partial r}$ for all η; (2) $\frac{\partial^2 \pi(\tau_H,\eta)}{\partial r \partial \eta} \geq \frac{\partial^2 \pi(\tau_L,\eta)}{\partial r \partial \eta} \geq 0$ for all η and r, with a strict inequality for some η; (3) $\pi(\tau_H,\eta) \geq \pi(\tau_L,\eta)$ for all η with strict inequality of some η (for (1), (2) and (3), refer to Lemma 2); and (4) the utility functions for both firm types are simply linear combinations of the expected profit functions for each firm type (refer to Equation 1.3). Increasing *Price* in the newsvendor model vertically translates the expected profit function, with the amount of the translation increasing in the capacity investment, η (refer to Lemma 2). As a result, the first and third effects dominate, resulting in a net increase in the likelihood of a pooling PBE.

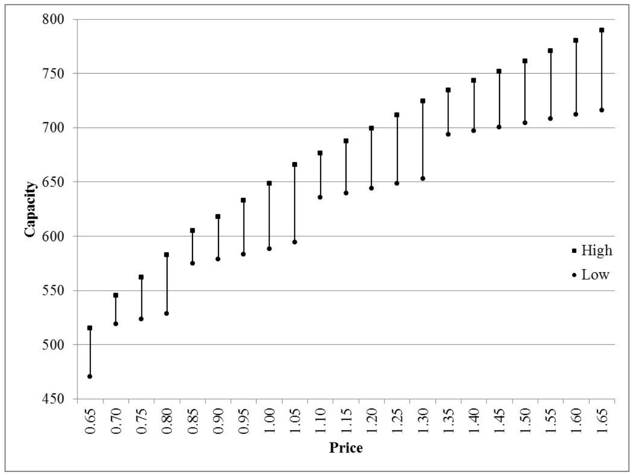
Price has a different effect when the Intuitive Criterion refinement is applied, however. The Intuitive Criterion refinement specifies a capacity investment range which will refine away a pooling PBE if there is a capacity investment alternative within this range. The low end of this range is defined by the *continuous* value of capacity which just satisfies (1). This represents the value above which a τ_L type is unwilling to deviate from the pooling equilibrium even if it were to result in a *high* valuation. The high end of this range is that which just satisfies (1.13). This represents the value above which a τ_H type is unwilling to deviate from the pooling equilibrium even if it were to result in a *high* valuation. Since increasing *Price* in the newsvendor model increases the skew of the utility functions, the capacity investment range specified by the Intuitive Criterion increases and it is less likely that the pooling PBE will survive refinement.This effect can be derived by noting that: (1) $\frac{\partial^2 \pi(\tau_H,\eta)}{\partial r \partial \eta} \geq \frac{\partial^2 \pi(\tau_L,\eta)}{\partial r \partial \eta} \geq 0$ for all η and r, with a strict inequality for some η (refer to Lemma 2) and (2) the utility functions for both firm types are simply linear combinations of the expected profit functions for each firm type (refer to Equation 1.3).

Figure 1.6.2 illustrates this effect by depicting the capacity range over which pooling equilibria are eliminated by the Intuitive Criterion refinement. We expand the set of values for *Price* to make the effect more apparent. As *Price* increases, the range increases in a saw-toothed pattern, and it becomes more likely to find a discrete capacity nQ in this range which will eliminate pooling PBE.

The impact of a change in salvage value is equivalent to a change in the cost of overage, $c - s$. Figure 1.6.1b uses the results in Columns 2, 4, and 6 of Table 1.7.1 to show that there is a significant difference in the average marginal effect of *Salvage* over the examined range of values of *Price*. Under continuous support and the Undefeated refinement, increasing *Salvage* increases the likelihood that a pooling PBE at η^p exists and survives refinement, and the marginal effect of *Salvage* increases with *Price*. At the other extreme, under discrete support and the Intuitive Criterion refinement, increasing *Salvage* decreases the likelihood that a pooling PBE at η^p exists and survives refinement, and the marginal effect of *Salvage* does not vary materially with *Price*. The intuition explaining the impact of *Salvage* is similar to the intuition explaining the impact of *Price*.

We briefly describe the empirical results associated with other parameters in the model. The coefficient on *ShortTermism* is positive and significant regardless of the support and refinement assumptions employed. As α increases, the utility received by a τ_H type in a pooling equilibrium decreases (refer to Equation (1.3)). Thus, pooling becomes less attractive to a τ_H type, and she is more willing to over-invest

Figure 1.6.2: The capacity investment range in which the Intuitive Criterion refinement will eliminate a pooling PBE at η^p. Demand follows a log-normal distribution with log-scale parameters $\mu_L = 6.0$ and $\mu_H = 6.25$, and shape parameters $\sigma^2 = 0.15$. In addition, $c = 0.40, s = 0.00, Q = 50$, short-termism $\alpha = 0.45$, the probability that the firm is type τ_L is $g(\tau_L) = 0.15$, and $r \in \{0.65, 0.70, \ldots, 1.65\}$.



to separate. However, a τ_L type is also more willing to over-invest to garner a higher short-term valuation. This increases the value of η^s such that a pooling outcome becomes more attractive to a τ_H type. As α gets increasingly large, the second effect dominates, resulting in a pooling PBE.

The coefficient on *PriorLow* is negative and significant regardless of the support and refinement assumptions employed. As *PriorLow* decreases, the short-term valuation that a τ_H type receives at η^p increases (refer to Lemma 2) and approaches the short-term valuation for a τ_H type under no information asymmetry. Simultaneously, η^p approaches η_H^*, which increases the expected long-term profit of a τ_H type choosing capacity investment η^p. Both factors make it more attractive for a τ_H type to pool than to separate.

The coefficient on *ScaleHigh* is also negative and significant regardless of the support and refinement assumptions. Intuitively, a lower value of *ScaleHigh* means there is less difference in performance prospects between the two types, which makes a pooling PBE more likely. The coefficient on *Shape* is positive and significant under continuous support and the Undefeated refinement but negative and significant under discrete support and the Intuitive refinement. The former result occurs because an increase in *Shape* increases the skewness of the utility functions, which improves the likelihood of pooling by increasing the cost of separation for a τ_H type. The latter result is because this increase in the skewness increases the likelihood that a discrete capacity investment alternative falls within the capacity range defined by the Intuitive Criterion.

The coefficient of *CapacityIncrement* is consistently positive and significant. The utility a τ_L type is weakly lower at η_L^* as Q increases, providing a stronger incentive for a τ_L type to pool. In addition, the value of η^s will be weakly larger as Q increases, which provides a stronger incentive for a τ_H type to pool. Finally, as Q increases, it is less likely that there will be a capacity investment choice that satisfies the conditions of the Intuitive Criterion refinement.

1.7 Managerial Implications and Discussion

1.7.1 Field Study Examples

Clarins Group. The investment phenomena captured by our model are present in a variety of real-world situations. French upscale beauty brand Clarins Group provides an example of how τ_H types can be compelled to under-invest in capacity. In 2008 with a global recession looming, many market analysts were generally pessimistic about sales of high-end beauty products that would be discretionary for many consumers and noted that "luring women to invest in high-end skin-care regimens is challenging when shoppers are cutting back" (Byron 2009). Clarins management, however, saw considerable opportunity to sell its products by opening a line of in-store spas, thereby dramatically increasing its retail capacity. In a personal interview in July 2012, Chairman Christian Courtin-Clarins that as a public company, the firm "felt pressure to make decisions based on quarterly drivers." Rather than compromise their investment strategy, the founding family opted to take the firm private in the summer of 2008. Mr. Courtin-Clarins revealed that one influencing factor was a desire to "have a long-term view in their investment decisions." By going private, the firm was able to invest substantially in opening "Clarins department-store skin spas" in 2009. Mr. Courtin-Clarins went on to say that it was "absolutely the case" that the spa initiative required a large, lumpy investment and that Clarins "could not have made this investment had we remained public." In the framework of our model, Clarins is a τ_H type and would have under-invested in capacity had they remained publicly traded. Going private reduced the firm's emphasis on short-term valuation (reducing α) and mitigated information asymmetry with its equity holders by moving from public market equity holders to private and family equity holders.

Arrow Electronics. Arrow Electronics, a Fortune 200 distributor of electronic components, reflects a situation in which a τ_L type over-invests in capacity. In 2000, at the height of the Internet bubble, the market was richly rewarding Internet initiatives of all forms (captured in our model by a low $g(\tau_L)$), and managers at Arrow Electronics felt tremendous pressure to capitalize on this trend (captured by a high α). Despite the Internet boom, Chairman and CEO Steve Kaufman, with his in-depth knowledge of the industry, resisted transforming Arrow's business model. In a personal interview on August 10, 2012, Kaufman contended that the Internet was no panacea and that "while it may help around the edges, the Internet could never replace Arrow's business model. The enthusiasm of the market, however, induced people to not distinguish between business models that might work and those that wouldn't." Feeling continued pressure, Arrow eventually made several investments (totaling approximately $50M) in five Internet ventures, including ChipCenter LLC, QuestLink Technology, and Virtual Chip Exchange. Kaufman noted "You hear the same thing from enough people and it starts to sound real. The Board began worrying about fiduciary responsibilities and the implications for the firm if I was wrong." Remarking on the size of the investments, Kaufman noted that "Although the public investors didn't think it was enough, the Board felt it was a good compromise between the outside view and my position that the Internet would not jeopardize the company." He also noted that two factors made their investment choice discrete – "There was a minimum efficient scale for the investments and for accounting purposes we wanted to be close to but not exceed a 20% ownership stake in any venture."

1.7.2 Discussion

We investigate the effect on a firm's capacity decision of short-termism and asymmetric information between the firm and its equity holders. In particular, we explore how the parameters of the newsvendor model impact the likelihood of a pooling PBE after relaxing common modeling assumptions so we may better account for real-world and operations-relevant constraints, such as discrete investment levels and Pareto-optimization decision rules. While stylized models in economics often employ these assumptions, operations management often deals with real-world aspects of decision problems. We strengthen the current operations management literature by not only showing that these real-world considerations lead to different outcomes than shown by the stylized economic models, but that the newsvendor model parameters play an important and counter-intuitive role in these outcomes. We are able to explain a broader set of outcomes than prior research (Bebchuk and Stole 1993, Lai et al. 2012), and reconcile this literature with empirical studies which have found that firms *under-invest* in long term projects (Bushee 1998, Graham et al. 2005, Roychowdhury 2006).

Our analysis provides evidence that firms have incentives to establish or maintain discrete capacity commitments. We show that in many circumstances the firm receives a higher utility from a pooling PBE compared to the least cost separating PBE, regardless of the firm's type. If the firm otherwise operates in an environment in which the capacity investment level has continuous support and beliefs are refined using logic similar to the Intuitive Criterion, then the firm can avoid costly separating by making a credible a priori commitment to adhere to discrete capacity investments. Firms can achieve this, for instance, by signing capacity contracts that have onerous terms if capacity is not ordered in discrete increments. Since the pooling PBE outcome is beneficial to both types of firms, the firm has incentives to make such credible commitments early, and even prior to the firm realizing its type.

Our paper can be extended and modified in subsequent research in other ways. For instance, future empirical work may exploit the finding that relaxing different modeling assumptions leads the parameters of the newsvendor model to have a different impact on the likelihood of a pooling PBE. Doing so will allow researchers to identify which assumptions more accurately reflect reality in different operating environments. In addition, our model can be employed to evaluate the impact of other types of information asymmetry, including information asymmetry on the firm's operating costs or its exposure to disruption risk. Finally, additional research can consider the impact of relaxing other modeling assumptions, including assumptions that there is infinite signal support and only two types of the informed player. Relaxing either assumption may also result in a pooling PBE uniquely surviving refinement. The intuition for the former is that when the signal is physically constrained to be less than η^s then it is impossible for a τ_H type to separate. The intuition for the latter is more involved, but well described in Cho and Kreps (1987). It is not immediately clear, however, what the implications of such relaxations are on the impacts of the newsvendor model parameters on the resulting PBE. We leave this to future research.

Table 1.7.1: The impact of model parameters on a pooling PBE at η^p existing and surviving refinement. Columns (1) and (2) employ continuous capacity support and the Undefeated refinement. Columns (3) and (4) employ discrete capacity support and the Intuitive Criterion refinement. Columns (5) and (6) employ discrete capacity support and the Undefeated refinement.

	Dependent Variable: *Pooling PBE*					
	(1)	(2)	(3)	(4)	(5)	(6)
Price, $r-\bar{r}$	11.770**	14.275**	-0.507**	-0.506*	7.806**	8.534**
	[0.134]	[0.160]	[0.046]	[0.046]	[0.060]	[0.064]
Salvage, $s-\bar{s}$	27.623**	33.027**	-1.319**	-1.333**	18.451**	20.040**
	[0.216]	[0.274]	[0.046]	[0.047]	[0.083]	[0.091]
*Price*², $(r-\bar{r})^2$		-14.634**		0.898+		-8.385**
		[1.193]		[0.462]		[0.566]
*Salvage*², $(s-\bar{s})^2$		108.027**		-3.999**		69.077**
		[1.438]		[0.464]		[0.616]
Price × *Salvage*		11.686**		0.020		10.797**
		[1.045]		[0.405]		[0.496]
ShortTermism, α	30.941**	37.790**	11.680**	11.684**	23.970**	26.307**
	[0.213]	[0.286]	[0.044]	[0.044]	[0.084]	[0.096]
PriorLow, $g(\tau_L)$	-22.415**	-27.186**	-1.765**	-1.766**	-16.407**	-17.957**
	[0.159]	[0.210]	[0.020]	[0.020]	[0.060]	[0.068]
ScaleHigh, μ_H	-8.445**	-10.259**	-4.517**	-4.519**	-9.524**	-10.422**
	[0.083]	[0.101]	[0.029]	[0.029]	[0.044]	[0.049]
Shape, σ^2	0.413**	0.502**	-1.508**	-1.508**	0.064	0.070
	[0.120]	[0.132]	[0.052]	[0.052]	[0.060]	[0.063]
CapacityIncrement, Q			0.029**	0.029**	0.022**	0.024**
			[0.000]	[0.000]	[0.000]	[0.000]
Constant	45.575**	54.030**	17.908**	17.955**	54.311**	58.602**
	[0.500]	[0.593]	[0.178]	[0.178]	[0.270]	[0.293]
Observations	218,880	218,880	656,640	656,640	656,640	656,640
Pseudo R^2	0.850	0.877	0.519	0.519	0.808	0.824
Mean of *Pooling PBE*	0.370	0.370	0.119	0.119	0.418	0.418
Capacity Support	Continuous	Continuous	Discrete	Discrete	Discrete	Discrete
Refinement	Undefeated	Undefeated	Intuitive	Intuitive	Undefeated	Undefeated

Notes: Models are estimated using a Logit regression. Standard errors in brackets. ** p<0.01, * p<0.05, + p<0.10

Appendix – Definitions

The following definitions are restated in our notation and reflect our focus on pure strategies.

Definition 1 Perfect Bayesian Equilibrium. According to Fudenberg and Tirole (1991), a PBE of a signaling game consists of a strategy profile, φ^*, and posterior beliefs, $\lambda(\tau)$. In the context of pure strategies, a strategy profile for the firm (player N), $\varphi_N(\tau)$, is a capacity investment, η, for each firm type, τ. A strategy profile for the equity holder (player E), $\varphi_E(\eta)$, is an equity price, $\rho(\eta)$, assigned to the firm for each capacity investment of the firm, η. The strategy profiles must be such that for the firm, $\varphi_N^*(\tau) = \arg\max_\eta U(\tau, \eta, \rho)$, for all τ. For the equity holder, $\varphi_E^*(\eta) = \arg\max_\rho \sum_\tau \lambda(\tau)V(\tau, \eta, \rho)$, for all η.

In addition, if $\sum_{\tau' \in T} g(\tau')1[\varphi_N^*(\tau') = \eta] > 0$ so that Bayes rule can be applied, then the equity holder's posterior beliefs are $\lambda(\tau) = \frac{g(\tau)1[\varphi_N^*(\tau)=\eta]}{\sum_{\tau' \in T} g(\tau')1[\varphi_N^*(\tau')=\eta]}$, where $g(\tau)$ is the equity holder's prior beliefs. If $\sum_{\tau' \in T} g(\tau')1[\varphi_N^*(\tau') = \eta] = 0$, then Bayes rule cannot be applied and the equity holder's posterior beliefs, $\lambda(\tau)$, may be any probability distribution on T. ■

Definition 2 Strict Dominance. Mas-Colell et al. (1995, p.469) state that a signal, η, is strictly dominated for a type $\tau_i \in T$ if there exists another signal η' such that the following inequality holds:

$$\max_{\rho \in P^*(T,\eta)} U(\tau_i, \eta, \rho) < \min_{\rho \in P^*(T,\eta')} U(\tau_i, \eta', \rho). \tag{1.11}$$

Form the set $S(\eta)$ consisting of all types τ_i such that this inequality does not hold. Then a PBE has *reasonable beliefs* if for all η with $S(\eta) \neq \emptyset$, $\lambda(\tau_i) > 0$ only if $\tau_i \in S(\eta)$. ■

In words, (1.11) states that a signal is strictly dominated for a type if the best utility which that type could possibly achieve by sending that signal is strictly lower than the worst utility which that type could possibly achieve by sending some other signal. A PBE has reasonable beliefs if those beliefs do not put a positive probability on any type sending a signal that is strictly dominated.

Definition 3 Intuitive Criterion Refinement. According to Cho and Kreps (1987), the Intuitive Criterion refinement is applied in two steps to evaluate a PBE involving η and ρ^*:

1. Form the set $S(\eta')$ for all $\eta' \neq \eta$ consisting of all types τ such that

$$U(\tau, \eta, \rho^*) > \max_{\rho \in P^*(T,\eta')} U(\tau, \eta', \rho). \tag{1.12}$$

2. If, for some out of equilibrium signal η', there exists some type $\tau' \in T \backslash S(\eta')$ such that

$$U(\tau', \eta, \rho^*) < \min_{\rho \in P^*(T \backslash S(\eta'),\eta')} U(\tau', \eta', \rho), \tag{1.13}$$

then the equilibrium fails the Intuitive Criterion. ■

In words, $S(\eta')$ consists of all types whose expected utility from choosing the in-equilibrium capacity investment, η, is strictly greater than their maximum possible utility from making an OOE capacity investment decision, $\eta' \neq \eta$, over the set of best responses available to the equity holder. The equilibrium fails the Intuitive Criterion if there is a firm type not in $S(\eta')$ for which the utility from the equilibrium capacity investment is less than the minimum possible utility that can be achieved by deviating from η to η' given the equity holder's set of best responses.

Definition 4 Undefeated Refinement. As in Mailath et al. (1993), we utilize some additional notation to present the Undefeated refinement for ease of exposition. A strategy profile for the firm (player N), $\varphi_N(\tau)$, is a capacity investment, η, for each firm type, τ. A strategy profile for the equity holder (player E), $\varphi_E(\eta)$, is an equity price, $\rho(\eta)$, assigned to the firm for each capacity investment of the firm, η. A PBE is represented as a triplet of the form, $\psi = (\varphi_N, \varphi_E, \lambda)$. With a slight abuse of notation, the utility of a type τ relative to a particular PBE, ψ, is represented as $U(\tau, \psi)$. The Undefeated refinement is applied by considering two equilibria at a time, $\psi = (\varphi_N, \varphi_E, \lambda)$ and $\psi' = (\varphi'_N, \varphi'_E, \lambda')$ and then iterating the following process across all of the equilibria in the model.

The PBE, ψ, defeats the PBE, ψ', if there exists a capacity investment, η, such that the following three conditions are satisfied:

1. $\forall \tau \in T : \varphi'_N \neq \eta$ and $K \equiv \{\tau \in T | \varphi_N = \eta\} \neq \emptyset$;
2. $\forall \tau \in K : U(\tau, \psi) \geq U(\tau, \psi')$ and $\exists \tau \in K : U(\tau, \psi) > U(\tau, \psi')$; and

3. $\exists \tau \in K : \lambda'(\tau) \neq \frac{g(\tau)\zeta(\tau)}{\sum_{\tilde{\tau}\in T} g(\tilde{\tau})\zeta(\tilde{\tau})}$ for any $\zeta : T \rightarrow [0, 1]$ satisfying

   (a) $\tilde{\tau} \in K$ and $U(\tilde{\tau}, \psi) > U(\tilde{\tau}, \psi')$ implies $\zeta(\tilde{\tau}) = 1$,

   (b) $\tilde{\tau} \notin K$ implies $\zeta(\tilde{\tau}) = 0$, and

   (c) $\tilde{\tau} \in K$ and $U(\tilde{\tau}, \psi) = U(\tilde{\tau}, \psi')$ implies $\zeta(\tilde{\tau}) \in [0, 1]$. ■

In words, condition 1 states that ψ' must have an OOE capacity investment choice that is an in-equilibrium capacity investment choice in ψ. Condition 2 states that in ψ, an in-equilibrium capacity investment must be chosen by a set of types that prefers (strictly prefers for at least one type) their utility under ψ compared to ψ'. Condition 3 checks whether the OOE beliefs used to sustain ψ' are reasonable in light of ψ. The reasonableness of the beliefs that sustain ψ' are checked by assigning for each type a probability, $\zeta(\tilde{\tau})$, that the type chooses the OOE capacity investment η. These probabilities are based on how the type behaves under ψ, so a probability of 1 is used if the type prefers the utility from η under ψ to the utility from η' under ψ', a probability of 0 is used if the type does not choose η under ψ, and any probability may be used if the type is indifferent between the utility from η under ψ and the utility from η' under ψ'.

Appendix – Proofs and Additional Findings

Proof of Lemma 1. We first show the existence of η^s. From (1.3), we get a τ_L type's utility function under the *high* valuation as $U(\tau_L, \eta, \rho(\eta|\lambda(\tau_H) = 1)) = (1 - \alpha)\pi(\tau_L, \eta) + \alpha\pi(\tau_H, \eta)$ and under the *low* valuation as $U(\tau_L, \eta, \rho(\eta|\lambda(\tau_L) = 1)) = \pi(\tau_L, \eta)$. Both functions are concave, bounded from above, and tend to $-\infty$ as η increases. The former function first order stochastically dominates the latter. Thus, it reaches its maximum for some η, $\eta_L^* \leq \eta \leq \eta_H^*$, and then decreases to $-\infty$. This implies that there exist values of $\eta \geq \eta_H^*$ such that $U(\tau_L, \eta, \rho(\eta|\lambda(\tau_H) = 1)) < U(\tau_L, \eta_L^*, \rho(\eta_L^*|\lambda(\tau_L) = 1))$. The minimum capacity investment over this set is η^s.

We now apply Definition 2 to actions $\eta \geq \eta^s$ for a τ_L type. For this, we set $\eta' = \eta_L^*$ and show that actions $\eta \geq \eta^s$ are dominated by η_L^* for a τ_L type. From inequality (1.11) in Definition 2, we need to show that

$$\max_{\rho\in P^*(T,\eta)} U(\tau_L, \eta, \rho) < \min_{\rho\in P^*(T,\eta_L^*)} U(\tau_L, \eta_L^*, \rho).$$

First order stochastic dominance and concavity of the utility function imply that the utility for a τ_L type, $U(\tau_L, \eta, \rho)$, is maximized with respect to ρ when $\lambda(\tau_L) = 0$ and is minimized when $\lambda(\tau_L) = 1$. Substituting these posterior beliefs into the utility function and using (1.3), for any $\eta \geq \eta^s$ we get

$$\begin{aligned}\max_{\rho \in P^*(T,\eta(\eta))} U(\tau_L, \eta, \rho) &= (1-\alpha)\pi(\tau_L, \eta) + \alpha\pi(\tau_H, \eta) \\ &\leq (1-\alpha)\pi(\tau_L, \eta^s) + \alpha\pi(\tau_H, \eta^s) \\ &< \pi(\tau_L, \eta_L^*) \\ &= \min_{\rho \in P^*(T,\eta_L^*)} U(\tau_L, \eta_L^*, \rho).\end{aligned}$$

Here, the first inequality follows because $(1-\alpha)\pi(\tau_L, \eta) + \alpha\pi(\tau_H, \eta)$ reaches its maximum at a capacity investment less than or equal to η^s and is decreasing in η for $\eta \geq \eta^s$. The second inequality follows from the definition of η^s.

According to the reasonable beliefs refinement in Definition 2, a PBE has reasonable beliefs if those beliefs put zero probability that a signal which is strictly dominated for a τ_i type was sent by a τ_i type, i.e. $\lambda(\tau_i) = 0$. For a τ_L type, since any $\eta \geq \eta^s$ meets the definition of strict dominance, the equity holder's beliefs should place zero probability that such a signal was sent by a τ_L type. Moreover, the definition of η^s implies that η^s is the smallest capacity investment greater than or equal to η_H^* which is strictly dominated for a τ_L type. This proves the lemma. ■

We require the following lemma for the subsequent proofs.

Lemma 2 *For firm types τ_H and τ_L for which F_{τ_H} FOSD F_{τ_L}, the following properties of the newsvendor model hold:*

1. $\pi(\tau_H, \eta) \geq \pi(\tau_L, \eta)$ *for all η with strict inequality for some η*
2. *When η is discrete,* $\pi(\tau_H, \eta + Q) - \pi(\tau_H, \eta) \geq \pi(\tau_L, \eta + Q) - \pi(\tau_L, \eta)$ *for all η with strict inequality for some η*
3. *When η is continuous,* $\frac{\partial \pi(\tau_H,\eta)}{\partial \eta} \geq \frac{\partial \pi(\tau_L,\eta)}{\partial \eta}$ *for all η with strict inequality for some η*
4. $\frac{\partial \pi(\tau_H,\eta)}{\partial r} \geq \frac{\partial \pi(\tau_L,\eta)}{\partial r} > 0$ *for all η*

5. $\frac{\partial \pi(\tau_H,\eta)}{\partial s} \geq \frac{\partial \pi(\tau_L,\eta)}{\partial s} > 0$ *for all* η

6. $\frac{\partial^2 \pi(\tau_H,\eta)}{\partial r \partial \eta} \geq \frac{\partial^2 \pi(\tau_L,\eta)}{\partial r \partial \eta} \geq 0$ *for all* η *and* r*, with a strict inequality for some* η

7. $\frac{\partial^2 \pi(\tau_L,\eta)}{\partial s \partial \eta} \geq \frac{\partial^2 \pi(\tau_H,\eta)}{\partial s \partial \eta} \geq 0$ *for all* η *and* s*, with a strict inequality for some* η

Proof. Omitted. ■

Proof of Proposition 1. We show that the three conditions stated in the proposition are sufficient for a pooling PBE at η^p. For this, we solve for the best response functions of the firm and the equity holder under the specified posterior beliefs of the equity holder. The best response function of the equity holder follows from (1.2) for all values of η and $\lambda(\tau)$.

Since $\eta_H^* \leq \eta^s$ then the posterior beliefs of the equity holder are well-defined. To see this, note that $\eta^p \leq \eta_H^*$ by first order stochastic dominance. Thus, $\eta^p \leq \eta_H^*$ and $\eta_H^* \leq \eta^s$ together imply that $\eta^p \leq \eta^s$. However, if $\eta^p = \eta^s$ then neither Inequality 1.6 nor 1.7 can hold under any reasonable belief structure. Therefore, it must be that $\eta^p < \eta^s$.

We now confirm that the proposed equilibrium maximizes the utility of each firm type so that no firm type has an incentive to deviate. We must show that $\eta^p = \arg\max_\eta U(\tau_j, \eta, \rho)$ for $j = L, H$ across the three intervals defined by the posterior beliefs of the equity holder, namely $\eta < \eta^p$, $\eta^p \leq \eta < \eta^s$, and $\eta \geq \eta^s$.

Consider first a τ_L type. The expected utility of the firm is given by (1.3) as

$$U(\tau_L, \eta, \rho^*) = \begin{cases} \pi(\tau_L, \eta) & \text{for } \eta < \eta^p, \\ (1 - \alpha + \alpha g(\tau_L))\pi(\tau_L, \eta) + \alpha g(\tau_H)\pi(\tau_H, \eta) & \text{for } \eta^p \leq \eta < \eta^s, \\ (1-\alpha)\pi(\tau_L, \eta) + \alpha\pi(\tau_H, \eta) & \text{for } \eta \geq \eta^s. \end{cases}$$

We have three cases. (i) A τ_L type does not deviate from η^p to any $\eta < \eta^p$ if $U(\tau_L, \eta^p, \rho^*) > \max_{\eta<\eta^p} U(\tau_L, \eta, \rho^*)$, i.e., if $U(\tau_L, \eta^p, \rho^*) > U(\tau_L, \eta_L^*, \rho^*)$. This gives inequality (1.6) as a sufficient condition in the proposition. (ii) In order to ensure that a τ_L type does not deviate from η^p to any $\eta^p < \eta < \eta^s$, it must be true that $U(\tau_L, \eta^p, \rho^*) \geq \max_{\eta^p \leq \eta < \eta^s} U(\tau_L, \eta, \rho^*)$. This condition holds because η^p maximizes the expected utility of a τ_H type under the *weighted* valuation, which implies by first order stochastic dominance that the maximizer of the expected utility of a τ_L type under the *weighted* valuation is less than or equal to η^p, and therefore, the expected utility of a τ_L type is decreasing in η in the interval $\eta^p < \eta < \eta^s$. (iii) Finally, a τ_L type does not deviate from η^p to any $\eta \geq \eta^s$ by the definition of η^s. By Lemma 1, a τ_L type receives a higher expected utility by choosing capacity η_L^* than by selecting any capacity investment $\eta \geq \eta^s$. This combined with the condition that $U(\tau_L, \eta^p, \rho^*) > U(\tau_L, \eta_L^*, \rho^*)$ precludes a deviation to any $\eta \geq \eta^s$ by a τ_L type.

Now consider a τ_H type. Her expected utility is also given by (1.3) as

$$U(\tau_H, \eta, \rho^*) = \begin{cases} \alpha\pi(\tau_L, \eta) + (1-\alpha)\pi(\tau_H, \eta) & \text{for } \eta < \eta^p, \\ \alpha g(\tau_L)\pi(\tau_L, \eta) + (1 - \alpha + \alpha g(\tau_H))\pi(\tau_H, \eta) & \text{for } \eta^p \leq \eta < \eta^s, \\ \pi(\tau_H, \eta) & \text{for } \eta \geq \eta^s. \end{cases}$$

Again, we have three cases. (i) Note that the expected utility of the firm for $\eta < \eta^p$ is computed under the *low* valuation. Its value is less than the corresponding utility under the *weighted* valuation. Moreover, η^p maximizes the expected utility of a τ_H type under the *weighted* valuation. Therefore, a τ_H type receives a higher utility by choosing capacity η^p than any $\eta < \eta^p$. Thus, she does not deviate from η^p to any $\eta < \eta^p$. (ii) A τ_H type also does not deviate from η^p to any $\eta^p < \eta < \eta^s$ because by definition η^p maximizes the expected utility of a τ_H type in this interval. (iii) Finally, in order to ensure that a τ_H type does not deviate from η^p to some $\eta \geq \eta^s$, it must be that $U(\tau_H, \eta^p, \rho^*) > \max_{\eta \geq \eta^s} U(\tau_H, \eta, \rho^*)$. Since $\eta_H^* \leq \eta^s$ the maximum on the right hand side of the inequality is achieved at η^s. This requirement can be simplified to $U(\tau_H, \eta^p, \rho^*) > U(\tau_H, \eta^s, \rho^*)$, which is a sufficient conditions for η^p to be the capacity investment that maximizes the expected utility of a τ_H type. Thus, the conditions specified in (1.6) and (1.7) are sufficient to show a pooling equilibrium at η^p. ■

Proof of Proposition 2. In the separating PBE, a τ_H type chooses the least cost separating capacity investment, η^s, and receives a *high* valuation while a τ_L type chooses $\eta = \eta_L^*$ and receives a *low* valuation. A separating PBE under reasonable beliefs is precluded if the equilibrium capacity investment for either type is strictly dominated by any alternative capacity investment. Recall that a capacity investment is strictly dominated if Inequality (1.11) is true. We evaluate whether Inequality (1.11) holds for either firm type. Consider first a τ_L type. The inequality simplifies to

$U(\tau_L, \eta_L^*, \rho^*) < \max_{\eta' \neq \eta_L^*} U(\tau_L, \eta', \rho(\eta'|\lambda(\tau_L) = 1))$. This is not true for any value of η'.

For a τ_H type, Inequality (1.11) is $U(\tau_H, \eta^s, \rho^*) < \max_{\eta' \neq \eta^s} U(\tau_H, \eta', \rho(\eta'|\lambda(\tau_L) = 1))$. There may be conditions under which this is true, and therefore η^s is strictly dominated for a τ_H type under those conditions. This implies that Inequality (1.9) must hold for a separating PBE to exist under reasonable beliefs. ■

Proof of Proposition 3. We prove that the conditions identified in Proposition 3 are necessary and sufficient for the pooling PBE from Proposition 1 to survive the Intuitive Criterion. We do this by showing that these conditions are equivalent to the conditions identified in the definition of the Intuitive Criterion refinement in the case of a pooling PBE at η^p. The Intuitive Criterion refinement is defined in Cho and Kreps (1987) and summarized using our notation in Definition 3. To evaluate the pooling PBE defined in Proposition 1 using the Intuitive Criterion refinement, form the set $S(\eta')$ for all $\eta' \neq \eta^p$ consisting of all types, τ, such that

$$U(\tau, \eta^p, \rho^*) > \max_{\rho \in P^*(T, \eta')} U(\tau, \eta', \rho). \tag{1.14}$$

The PBE fails the Intuitive Criterion if there exists some type $\tau' \in T$ and $\tau' \notin S(\eta')$ such that

$$U(\tau', \eta^p, \rho^*) < \min_{\rho \in P^*(T \setminus S(\eta), \eta')} U(\tau', \eta', \rho) \tag{1.15}$$

To apply the Intuitive Criterion, there are two ranges of η' that we must evaluate, $\eta' < \eta^p$ and $\eta' > \eta^p$. We first consider a deviation to $\eta' < \eta^p$. Recall that the utility function of a type τ is $U(\tau, \eta', \rho) = \alpha\rho(\eta') + \{1 - \alpha\}\, \pi(\tau, \eta')$. Using the result from Lemma 2 that $\frac{\Delta\pi(\tau_H, \eta)}{\Delta\eta} \geq \frac{\Delta\pi(\tau_L, \eta)}{\Delta\eta}$, any deviation to $\eta' < \eta^p$ that yields in a higher utility for a τ_H type will also yield in a higher utility for a τ_L type. Therefore by (1.14), for any $\eta' < \eta^p$, $S(\eta') = \emptyset$, $S(\eta') = \tau_H$ or $S(\eta') = T$. From (1.15), the Intuitive Criterion will not eliminate the equilibrium with a value of η' if $S(\eta') = \emptyset$ or $S(\eta') = T$. If the value of η' is such that $S(\eta') = \tau_H$, then Inequality (1.15) can be expressed as $U(\tau_L, \eta^p, \rho^*) < U(\tau_L, \eta', \rho(\eta'|\lambda(\tau_L) = 1))$. However, this inequality cannot be true for a pooling PBE at η^p since the existence of a pooling PBE at η^p already requires that $U(\tau_L, \eta^p, \rho^*) > U(\tau_L, \eta_L^*, \rho^*)$.

We next consider a deviation to $\eta' > \eta^p$. Recalling again the form of the firm's utility function and the results of Lemma 2, any deviation to $\eta' > \eta^p$ that results in a higher utility for a τ_L type will also result in a higher utility for a τ_H type. Therefore, for any $\eta' > \eta^p$, $S(\eta') = \emptyset$, $S(\eta') = \tau_L$ or $S(\eta') = T$. Again from (1.15), the Intuitive Criterion will not eliminate the equilibrium with a value of η' if $S(\eta') = \emptyset$ or $S(\eta') = T$. If there exists some η' such that $S(\eta') = \tau_L$, then inequality (1.14) could be expressed as

$$U(\tau_L, \eta^p, \rho^*) > U(\tau_L, \eta', \rho(\eta'|\lambda(\tau_H) = 1))$$

and inequality (1.15) could be expressed as

$$U(\tau_H, \eta^p, \rho^*) < U(\tau_H, \eta', \rho(\eta'|\lambda(\tau_H) = 1))$$

By the definition of the Intuitive Criterion refinement, the pooling PBE identified in Proposition 1 will survive the Intuitive Criterion refinement if and only if there does not exist a capacity investment for which both of these conditions are true. ■

Proof of Proposition 4. We seek to prove that if one or more pooling PBE exists under reasonable beliefs, then at least one will survive the Undefeated refinement but no separating PBE will.

Let Z represent the set of all capacity investment levels at which there is a pooling PBE (based on Corollary 1). Let η^{Lp} be the maximum capacity investment at the pooling PBE within this set which maximizes the utility of a τ_L type and let η^{Hp} be the minimum capacity investment at the pooling PBE within this set which maximizes the utility of a τ_H type,

$$\begin{aligned}\eta^{Lp} &= \max\left\{\eta : \arg\max_{\eta\in Z}\ U(\tau_L, \eta, \rho(\eta|\lambda(\tau_L) = g(\tau_L)))\right\},\\ \eta^{Hp} &= \min\left\{\eta : \arg\max_{\eta\in Z}\ U(\tau_H, \eta, \rho(\eta|\lambda(\tau_H) = g(\tau_H)))\right\}.\end{aligned}$$

Any pooling PBE in Z defeats the least cost separating PBE (if one exists based on Proposition 2). This is from the definition of the Undefeated refinement and because a pooling PBE based on Corollary 1 only exists if it provides a utility greater than the separating PBE for both firm types. Furthermore, from the concavity of the utility functions, the pooling PBE at η^{Lp} defeats any pooling PBE at $\eta < \eta^{Lp}$ and the pooling PBE at η^{Hp} defeats any pooling PBE at $\eta > \eta^{Hp}$.

By FOSD, $\eta^{Lp} \leq \eta^{Hp}$. If $\eta^{Lp} = \eta^{Hp}$ then the pooling PBE at this capacity investment is the unique undefeated PBE since there is no other PBE which provides at least the same utility for both firm types and a higher utility for at least one of the firm types. If $\eta^{Lp} < \eta^{Hp}$ then the pooling PBEs at all $\eta \in [\eta^{Lp}, \eta^{Hp}]$ are undefeated. This is from the concavity of the utility functions, which implies that for all of the pooling PBEs at a capacity investment level $\eta \in [\eta^{Lp}, \eta^{Hp}]$, no other PBE exists which provides at least the same utility for both firm types and a higher utility for at least one of the firm types. ■

1.7.3 Pooling PBE with Continuous Capacity

To analyze the existence of pooling PBE when there is continuous support of the capacity investment, we utilize the same notation as in the analysis of the existence of pooling PBE under discrete support of the capacity investment. This allows us to reduce the amount of additional notation and build on the intuition developed under the discrete case. Proposition 1 and Corollary 1 can be expressed more simply when there is continuous support. They are restated below as Proposition 5 and Corollary 2.

We utilize the following lemma in the proof of Proposition 5.

Lemma 3 *Provided $U(\tau_H, \eta^p, \rho^*) > U(\tau_H, \eta^s, \rho^*)$, then a τ_L type is unwilling to deviate from the pooling equilibrium at η^p to any $\eta < \eta^p$*

Proof of Lemma 3. Say that it was otherwise, that $U(\tau_H, \eta^p, \rho^*) > U(\tau_H, \eta^s, \rho^*)$ holds, but the τ_L type is willing to deviate from the pooling equilibrium to an $\eta < \eta^p$. The latter means that $U(\tau_L, \eta^p, \rho^*) < \max_{\eta<\eta^p} U(\tau_L, \eta, \rho^*)$. From (1.19) the capital provider's beliefs are $\lambda(\tau_L) = 1$ in the region $\eta < \eta^p$, so by the definition of η_L^*, this inequality becomes:

$$U(\tau_L, \eta^p, \rho^*) < U(\tau_L, \eta_L^*, \rho^*) \tag{1.16}$$

From Lemma 1, $U(\tau_L, \eta^s, \rho(\eta^s|\lambda(\tau_H) = 1)) < U(\tau_L, \eta_L^*, \rho(\eta_L^*|\lambda(\tau_L) = 1))$. Since η is continuous, this means that for some arbitrarily small value of ε, $U(\tau_L, \eta^s, \rho(\eta^s|\lambda(\tau_H) = 1)) + \varepsilon = U(\tau_L, \eta_L^*, \rho(\eta_L^*|\lambda(\tau_L) = 1))$. Substituting this into (1.16) yields $U(\tau_L, \eta^p, \rho^*) < U(\tau_L, \eta^s, \rho(\eta^s|\lambda(\tau_H) = 1)) + \varepsilon$. Using the definition of the firm's utility function and simplifying terms:

$$\alpha[\rho^*(\eta^p) - \rho^*(\eta^s)] - \varepsilon < (1-\alpha)[\pi(\tau_L, \eta^s) - \pi(\tau_L, \eta^p)] \tag{1.17}$$

If $U(\tau_H, \eta^p, \rho^*) > U(\tau_H, \eta^s, \rho^*)$ holds then we can include the same arbitrarily small value of ε in this inequality to form $U(\tau_H, \eta^p, \rho^*) \geq U(\tau_H, \eta^s, \rho^*) + \varepsilon$. By using the definition of the firm's utility function and simplifying terms, this inequality becomes:

$$\alpha[\rho^*(\eta^p) - \rho^*(\eta^s)] - \varepsilon \geq (1-\alpha)[\pi(\tau_H, \eta^s) - \pi(\tau_H, \eta^p)] \tag{1.18}$$

For both Inequalities 1.17 and 1.18 to be true, it must be that $[\pi(\tau_H, \eta^s) - \pi(\tau_H, \eta^p)] < [\pi(\tau_L, \eta^s) - \pi(\tau_L, \eta^p)]$, where $\eta^s > \eta^p$. However, this cannot be true since $\frac{\partial \pi(\tau_L, \eta)}{\partial \eta} \leq \frac{\partial \pi(\tau_H, \eta)}{\partial \eta}$ for all η. To see this, note that $\pi(\tau, \eta) = (r-s)\int_0^\eta \overline{F_\tau}(x)dx - (c-s)\eta$, so $\frac{\partial \pi(\tau, \eta)}{\partial \eta} = (r-s)\overline{F_\tau}(\eta) - (c-s)$. From this it is clear that since $F_{\tau_H}(\eta)$ first order stochastically dominates $F_{\tau_L}(\eta)$, $\frac{\partial \pi(\tau_H, \eta)}{\partial \eta} \geq \frac{\partial \pi(\tau_L, \eta)}{\partial \eta}$ for all η and $\frac{\partial \pi(\tau_H, \eta)}{\partial \eta} > \frac{\partial \pi(\tau_L, \eta)}{\partial \eta}$ for some η. Therefore, if $U(\tau_H, \eta^p, \rho^*) > U(\tau_H, \eta^s, \rho^*)$ holds then a τ_L type is unwilling to deviate from the pooling equilibrium to any $\eta < \eta^p$. ■

Proposition 5 *When η has continuous support on $\Re^+$, there exists a pooling PBE in which the firm chooses capacity $\eta^p < \eta^s$ regardless of its type, the equity holder's response function ρ^* is given by (1.2), and equity holder's reasonable posterior beliefs are given by*

$$\lambda(\tau_L) = 1 - \lambda(\tau_H); \qquad \lambda(\tau_H) = \begin{cases} 0 & \eta < \eta^p, \\ g(\tau_H) & \eta^p \leq \eta < \eta^s, \\ 1 & \eta \geq \eta^s. \end{cases} \tag{1.19}$$

if the following condition holds:

$$U(\tau_H, \eta^p, \rho^*) \quad > \quad U(\tau_H, \eta^s, \rho^*), \tag{1.20}$$

Proof of Proposition 5. We show that the condition stated in the proposition is sufficient for a pooling PBE at η^p. For this, we solve for the best response functions of the firm and the equity holder under the specified posterior beliefs of the equity holder. The best response function of the equity holder follows from (1.2) for all values of η and $\lambda(\tau)$.

Note that by first order stochastic dominance $\eta^p < \eta_H^*$. This means that $\eta^p < \eta^s$ and therefore the belief structure given by (1.19) is well formed. We now confirm that the proposed equilibrium maximizes the utility of each firm type so that no firm type has an incentive to deviate. We must show that $\eta^p = \arg\max_\eta U(\tau_j, \eta, \rho^*)$ for $j = L, H$ across the three intervals defined by the posterior beliefs of the equity holder, namely $\eta < \eta^p$, $\eta^p \leq \eta < \eta^s$, and $\eta \geq \eta^s$.

First consider a τ_H type. Her expected utility is given by (1.3) as

$$U(\tau_H, \eta, \rho^*) = \begin{cases} \alpha\pi(\tau_L, \eta) + (1-\alpha)\pi(\tau_H, \eta) & \text{for } \eta < \eta^p, \\ \alpha g(\tau_L)\pi(\tau_L, \eta) + (1 - \alpha + \alpha g(\tau_H))\pi(\tau_H, \eta) & \text{for } \eta^p \leq \eta < \eta^s, \\ \pi(\tau_H, \eta) & \text{for } \eta \geq \eta^s. \end{cases}$$

We have three cases. (i) Note that the expected utility of the firm for $\eta < \eta^p$ is computed under the *low* valuation. Its value is less than the corresponding utility under the *weighted* valuation. Moreover, η^p maximizes the expected utility of a τ_H type under the *weighted* valuation. Therefore, a τ_H type receives a higher utility by choosing capacity η^p than any $\eta < \eta^p$. Thus, she does not deviate from η^p to any $\eta < \eta^p$. (ii) A τ_H type also does not deviate from η^p to any $\eta^p < \eta < \eta^s$ because by definition η^p maximizes the expected utility of a τ_H type in this interval. (iii) Finally, in order to ensure that a τ_H type does not deviate from η^p to some $\eta \geq \eta^s$, it must be that $U(\tau_H, \eta^p, \rho^*) > \max_{\eta \geq \eta^s} U(\tau_H, \eta, \rho^*)$. Since $\eta_H^* \geq \eta^s$, the maximum on the right hand side of the inequality is achieved at η^s. Thus, this requirement can be simplified to $U(\tau_H, \eta^p, \rho^*) > U(\tau_H, \eta^s, \rho^*)$. Thus, $U(\tau_H, \eta^p, \rho^*) > U(\tau_H, \eta^s, \rho^*)$ is a sufficient condition for η^p to be the capacity investment that maximizes the expected utility of a τ_H type.

Next consider a τ_L type. The expected utility of the firm is also given by (1.3) as

$$U(\tau_L, \eta, \rho^*) = \begin{cases} \pi(\tau_L, \eta) & \text{for } \eta < \eta^p, \\ (1 - \alpha + \alpha g(\tau_L))\pi(\tau_L, \eta) + \alpha g(\tau_H)\pi(\tau_H, \eta) & \text{for } \eta^p \leq \eta < \eta^s, \\ (1-\alpha)\pi(\tau_L, \eta) + \alpha\pi(\tau_H, \eta) & \text{for } \eta \geq \eta^s. \end{cases}$$

We have three cases. (i) By Lemma 3, provided (1.20) holds, a τ_L type will not deviate from η^p to any $\eta < \eta^p$. (ii) In order to ensure that a τ_L type does not deviate from η^p to any $\eta^p < \eta < \eta^s$, it must be true that $U(\tau_L, \eta^p, \rho^*) \geq \max_{\eta^p \leq \eta < \eta^s} U(\tau_L, \eta, \rho^*)$. This condition holds because η^p maximizes the expected utility of a τ_H type under the *weighted* valuation, which implies by first order stochastic dominance that the maximizer of the expected utility of a τ_L type under the *weighted* valuation is less than or equal to η^p, and therefore, the expected utility of a τ_L type is decreasing in η in the interval $\eta^p < \eta < \eta^s$. (iii) Finally, a τ_L type does not deviate from η^p to any $\eta \geq \eta^s$ by the definition of η^s. By Lemma 1, a τ_L type receives a higher expected utility by choosing capacity η_L^* than by selecting any capacity investment $\eta \geq \eta^s$. By first order stochastic dominance, $\eta_L^* \leq \eta^p$, and we have already shown in Lemma 3 that provided (1.20) holds, a τ_L type will not deviate from η^p to any $\eta < \eta^p$.

Thus, the condition specified in (1.20) is sufficient to show a pooling equilibrium at η^p. ■

Corollary 2 *When η has continuous support on $\Re^+$, there exists a pooling PBE in which the firm chooses capacity $\eta^{gp} < \eta^s$ regardless of its type, the equity holder's response function ρ^* is given by (1.2), and posterior beliefs which are reasonable under strict dominance are given by*

$$\lambda(\tau_L) = 1 - \lambda(\tau_H); \qquad \lambda(\tau_H) = \begin{cases} 0 & \eta < \eta^{gp}, \\ g(\tau_H) & \eta = \eta^{gp}, \\ 0 & \eta^{gp} < \eta < \eta^s, \\ 1 & \eta \geq \eta^s. \end{cases}$$

if the following condition holds:

$$U(\tau_H, \eta^{gp}, \rho^*) > \pi(\tau_H, \eta^s),$$

2

The Games People Play: Experiments on Decision Making Under Information Asymmetry

2.1 Introduction

Individuals are often required to make decisions in settings with information asymmetry, including consumer purchases (Milgrom and Roberts 1986), competitive entry (Aghion and Bolton 1987), and capital project and capacity investments (Bebchuk and Stole 1993). Although game theorists have created a variety of tools to aid in the analysis of such decisions, these tools can produce an abundance of justifiable outcomes. Unfortunately, having a model which predict that anything can happen is about as useful for practical decision making as having no model at all. To address this, researchers have developed an assortment of refinement mechanisms that pare down the set of equilibrium outcomes by imposing assumptions on how participants in the decision setting form their beliefs. The question of which of these refinement mechanisms to employ has received little attention in the operations management literature. This is surprising given the wide range of applied issues that game theory has been used to study in operations management.

We examine the predictive power of different refinement mechanisms through a series of controlled experiments in a decision context relevant to operations management – a capacity expansion decision. We focus on testing two particular refinement mechanisms. The first is the Intuitive Criterion refinement, which is based on equilibrium dominance logic. We include it in our analysis because it is arguably the most commonly applied refinement approach in the literature.[1] The second is the Undefeated refinement, which is based on Pareto optimization logic. While not widely employed in the literature, we argue that it may be more appropriate to describe decision outcomes in operations management because it can be applied in practical settings as a simple heuristic.

Our paper experimentally analyzes a signaling game between a manager of a firm and an equity holder of the firm. This game is based on a stylized version of the model in Schmidt et al. (2012). The firm can be one of two types with respect to its market prospects – a "Small" opportunity type or a "Big" opportunity type. The firm's type is revealed to the manager but not to the equity holder due to information asymmetry between them. The manager makes a capacity decision after learning the firm's type. The investor sets a price for the firm after seeing the manager's capacity decision. The manager's payoff depends on the firm's type, the manager's capacity decision, and the price the investor sets for the firm. The investor's payoff depends on being as close as possible to the true value of the firm.

The assumptions captured in our experiment[2] are commonly used in the signaling game literature (Kreps and Sobel 1992). The predicted outcomes in our experiments, and from signaling game models generally, can vary dramatically depending on whether the Undefeated refinement or the Intuitive Criterion refinement is applied. Since the choice of which refinement to employ is at the discretion of the researcher, it is important to examine the validity of the differing predictions of these methods.

Our experiment reveals that participants are much more likely to make decisions that are predicted by

[1] For instance, Riley (2001) notes that the "Intuitive Criterion has dominated the literature in the years since its introduction."

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

the Undefeated refinement than by the Intuitive Criterion refinement. This is is particularly true when the complexity of the game is increased. Participants who more often make decisions which are congruent with the Undefeated refinement report a higher level of understanding of the game and have higher payoffs than those who more often make decisions which are congruent with the Intuitive Criterion refinement. Our findings represent a significant contribution to the literature as they provide the first evidence that the Undefeated refinement may be more predictive of operations management decisions made under information asymmetry than the more commonly applied Intuitive Criterion refinement. This result is practically appealing because in general settings the outcomes predicted by the Undefeated refinement yield a Pareto improvement compared to the outcomes predicted by the Intuitive Criterion refinement.

2.2 Literature Review

Operations management researchers have increasingly employed signaling game theory to study the impact of information asymmetry across a variety of topics, including consumer purchases (Debo and Veeraraghavan 2010), competitive entry (Anand and Goyal 2009), new product introductions (Lariviere and Padmanabhan 1997), franchising (Desai and Srinivasan 1995), channel stuffing (Lai et al. 2011), supply chain coordination (Cachon and Lariviere 2001, İşlegen and Plambeck 2007, Özer and Wei 2006), and capital project and capacity investments (Lai et al. 2012). In all of these cases the researchers must decide how to address the fact that multiple, and possibly an infinite number of equilibria may exist in their models. Cachon and Lariviere (2001), Özer and Wei (2006) and İşlegen and Plambeck (2007) acknowledge that multiple equilibria exist, but opt to focus their analyses on the least cost separating PBE as they are particularly interested in examining situations in which the more informed player can credibly reveal her type.

Other researchers address the issue of multiple equilibria by invoking the Intuitive Criterion refinement to refine the beliefs of the participants. Desai and Srinivasan (1995), Lai et al. (2011), Lariviere and Padmanabhan (1997) and Lai et al. (2012) use the Intuitive Criterion refinement to eliminate all possible pooling equilibrium outcomes such that only the least cost separating equilibrium remains. More elaborate signaling games, however, such as those with more than one signaling mechanism (Debo and Veeraraghavan 2010) or more than two players (Anand and Goyal 2009), may not result in a unique prediction despite employing the Intuitive Criterion refinement to pare down the set of equilibria. Missing from this research is a consideration of alternative refinement methods which may yield different predicted outcomes if applied to these models.

Which refinement mechanism is most appropriate is an unsettled question. There is a rich literature, primarily in economics, which uses controlled experiments to examine the behavior of subjects in signaling games. Brandts and Holt (1992) focuses on the predictive power of equilibrium dominance refinements only, including the Intuitive Criterion. While finding support for the Intuitive Criterion, they also find that in repeat games an equilibrium eliminated by the Intuitive Criterion can be supported depending on how subjects behave early in the experiment. Banks et al. (1994) test which refinement subjects employ from a set of nested refinements that use increasingly stringent assumptions related to equilibrium dominance. They explicitly test and find support for the application of the Intuitive Criterion refinement, but they do not include tests of alternative refinements based on Pareto optimization. Cooper and Kagel (2005) compare the performance of individual players to 2-person teams and find that the latter behave more strategically and attribute it to greater learning transfer.

The experimental evidence that players employ the Intuitive Criterion or more restrictive refinements is challenged by Partow and Schotter (1993). They modify the experiments by masking the other player's payoffs and get similar results to the original experiments. From this, they infer that subjects are not undertaking the complex refinement logic suggested by the refinement theory but rather using simple heuristics based exclusively on their own payoffs. These conflicting findings make clear that the experimental evidence on refinement logic has not yet been conclusive.

Finally, we take some inspiration from a broad literature on managers making operational decisions that do not maximize expected profits. Several experimental studies have identified that decision makers may deviate from the expected-profit-maximizing capacity choice due to decision biases, including anchoring, demand chasing, and inventory error minimization (Bolton and Katok 2008, Bostian et al. 2008, Kremer et al. 2010, Schweitzer and Cachon 2000). Deshpande et al. (2003) and van Donselaar et al. (2010) use large sample observational data to provide empirical evidence that decisions in practice may differ from model-based rules. Our findings highlight that there is considerable opportunity to explore how information asymmetries may also lead to such behaviors.

2.3 Theory

Our paper experimentally analyzes a signaling game between a manager of a firm (hereafter, the firm) and an equity holder of the firm (hereafter, the investor). This game is based on a simplified version of the model in Schmidt et al. (2012). We focus on the relatively common scenario in which an investor has less information than the firm concerning the *quality* of demand for the firm's product (Berle and Means 1932, Stein 1988). The firm can be one of two types with respect to its market prospects – a "Small" opportunity type or a "Big" opportunity type. The firm's type is revealed to the firm but not to the investor due to information asymmetry between them. The firm moves first by making a capacity decision after learning its type. The investor sets a price for the firm after seeing the firm's capacity decision. The firm's payoff depends on the firm's type, the firm's capacity decision, and the price the investor sets for the firm. The investor's payoff depends on being as close as possible to the true value of the firm.

The equilibrium concept used in signaling games is referred to as Perfect Bayesian Equilibrium (PBE). In a PBE, neither player has an incentive to deviate from their choices so the resulting outcome is stable. For a technical definition of a PBE, refer to (Fudenberg and Tirole 1991). In cases where multiple PBE exist, refinements to the players' out-of-equilibrium (OOE) beliefs can further pare the number of predicted PBE outcomes. Our experiment examines the Intuitive Criterion and Undefeated refinements.

2.3.1 The Intuitive Criterion Refinement

The Intuitive Criterion refinement is applied by considering all possible OOE capacity levels for a particular PBE and identifying whether, compared to the PBE results, a capacity choice exists which *would not* provide a "Small" opportunity firm with a higher payoff using a *Big* valuation but *would* provide a "Big" opportunity firm with a higher payoff using a *Big* valuation. If such a capacity choice does exist then the Intuitive Criterion refinement eliminates the PBE. For the formal definition of the Intuitive Criterion refinement, please refer to (Cho and Kreps 1987). While it is widely applied in the literature, the Intuitive Criterion may not be appropriate in some operations management settings. For a discussion of some of the criticisms of the Intuitive Criterion, refer to Bolton and Dewatripont (2005), Mailath et al.

(1993), Riley (2001) and Salanie (2005).

2.3.2 The Undefeated Refinement

The Undefeated refinement is based on Pareto-optimization which may be more readily exercised as a heuristic in operations management settings. If there exists multiple PBE in a game, and one of those PBE is a Pareto improvement over the other, then the Pareto dominated PBE is eliminated and the non-Pareto dominated PBE is said to be "undefeated" or to survive the Undefeated refinement. For a technical definition of the Undefeated refinement, please refer to (Mailath et al. 1993). The Undefeated refinement has been applied in the finance and economics literature (Fishman and Hagerty 2003, Gomes 2000, Spiegel and Spulber 1997, Taylor 1999) and it addresses many of the concerns raised about the Intuitive Criterion refinement.

There are several features of the Undefeated refinement that lead us to believe that it will be a stronger predictor of firm behavior than the Intuitive Criterion refinement. By construction the Undefeated refinement does not eliminate any PBE that is Pareto efficient, as is possible with the Intuitive Criterion refinement. In addition, unlike the Intuitive Criterion refinement, the Undefeated refinement does not rely on unmodeled "speeches" from the firm in order to convey additional information to the investor. Instead, the Undefeated refinement ensures that OOE beliefs are restricted only by other equilibria in the model. Finally, at least one PBE will survive the Undefeated refinement since it eliminates PBE by performing a Pareto comparison to other PBE.

2.4 Data

2.4.1 Experiment

Eighty subjects (45% female, median age=21) participated in the experiment across four sessions. Detailed demographic information are presented in Table 2.7.2. The sessions were held in the Computer Lab for Experimental Research (CLER) at Harvard Business School. All interaction among the subjects during the experiment was conducted anonymously through a web-hosted software program, as was all of the random assignments of the subjects to their roles, types and partners in each round.

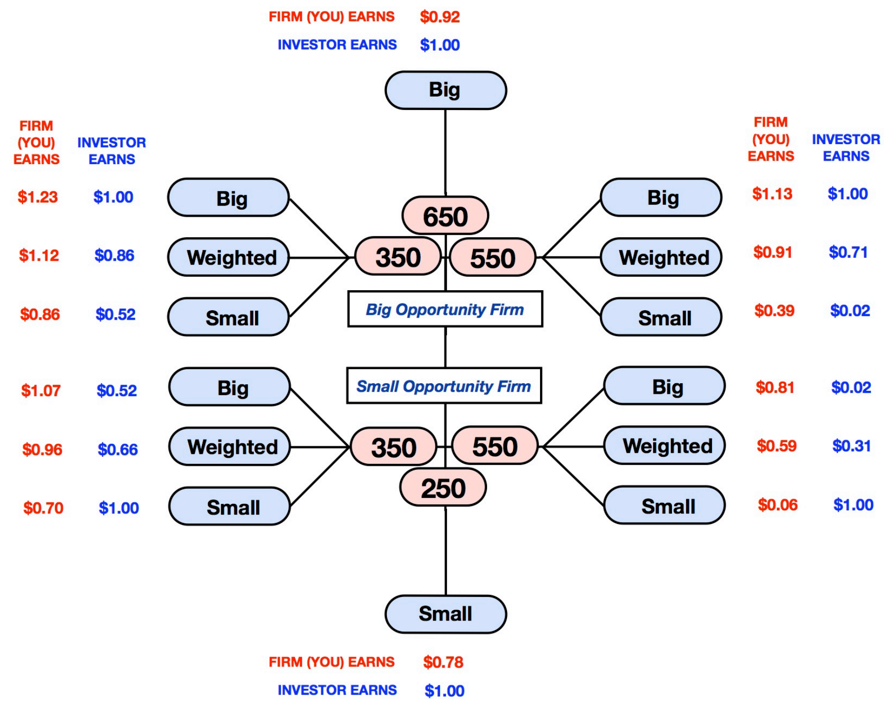
Each session of the experiment has eight scenarios. Each subject plays each scenario as a firm and as an investor, and therefore plays a total of 16 rounds. In each scenario, the capacity choices available to firms represent different combinations of separating PBE, pooling PBE, and choices that are not a PBE. Although we collected data on the subjects' actions for all rounds, we focus the analysis in this paper on the subjects' actions when playing the role of the firm.

Figure 2.4.1 provides the extensive form view of Scenario 4 from the firm's perspective. The investor's perspective is quite similar except for minor coloration differences. In this scenario, a "Big" opportunity firm can choose to open either 350, 550 or 650 stores, while a "Small" opportunity firm can choose to open either 250, 350, or 550 stores. If the firm chooses to open either 350 or 550 stores, then the investor must decide whether to award the firm a "Small," "Weighted," or "Big" valuation. Figure 2.4.2 provides the extensive form view of Scenario 8 from the investors's perspective. In this scenario, a "Big" opportunity firm can choose to open either 525, 675 or 775 stores, while a "Small" opportunity firm can choose to open either 475, 525, or 675 stores. If the firm chooses to open either 525 or 675 stores, then the investor must decide whether to award the firm a "Small," "Weighted," or "Big" valuation. Choice 650 in Scenario 4 and 775 in Scenario 8 uniquely identify a "Big" opportunity firm, while Choice 250 in Scenario 4 and 475 in Scenario 8 uniquely identify a "Small" opportunity firm. If the firm selects any of these choices then they perfectly reveal their type, and the Investor's pricing decision is made automatically. The firm's payoff depends on the firm's type, the firm's capacity decision, and the price the investor sets for the firm. The investor's payoff depends on being as close as possible to the true value of the firm.

Figures 2.7.1, 2.7.2, and 2.7.3 in the Appendix provide the extensive forms for the remaining 6 scenarios. Note that Scenarios 1, 2, and 3, are simply all of the 2-choice combinations from the set of 3 choices in Scenario 4; and Scenarios 5, 6, and 7, are simply all of the 2-choice combinations from the set of 3 choices in Scenario 8. Also note that Scenario 1 is a similar structure to Scenario 5, Scenario 2 is a similar structure to Scenario 6, and so on. As shown in Table 2.7.1, these scenario "pairs" also have similar predicted outcomes under the Undefeated and Intuitive Criterion refinements. This is by design so that we can examine whether participants acted consistently across scenarios.

At the beginning of the experiment, a monitor reads a script that provide instructions to the subjects.

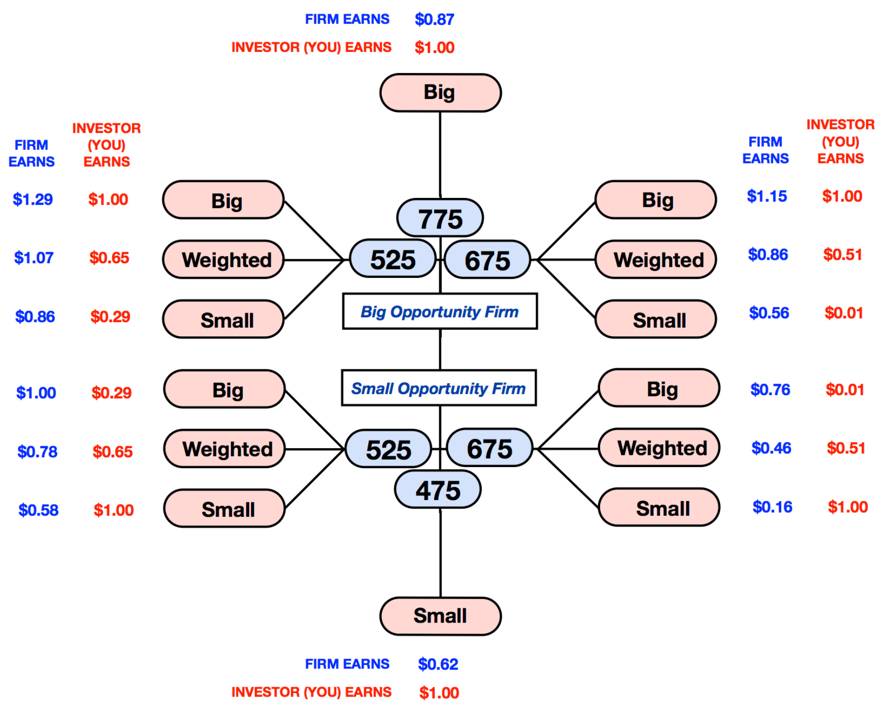
Figure 2.4.1: Extensive form of Scenario 4, with the display formatted for presentation to a firm.



The text of the script is in the appendix and the accompanying presentation slides are available by request. At the conclusion of the instructions, the software randomly determines whether scenarios 1 through 4 or 5 through 8 will be presented first. The payoffs from the first set of 4 scenarios in every session do not factor in to the subjects' compensation while the payoffs from the second set of 4 scenarios are added to the subjects' compensation.

The software also randomly and anonymously assigns subjects to groups that have an even number of no less than eight and no more than 14 players. Each group is randomly assigned a sequence for the order of presentation of the first four scenarios. Subjects in each group are randomly assigned to begin either in the role of a firm or the investor. Each subject is randomly and anonymously paired with another subject in the group in the opposite role and the first scenario is presented to all the players. After each scenario, subjects are randomly and anonymously paired with another subject. After completing all four scenarios,

Figure 2.4.2: Extensive form of Scenario 8, with the display formatted for presentation to a investor.



subjects swap roles and play the same scenarios in the opposite role, again with random and anonymous pairings for each scenario. After completing all four scenarios as both an investor and a firm, subjects are randomly drawn into new groups and the whole process is repeated for the next four scenarios.

At the start of each round, after the subject learns whether it will play the role of a firm or an investor but before the firm's type is revealed, we present the extensive form of the scenario and ask firms to identify their anticipated choice if they are assigned to be a "Big" opportunity firm, and their anticipated choice if they are assigned to be a "Small" opportunity firm. Similarly, investors are asked their anticipated pricing decisions based on all the alternative store choices that the firm could possibly make for the current scenario. The firm's type is then revealed to the firm and the firm can confirm or change their choice. This choice is then revealed to the investor paired with this firm, and the investor can confirm or change their price decision. Asking subjects to enter their anticipated decisions prior to revealing the firm's type to the firm or the firm's choice to the investor accomplishes two things. First, it encourages the subjects to consider the problem from different perspectives before making their final decision. Second, it allows us to measure whether firms and investors deviate from their original strategies once information has been revealed to them.

We lost 10 observations because a technical problem prevented five subjects from completing all eight scenarios as a firm. Our final sample consists of 630 firm-scenario observations.

2.4.2 Measures

Table 2.7.3 summarizes the variables used in our analysis, Table 2.7.4 provides summary statistics and Table 2.7.5 provides correlations. We create several variables to track information related to the set up of the game in each round of the experiment. *Big* is set to '1' to identify those subjects that are randomly assigned to have a "Big" opportunity in the current round. *Money* identifies whether the current round will affect the subject's compensation. *Session* identifies which of the four experimental sessions this round was run in. *Complexity* identifies whether the firm is facing greater complexity (i.e., there are three capacity choices as opposed to two) in the current round or not. Finally, *Order* is a dummy variable identifying whether the subject was first presented with Scenarios 1 through 4 or first presented with scenarios 5 through 8.

We also collect several measures that are generated by the experiment. *Undefeated* is set to '1' if the subject's choice conforms to what is predicted by the Undefeated refinement, and '0' if it does not. *Intuitive* is set to '1' if the subject's choice conforms to what is predicted by the Intuitive Criterion refinement, and '0' if it does not. *Payoff* captures the payoff the subject received in the round, regardless of whether this amount was added to the subject's compensation. *Switch* identifies whether the subject's final choice deviated from the initial strategy they entered prior to learning their type. Finally, *Wait* tracks the amount of time the subject waited in the current round. This is influenced by how long it takes the other player in the game to make their decision.

We ask participants to complete a post-experiment survey to collect information about their experience. In particular, we ask "On a scale of 1-7 (1: 'I did not understand the game at all', 7: 'I understood the game completely') how well do you feel you understood the game we just played?" From this response we generate a dummy variable, *Understanding*, which is set to '1' if the subject rated their understanding as a '5' or higher and '0' if they rated it a '4' or lower. We also capture demographic information in a set of mostly categorical variables – *Age, Gender, Ethnicity, Education, Student, ESL* (English as a second language), and *Married*.

2.4.3 Empirical Models

Impact of *Understanding* on Refinement Predictions

We are interested in understanding the relationship between each subject's self-reported level of understanding of the game and the likelihood that their decisions are predicted by either the Undefeated refinement or the Intuitive Criterion refinement. Any predictive power associated with the refinements could justifiably be called into question if subjects report having a low understanding of the game. We examine this relationship for the Undefeated refinement by estimating the following model:

$$\begin{aligned} Pr(Undefeated_i) = F(\beta_0 + \beta_2 \cdot Understanding_j + \beta_3 \cdot Big_i + \beta_4 \cdot Order_i + \beta_5 \cdot Switch_i + \\ \beta_6 \cdot Money_i + \xi' X_j + \varepsilon_i), \end{aligned} \qquad (2.1)$$

where subscript i denotes the subject-round observation and j denotes the subject. The vector X_j includes control variables: *Session, Wait, Age, Gender, Ethnicity, Education, Student, ESL*, and *Married*. To examine this relationship for the Intuitive Criterion refinement, *Intuitive* is used as the dependent variable in place of *Undefeated*.

Impact of *Complexity* on Refinement Predictions

We evaluate whether increasing the complexity of the game impacts the likelihood that the outcomes are predicted by the refinements of interest. We capture the higher complexity construct with *Complexity*, which identifies the two scenarios among the eight tested which have three capacity choices as opposed to two. After adding *Complexity* to our specification, we estimate the following model:

$$Pr(Undefeated_i) = F(\beta_0 + \beta_1 \cdot Complexity_i + \beta_2 \cdot Understanding_j + \beta_3 \cdot Big_i + \beta_4 \cdot Order_i + \beta_5 \cdot Switch_i + \beta_6 \cdot Money_i + \xi' X_j + \varepsilon_i). \quad (2.2)$$

IMPACT OF REFINEMENTS ON PAYOUTS

To evaluate whether subjects who make choices that are consistent with the Undefeated refinement or the Intuitive Criterion refinement earn a higher payoff, we include *Undefeated* and *Intuitive* in the following specification:

$$Payoff_i = \gamma_0 + \gamma_1 \cdot Undefeated_i + \gamma_2 \cdot Intuitive_i + \gamma_3 \cdot Understanding_j + \gamma_4 \cdot Big_i + \gamma_5 \cdot Order_i + \gamma_6 \cdot Switch_i + \gamma_7 \cdot Money_i + \xi' X_j + \varepsilon_i. \quad (2.3)$$

where *Payoff* is the realized payoff for the subject in each round. We limit our analysis to scenarios 4 and 8 since those are the only two scenarios in which both the Undefeated and Intuitive Criterion refinements have a single predictions that are unique from each other.

2.5 RESULTS

Table 2.7.6 summarizes whether the subjects make choices that are predicted by the Intuitive Criterion or Undefeated refinements in each of the eight scenarios. From Panel A it is clear that the overwhelming number of choices do conform with the Undefeated refinement, from a low 57.3% for Scenario 2 to a high of 83.1% for Scenario 1. Panel B, on the other hand, indicates that there is conformance to the Intuitive Criterion refinement on far fewer occasions, from a low 9% for Scenario 4 to a high of 61.2% for Scenario 6. Recall that both 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 16.1% of the time (Scenario 8).

One concern may be that a lack of understanding led to the pattern of results we observe. Several features of our experimental design were intended to reduce this possibility, including asking subjects to enter their strategies before each round of play, having subjects switch roles and play the game both as a firm and an investor, and including two sets of four scenarios to test for consistent behavior. As discussed in Section 2.4.1, Scenarios 1 through 4 and Scenarios 5 through 8 have a similar structure and the Intuitive Criterion and Undefeated refinements have the same predictions (refer to Table 2.7.1). The fact that we get a very similar behavior patter in Scenarios 1 through 4 and Scenarios 5 through 8 (refer to Table 2.7.6) provides us with some assurance that the subjects understood the game.

We estimate the models in Equations (2.1) and (2.2) using a logistic regression with robust standard errors clustered by participant. Results are presented as odds ratios. We estimate the model in Equation (2.3) using OLS with with robust standard errors clustered by participant. Tables 2.7.7, 2.7.8 and 2.7.9 report the main results from these regressions.

2.5.1 Impact of *Understanding* on Refinement Predictions

The results of the logistic regression estimating the specification in Equation (2.1) are presented in Table 2.7.7. Models (1) and (2) exclude demographic controls while model (3) and (4) include them. Models (1) and (3) test which variables are associated with the likelihood that the firm's capacity choice is consistent with the Undefeated refinement. We estimate Models (1) and (3) using observations from scenarios 1, 3, 4, 5, 7, and 8. For each of these scenarios, the Undefeated refinement has a single predictions that is different from that predicted by the Intuitive Criterion refinement.

Models (2) and (4) test which variables are associated with the likelihood that the firm's capacity choice is consistent with the Intuitive Criterion refinement. For both models we exclude *Order* as there is only one observation for which both *Intuitive* and *Order* are non-zero.[3] We estimate Models (2) and (4) using observations from scenarios 4 and 8. These are the only two scenarios for which the Intuitive Criterion refinement has a single predictions that is different from that predicted by the Undefeated refinement.

In Model (1), the odds ratio on *Understanding* is 3.40 (SE 1.89, $p < 0.05$), indicating that subjects who indicated a having a high level of understanding about the game were 3.4 times as likely to make a capacity

[3]As a robustness check, we exclude *Order* from our estimation of *Undefeated* as well and our inferences do not change (Table 2.7.11, Models (1) and (2)).

choice that was consistent with the Undefeated refinement as subjects who did not have a high level of understanding. In Model (2), the odds ratio on *Understanding* is insignificant (odds ratio 0.36, SE 0.27, $p > 0.10$) indicating that between those with and without high level of understanding there is no difference in the likelihood of making a capacity choice consistent with the Intuitive Criterion refinement. The difference between the coefficients on the impact of *Understanding* between the two models is significant (Wald χ^2 4.91, $p < 0.05$). Similar results are obtained by comparing models (3) and (4). That our results are robust to the inclusion of controls such as education, age and the use of English as a second language indicates that the result is not driven by higher aptitude.

We consider other break points on the Likert scale to indicate the subject had a high understanding of the game, as well capturing their understanding in a more granular categorical variable (not presented) and our inferences remain unchanged. We cannot use the full 7-point scale from the original survey question because the subjects generally indicated they had a high level of understanding of the game (the mean response using the 7-point scale was 5.9), so some of the categories are sparsely populated.

These results indicate that a high understanding of the game is positively associated with choices predicted by Undefeated. This is reinforced by noting that the odds ratio on *Switch* for model (1) is significant and less than 1 (odds ratio 0.14, SE 0.07, $p < 0.01$), indicating that subjects who make a choice consistent with the Undefeated refinement are much less likely to deviate from the strategy they set prior to the revelation of their type. This lack of second guessing would naturally correspond to a higher level of understanding of the game.

2.5.2 Impact of *Complexity* on Refinement Predictions

Table 2.7.7 presents the results of the logistic regression estimating the impact of increased complexity on the likelihood that the firm's choices are consistent with either the Undefeated refinement or Intuitive Criterion refinement. Model (1) examines the impact of complexity on whether firm choices are consistent with the Undefeated refinement. We estimate this model using observations from all of the scenarios since Undefeated refinement has a unique prediction in each scenario. Model (2) examines the impact of complexity on whether firm choices are consistent with the Intuitive Criterion refinement. We estimate this model using observations from scenarios 2, 4, 6, and 8 since these are the only scenarios for which the Intuitive Criterion refinement results in (at least) one unique PBE. We again exclude *Order* as there is only one observation for which both *Intuitive* and *Order* are non-zero.[4]

Recall that our construct for increased complexity in the firm's decision is captured by the variable *Complexity*, which identifies scenarios which have 3 as opposed to 2 capacity choices. In Model (1), the odds ratio on *Complexity* is 1.03 (SE 0.19, $p > 0.10$), indicating that scenarios with greater complexity do not induce the firm to make choices that are more or less consistent with the Undefeated refinement. In Model (2), the odds ratio on *Complexity* is significant (odds ratio 0.07, SE 0.03, $p < 0.01$) both statistically and economically. The result indicates that an increase in complexity reduces by a factor of .07 the number of firm choices that are consistent with the Intuitive Criterion refinement. The difference between the coefficients on the impact of *Complexity* between the two models is significant (Wald χ^2 33.78, $p < 0.01$).

This provides further support that the Undefeated refinement may be more appropriate in many operations management settings. Our analysis focuses on relatively constrained decision framework – the firm has at most three options to choose from. In many operations management decisions the firm has many more options to choose from. This finding bears further examination to confirm whether even greater increases in complexity further diminish the predictive power of the Intuitive Criterion refinement.

2.5.3 Impact of Refinements on Payouts

Table 2.7.9 presents the OLS estimation of Equation 2.3 specifying the relationship between the subject's payoffs and whether their choices are consistent with either the Intuitive Criterion or Undefeated refinements. Model (1) excludes demographic controls while Model (2) includes demographic controls. We estimate the results for both models using scenarios 4 and 8, which are the only two scenarios for which both the Undefeated refinement and the Intuitive Criterion refinement make unique, differentiated predictions.

In both Models (1) and (2) a Wald test comparing the coefficient on *Undefeated* to the coefficient on *Intuitive* indicates that subjects whose choices are predicted my the Undefeated refinement have higher

[4] As a robustness check, we exclude *Order* from our estimation of *Undefeated* as well and our inferences do not change (Table 2.7.11, Models (3) and (4)).

payoffs than those whose choices are predicted my the Intuitive Criterion refinement. For model (1), the difference in these coefficients is 0.26 (Wald χ^2 140.22, $p < 0.01$), while in Model (2) the difference is 0.25 (Wald χ^2 107.86, $p < 0.01$), indicating that subjects make about $0.25 more per round by making choices consistent with the Undefeated refinement rather than the Intuitive Criterion refinement. This is somewhat intuitive since the Undefeated refinement relies on choosing PBE based on Pareto dominance of the payoffs, and it is reassuring to recover this result in an experimental setting.

2.6 Implications and Conclusions

We explore how individuals make decisions relevant in an operations management setting when there is information asymmetry between the firm and an outside investor. While stylized models in economics often employ assumptions that can abstract from reality, operations management deals with real-world aspects of decision problems. A common assumption in the signaling game literature is that beliefs among the participants in the game are refined using the Intuitive Criterion refinement. Through a series of experiments, we show that the predictive power of this refinement can be exceptionally low, and that the Undefeated refinement performs much better. Importantly, we provide evidence that the subjects making decisions which aligned with the Undefeated refinement reported a higher understanding of the game than those who made decisions which aligned with the Intuitive Criterion refinement. These subjects also earned higher payouts.

Other experiments have tested the predictive power of refinements with mixed results. To our knowledge, we are the first to explicitly perform such tests on the Undefeated refinement, particularly in a setting relevant to operations management. Our experimental results reveal that the predictive power of the Undefeated refinement is robust to increases in the complexity of the decision maker's choice set, while that of the Intuitive Criterion refinement deteriorates with greater complexity.

Our results have implications for the burgeoning set of operations research involving information asymmetry and applications of the Intuitive Criterion refinement. Not only does the Undefeated refinement predict different outcomes than the Intuitive Criterion refinement in many cases, but the greater accuracy of those predictions should encourage researchers to include it in future analyses.

2.7 Appendix

2.7.1 Tables

Table 2.7.1: Summary of predictions to each scenario by the Undefeated refinement or Intuitive Criterion refinement.

	Scenario:			
	1	2	3	4
Undefeated	350	Separating	350	350
Intuitive Criterion	Any	Separating	None	Separating
	Scenario:			
	5	6	7	8
Undefeated	525	Separating	525	525
Intuitive Criterion	Any	Separating	None	Separating

Note: The Intuitive Criterion has no refinement power in Scenarios 1 and 5 and results in the the elimination of all PBE in Scenarios 3 and 7. Both the Intuitive Criterion and Undefeated refinements have the same predicted outcome in Scenarios 2 and 6.

Table 2.7.2: Sample summary

Gender	Frequency	Percent
Male	43	53.75
Female	36	45.00
Missing	1	1.25
Total	80	100
Ethnicity	**Frequency**	**Percent**
African American	7	8.75
Asian	13	16.25
Caucasian	41	51.25
Hispanic	11	13.75
Pacific Islander	6	7.50
Missing	2	2.50
Total	80	100.00
Education Attained	**Frequency**	**Percent**
High school	7	8.75
Some college	49	61.25
Bachelors degree	16	20.00
Masters degree	7	8.75
Missing	1	1.25
Total	80	100.00
Student Status	**Frequency**	**Percent**
Not a student	13	16.25
Full time student	65	81.25
Part time student	1	1.25
Missing	1	1.25
Total	80	100.00
Primary Language	**Frequency**	**Percent**
English is primary language	67	83.75
English is secondary language	12	15.00
Missing	1	1.25
Total	80	100.00
Marital Status	**Frequency**	**Percent**
Not married	76	95.00
Married	3	3.75
Missing	1	1.25
Total	80	100.00

Table 2.7.3: Description of Variables

Variable	Description
Undefeated	Indicator identifying that the Undefeated refinement predicts the firm's choice ('1') or not ('0')
Intuitive	Indicator identifying that the Intuitive Criterion refinement predicts the firm's choice ('1') or not ('0')
Payoff	Payoff the subject received in the round
Understanding	Indicator identifying subject rated their understanding as a '5' or higher ('1'), or a '4' or lower ('0') on a 7-point Likert scale
Big	Indicator identifying subject is a Big type in current round ('1') or a Small type ('0')
Order	Scenarios 1 through 4 were presented to subject fist ('1') or scenarios 5 through 8 were presented first ('0')
Switch	Identifies whether the subject's final choice deviates from their initial strategy ('1') or not ('0')
Money	Earnings from the round was added to the subject's payout
Session	Identifier for the experimental session
Complexity	Identifies whether the firm faces three capacity choices ('1') or two capacity choices ('0')
Wait	Amount of time the subject waited in the current round
Age	Subject's age
Gender	Indicator identifying subject is female ('1') or male ('0')
Ethnicity	African-American ('1'), American Indian ('2'), Asian ('3'), Caucasian ('4'), Hispanic ('5'), Pacific Islander ('6'), Other ('7')

continued on the next page

Table 2.7.3 – continued from previous page

Variable	Description
Education	Subject has a high school diploma ('1'), some college ('2'), a bachelors degree ('4'), or a masters degree ('5')
Student	Subject is not a student ('0'), is a full time student ('1'), or a part time student ('2')
ESL	Indicator identifying English is subject's second language ('1') or primary language ('0')
Married	Indicator identifying subject as married ('1') or not ('0')

Table 2.7.4: Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Undefeated	0.74	0.44	0	1	630
Intuitive	0.36	0.48	0	1	314
Payoff	0.99	0.22	0	1.29	630
Understanding	0.84	0.37	0	1	630
Big	0.60	0.49	0	1	630
Order	0.06	0.24	0	1	630
Switch	0.10	0.29	0	1	630
Money	0.49	0.50	0	1	630
Session	2.22	1.17	1	4	630
Complexity	2.25	0.43	2	3	630
Wait	12.6	25.51	0	166	630
Age	22.24	3.86	18	38	622

Table 2.7.5: Correlations

Variables	Undefeated	Intuitive	Payoff	Understanding	Big	Order	Switch	Money	Session	Complexity	Wait	Age
Undefeated	1.00											
Intuitive	0.25	1.00										
Payoff	0.17	-0.56	1.00									
Understanding	0.11	-0.02	0.03	1.00								
Big	-0.15	-0.38	0.62	0.01	1.00							
Order	-0.06	0.05	-0.02	0.11	0.04	1.00						
Switch	-0.16	0.05	-0.16	0.05	-0.06	0.00	1.00					
Money	0.07	-0.07	0.28	0.04	0.11	-0.26	-0.01	1.00				
Session	-0.01	0.09	-0.08	0.28	0.01	0.17	0.00	0.02	1.00			
Complexity	-0.02	-0.49	0.11	-0.00	0.06	-0.00	0.09	-0.00	-0.00	1.00		
Wait	0.05	0.08	0.03	-0.08	-0.01	-0.03	-0.06	0.00	-0.03	-0.01	1.00	
Age	-0.11	0.03	-0.00	-0.15	0.01	-0.14	-0.02	-0.01	-0.07	-0.00	-0.04	1.00

Table 2.7.6: Summary of whether subject choices made decisions which conformed to predictions of the Undefeated refinement or Intuitive Criterion refinement in each scenario.

Panel A. Does the subject's choice conform with that predicted by the Undefeated refinement?

	Scenario: 1	2*	3	4	5	6*	7	8	Total
No	13	32	14	19	14	31	14	24	161
	16.9%	42.7%	17.5%	24.4%	17.5%	38.8%	17.7%	29.6%	25.6%
Yes	64	43	66	59	66	49	65	57	469
	83.1%	57.3%	82.5%	75.6%	82.5%	61.2%	82.3%	70.4%	74.4%
Total	77	75	80	78	80	80	79	81	630
	100%	100%	100%	100%	100%	100%	100%	100%	100%

Panel B. Does the subject's choice conform with that predicted by the Intuitive Criterion?

	Scenario: 2*	4	6*	8	Total
No	32	71	31	68	202
	42.7%	91.0%	38.8%	83.9%	64.3%
Yes	43	7	49	13	112
	57.3%	9.0%	61.2%	16.1%	35.7%
Total	75	78	80	81	314
	100%	100%	100%	100%	100%

**Both the Intuitive Criterion and Undefeated refinements have the same predicted outcome in Scenarios 2 and 6. The Intuitive Criterion has no refinement power in Scenarios 1 and 5 and results in the elimination of all PBE in Scenarios 3 and 7.*

Table 2.7.7: Estimating whether the subject's choice is consistent with the Undefeated refinement or the Intuitive Criterion refinement.

	Dependent Variable:			
	Undefeated	*Intuitive*	*Undefeated*	*Intuitive*
	(1)	(2)	(3)	(4)
Understanding	3.40*	0.36	4.41*	0.19
	[1.89]	[0.27]	[3.04]	[0.20]
Big	0.66	0.25*	0.66	0.21*
	[0.19]	[0.15]	[0.19]	[0.14]
Order	0.19*		0.07*	
	[0.13]		[0.08]	
Switch	0.14**	3.05+	0.13**	2.36
	[0.07]	[2.03]	[0.07]	[1.91]
Money	1.57+	0.47	1.67+	0.43
	[0.40]	[0.27]	[0.45]	[0.27]
Constant	2.45*	0.57	73.22**	0.32
	[1.00]	[0.40]	[100.96]	[0.88]
Observations	475	159	475	157
Pseudo R^2	0.11	0.16	0.19	0.26
Mean DV	0.79	0.13	0.79	0.13
Pearson χ^2	213.07	83.91	370.91	119.90
Pearson p-value	0.49	0.45	0.36	0.80
Wald χ^2		4.91*		5.05*
Wald p-value		0.03		0.02

Notes: Logistic estimation with results presented as odds ratios. Robust standard errors clustered by subject in brackets. Models (1) and (2) are estimated using scenarios 1, 3, 4, 5, 7 and 8 and include controls *Session* and *Wait*. Models (3) and (4) are estimated using scenarios 4 and 8 and also include controls *Age, Gender, Ethnicity, Education, Student, ESL,* and *Married*. Pearson χ^2 and Pearson p-value assess the goodness of fit of the model. Wald χ^2 and Wald p-value provide a test of the equivalency of the coefficient on *Understanding* across models (1) and (2), and models (3) and (4). ** p<0.01, * p<0.05, + p<0.10

Table 2.7.8: Estimating whether the adding complexity to the game (increasing the number of choices from 2 to 3) impacts the likelihood that the subject's choice is predicted by the Undefeated refinement or the Intuitive Criterion refinement.

	Dependent Variable:	
	Undefeated	*Intuitive*
	(1)	(2)
Complexity	1.03	0.07**
	[0.19]	[0.03]
Understanding	2.99**	0.78
	[1.19]	[0.46]
Big	0.40**	0.16**
	[0.09]	[0.05]
Order	0.25**	
	[0.11]	
Switch	0.25**	1.59
	[0.09]	[0.81]
Money	1.38	0.83
	[0.28]	[0.24]
Constant	32.80**	4.98
	[37.08]	[10.85]
Observations	630	314
Pseudo R^2	0.12	0.32
Mean DV	0.74	0.36
Pearson χ^2	494.20	310.86
Pearson p-value	0.70	0.15
Wald χ^2		33.78**
Wald p-value		0.00

Notes: Logistic estimation with results presented as odds ratios. Robust standard errors clustered by subject in brackets. Model (1) is estimated using all scenarios and Model (2) is estimated are estimated using scenarios 2, 4, 6, and 8. Included controls – *Session, Wait, Age, Gender, Ethnicity, Education, Student, ESL*, and *Married*. Pearson χ^2 and Pearson p-value assess the goodness of fit of the model. Wald χ^2 and Wald p-value provide a test of the equivalency of the coefficient on *Complexity* across models (1) and (2).
** p<0.01, * p<0.05, + p<0.10

Table 2.7.9: Estimating how the subject's payout depends on their choice being predicted by the Undefeated refinement or the Intuitive Criterion refinement.

		Dependent Variable: *Payoff*	
		(1)	(2)
(A)	*Undefeated*	0.10*	0.06
		[0.04]	[0.04]
(B)	*Intuitive*	-0.16**	-0.19**
		[0.04]	[0.04]
	Understanding	-0.01	0.00
		[0.02]	[0.03]
	Big	0.20**	0.19**
		[0.03]	[0.03]
	Order	0.16	0.15
		[0.13]	[0.15]
	Switch	-0.02	-0.02
		[0.06]	[0.06]
	Money	0.10**	0.10**
		[0.02]	[0.02]
	Constant	0.83**	0.95**
		[0.04]	[0.11]
	Observations	159	159
	R^2	0.54	0.57
	Mean DV	1.03	1.03
	Wald χ^2: (A)-(B)=0?	140.22**	107.86**

Notes: OLS estimation with robust standard errors clustered by subject in brackets. The models are estimated using uses scenarios 4 and 8. Model (1) includes controls *Session* and *Wait*. Model (2) also includes controls *Age, Gender, Ethnicity, Education, Student, ESL,* and *Married*. ** p<0.01, * p<0.05, + p<0.10

Table 2.7.10: Estimating whether the subject's choice is consistent with the Undefeated refinement or the Intuitive Criterion refinement.

	Dependent Variable:			
	Undefeated	*Intuitive*	*Undefeated*	*Intuitive*
	(1)	(2)	(3)	(4)
Understanding	2.99**	0.84	5.97+	0.19
	[1.19]	[0.39]	[5.68]	[0.20]
Big	0.40**	0.20**	0.63	0.21*
	[0.09]	[0.05]	[0.29]	[0.14]
Order	0.25**		0.13*	
	[0.11]		[0.12]	
Switch	0.25**	1.35	0.25*	2.36
	[0.09]	[0.52]	[0.17]	[1.91]
Money	1.38	0.89	2.21+	0.43
	[0.28]	[0.20]	[0.93]	[0.27]
Constant	33.01**	1.78	4.84	0.32
	[37.52]	[2.61]	[10.38]	[0.88]
Observations	630	314	157	157
Pseudo R^2	0.12	0.13	0.18	0.26
Mean DV	0.74	0.36	0.73	0.13
Pearson χ^2	449.22	268.88	145.92	119.90
Pearson p-value	0.55	0.34	0.25	0.80
Wald χ^2		5.56*		3.88*
Wald p-value		0.02		0.05

Notes: Logistic estimation with results presented as odds ratios. Robust standard errors clustered by subject in brackets. The *Undefeated* dependent variable in column (1) uses all scenarios while column (3) uses scenarios 4 and 8. The *Intuitive* dependent variable in column (2) uses scenarios 2, 4, 6 and 8 while column (4) uses scenarios 4 and 8. Models (1) and (2) include controls *Session* and *Wait*. Models (3) and (4) also include controls *Age, Gender, Ethnicity, Education, Student, ESL,* and *Married*. Pearson χ^2 and Pearson p-value assess the goodness of fit of the model. Wald χ^2 and Wald p-value provide a test of the equivalency of the coefficient on *Understanding* across models (1) and (2), and models (3) and (4). ** $p<0.01$, * $p<0.05$, + $p<0.10$

Table 2.7.11: Robustness tests on the impact of *Understanding* and *Complexity* after removing *Order* from specifications with *Undefeated* as a dependent variable

	Dependent Variable:			
	Undefeated	*Intuitive*	*Undefeated*	*Intuitive*
	(1)	(2)	(3)	(4)
Complexity			1.04	0.07**
			[0.19]	[0.03]
Understanding	4.25*	0.19	2.94**	0.78
	[2.89]	[0.20]	[1.16]	[0.46]
Big	0.62+	0.21*	0.39**	0.16**
	[0.18]	[0.14]	[0.09]	[0.05]
Switch	0.15**	2.36	0.27**	1.59
	[0.08]	[1.91]	[0.10]	[0.81]
Money	2.14**	0.43	1.59*	0.83
	[0.56]	[0.27]	[0.30]	[0.24]
Constant	62.70**	0.32	30.50**	4.98
	[85.79]	[0.88]	[34.31]	[10.85]
Observations	475	157	630	314
Pseudo R2	0.17	0.26	0.11	0.32
Mean DV	0.79	0.13	0.74	0.36
Pearson χ^2	366.74	119.90	495.78	310.86
Pearson p-value	0.44	0.80	0.69	0.15
Wald χ^2		4.93		33.94
Wald p-value		0.03		0.00

Notes: Logistic estimation with results presented as odds ratios. Robust standard errors clustered by subject in brackets. The *Undefeated* dependent variable in column (1) uses game types 1, 3 and 4; while column (3) uses all game types. The *Intuitive* dependent variable in column (2) uses game type 4 while column (4) uses game types 2 and 4. Included controls – *Session, Wait, Age, Gender, Ethnicity, Education, Student, ESL,* and *Married*. Pearson χ^2 and Pearson p-value assess the goodness of fit of the model. Wald χ^2 and Wald p-value provide a test of the equivalency of the coefficient on *Understanding* across models (1) and (2), and test of the equivalency of the coefficient on *Complexity* across models (3) and (4). ** p<0.01, * p<0.05, + p<0.10

2.7.2 Subject Instructions Script

The script read to all subjects in the experiment is below. A copy of the presentation slides that accompany the script are available upon request from the authors.

Slide 1. Welcome. I will first take you through an overview of the game that you will play and then walk you through an example that will describe exactly how you will play this game on the computer.

Slide 2. You will be randomly assigned to play the role of either a Firm or an Investor. Firms and Investors will then be randomly and anonymously paired with different people in each round.

Slide 3. Firms will either have a "Small" or "Big" market opportunity, which is just the number of customers the Firm expects to have for its product or service. Both the Firm and Investor will know the Firm's likelihood of getting a "Small" or "Big" market opportunity, but only the Firm will know for sure its actual opportunity.

Slide 4. Knowing its market opportunity, the Firm will decide how many stores to open. The Firm's payoff depends not only on this decision, but on the price the Investor sets for the Firm.

Slide 5. The Investor learns how many stores the Firm will open and sets a price for the Firm. The Investor's payoff depends on setting a price close to the Firm's actual value.

Slide 6. You will see a picture similar to this in each game you play. I will cover the information on this picture.

As I mentioned previously, in each round the Firm is randomly assigned either a "Big" market opportunity or a "Small" market opportunity.

Slide 7. Here the Firm has three choices for the number of stores to open, depending on its market opportunity. This is the most complex situation you will see. You will also see situations in which only two of three choices are available. In this example, a "Big" opportunity Firm can choose to open 200, 260 or 280 stores while a "Small" opportunity Firm can choose to open 180, 200, or 260 stores. Note that your information is always in red and the other player's information is in blue.

Slide 8. Depending on the Firm's choice, the Investor has either no choice or three choices for what price to set for the Firm. In this example, only a Firm with a "Big" opportunity can open 280 stores, and only Firm with a "Small" opportunity can open 180 stores. Note that both a "Big" and a "Small" opportunity Firm can open either 200 or 260 stores. If the Investor sees one of these choices the Investor must decide whether to set a “Big”, “Small” or “Weighted” price to the Firm. A “Weighted” price is simply a weighted average price.

Slide 9. If you are a Firm, your payoff depends on the size of the opportunity, your store choice, and the price the Investor sets. In this example, if a “Big” Firm chooses 280 stores it will get a payoff of $0.87. If, however, a “Big” Firm chooses 200 stores it will get a payoff of either $1.13, $0.95 or $0.78 depending on whether the Investor sets a price of “Big”, “Weighted” or “Small”. Similarly, if a “Big” Firm chooses 260 stores it will get a payoff of either $1.00, $0.73 or $0.45 depending on whether the Investor sets a price of “Big”, “Weighted” or “Small”.

Slide 10. If you are an Investor, your payoff depends on setting a price close to the Firm’s actual value. For instance, in this example if the Firm chooses 200 stores and the Investor sets a price of “Big”, the Investor will receive a payoff of $1.00 if the Firm is “Big,” and a payoff of $0.42 if the Firm is instead “Small”.

Slide 11. When the game begins, you will be told on screen whether you are a Firm or an Investor and the chance the Firm has of getting a “Big” or “Small” market opportunity. You will see a graphic with the choices and payoffs for your game. Firms and Investors will receive the same information and will be asked to define their strategies. If you are a Firm, you will be asked “If you faced a Big market opportunity, how many stores would you open?” and “If you faced a Small market opportunity, how many stores would you open?”

Slide 12. If you are an Investor, you will be asked “If the Firm opened X stores, what price would you give them?”

Slide 13. The Firm’s market opportunity is then randomly assigned and the Firm confirms their store quantity choice.

Slide 14. The Investor sees the Firm’s store quantity choice and confirms the price they want to give to the Firm.

Slide 15. The Firm and Investor learn what their pay-outs are for the previous game. Firms and Investors are randomly assigned to new partners, Firms are randomly assigned a “Big” or “Small” opportunity and a new game begins with different choices. After a few games, Firms and Investors will swap roles.

Slide 16. The first several rounds will be practice rounds and the next several rounds will be for money. We will make it clear when you are playing for money. In addition to your show-up fee, you will be paid the sum of all your individual payoffs from the money rounds at the end of today's session.

You should try to make as much money as possible. You are not taking money from other players.

You are playing with other people, and they can't move forward unless you move forward. Please make your decisions in a timely fashion–be thoughtful but move quickly.

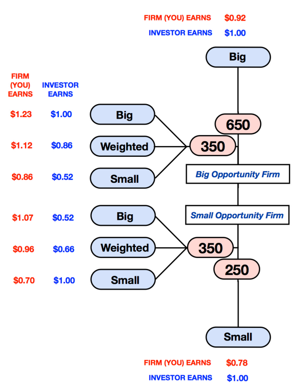
If your screen is black it means you are waiting for another player to make a decision.

Please don't close your browser, or press next, back or refresh on the browser, as this can disrupt the game. If you have any questions during the practice rounds, please raise your hand, and one of us will come around and answer your question. Thank you! You may now begin.

2.7.3 Extensive Form Representations

Figure 2.7.1: Extensive form of Scenarios 1 and 5.

(a) Firm and investor payoffs for Scenario 1. Display of information is formatted for a firm.



(b) Firm and investor payoffs for Scenario 5. Display of information is formatted for an investor.

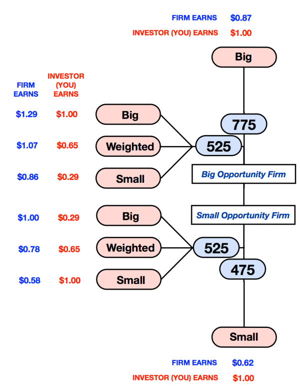
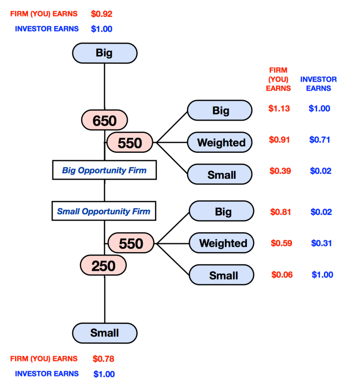


Figure 2.7.2: Extensive form of Scenarios 2 and 6.

(a) Firm and investor payoffs for Scenario 2. Display of information is formatted for a firm.



(b) Firm and investor payoffs for Scenario 6. Display of information is formatted for an investor.

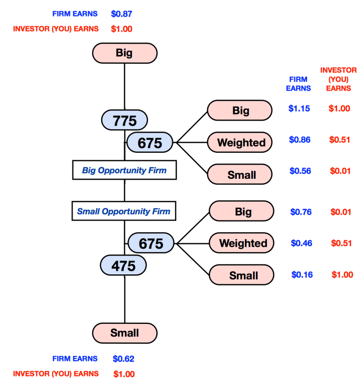
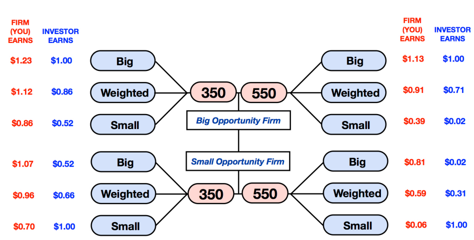
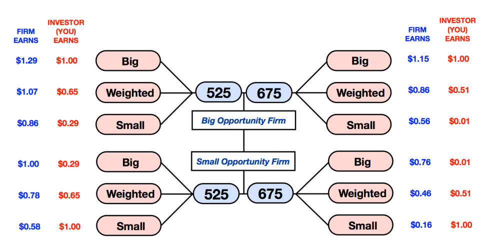


Figure 2.7.3: Extensive form of Scenarios 3 and 7.

(a) Firm and investor payoffs for Scenario 3. Display of information is formatted for a firm.



(b) Firm and investor payoffs for Scenario 7. Display of information is formatted for an investor.



3

Managerial Discretion and the Market's Response to Supply Chain Disruptions

3.1 Introduction

Anecdotal and empirical evidence indicates that supply chain disruptions affect firm performance. Such disruptions have also been found to be extremely damaging to firm value, reducing the value of the firm's common equity on average in excess of 10% (Hendricks and Singhal 2003, World Economic Forum and Accenture 2013). While it is not surprising that a disruption to a company's supply chain or operations can impose costs on the company and affect its market value, the magnitude of the impact identified in the literature is incredible. Surprisingly, no research has currently examined whether this potential market response induces management to behave strategically in deciding whether or not to reveal disruptions.

This is the focus of our research.

We examine whether managers exercise significant discretion in disclosing material disruptions to the market, and whether such actions are related to the market's response either through a selection effect or a treatment effect. We gain insight into these issues by taking advantage of a change in U.S. securities regulations. Section 409 of the Sarbanes Oxley Act of 2002 (SOX), implemented during the sample period, compels firms to promptly disclose events that may impair their operations or financial condition. We utilize the enforcement of Section 409 as an exogenous policy shock in our model. Our empirical findings and interviews with current and former executives provide evidence that, prior to the regulatory change, managers exercised significant discretion in the disclosure of material disruptions.

We also use SOX Section 409 to analyze whether changes in managerial discretion influences the relationship between the announcement of a disruption and the stock market's response. In keeping with prior empirical studies, we find a negative impact on company value that is statistically significant and economically meaningful. We find, however, that the impact is considerably smaller after the new disclosure laws go into effect. We cannot conclusively determine whether this is a selection effect (managers failing to disclose material disruptions), a treatment effect (the markets responding more favorably to disruptions based on the knowledge that there is less information asymmetry with the firm), or both. We run a series of robustness tests which provides some evidence that both factors may be at play.

3.2 Literature Review

We build on the literature dealing with supply-chain risk management, principally those studies examining the impact of disruptions on firms and their stakeholders. Supply-chain risk management remains a nascent area of academic research, characterized by diverse viewpoints on the scope of the field and on appropriate analytical methodologies (Sodhi et al. 2012). There is abundant evidence, however, that disruptions can have a material and negative impact on company performance (Hendricks and Singhal 2003, 2005a,b, Sheffi 2005, World Economic Forum and Accenture 2013), and emerging research that explores how firm actions or characteristics may mitigate the impact of disruptions. Braunscheidel and Suresh (2009) use survey results to investigate whether features of the firm's culture and organizational integration practices are associated with the agility with which the firm's management responds to disruptions. Kleindorfer and Saad (2005) provide evidence that changes to risk assessment and risk mitigation practices reduced the impact of disruptions in the chemical industry.

Another stream of research considers how firms can coordinate with their suppliers to minimize the impact of disruptions. Tomlin (2006) provides some theoretical insight on this question by developing a model of a single product firm that can source from two suppliers – one that is reliable but more expensive than the second, less reliable supplier. The author finds that characteristics of disruptions, such as the frequency and duration, affect the firm's outcomes and should therefore influence the firm's optimal sourcing strategy. Tang (2006) theorizes that firms may be able to influence their vulnerability to disruptions by adopting different supply-chain strategies (including postponement, and storing inventory at strategic locations). Christopher and Lee (2004) assert that disruption risks can be mitigated by developing mutual confidence among the participants in the supply chain. Using qualitative findings from phone interviews and focus groups, Craighead et al. (2007) propose that supply-chain density, complexity and node criticality contribute to the severity of disruptions, and that the ability to quickly disseminate information within the supply chain dampens the severity of disruptions.

Our analysis differs from and builds on this literature in two ways. We are the first to consider in the empirical literature whether managers act strategically in their decision to disclose disruptions to their investors. We also explore whether such strategic disclosure influences the impact of disruptions on firm value.

3.3 Theory and Hypotheses

3.3.1 Managerial Discretion in Announcing Disruptions

Managers have a well-established responsibility to disclose material information about the firm's condition to investors. By the early 1900's, many U.S. stock exchanges had instituted disclosure requirements as a prerequisite for listing a firm's securities (Berle and Means 1932). Federal legislation dating back to the 1933 Securities Act mandated that managers disclose material information that a reasonable investor would require to make an investment decision (Simon 1989). The benefits of reducing information asymmetry with the investors is such that many firms voluntarily enlisted financial intermediaries, including external auditors, to provide credible information to investors well before the passage of federal laws requiring this practice (Easterbrook and Fischel 1984).

When firms do experience negative events, their managers face a number of incentives to disclose such information to investors, including advantaging their firm's securities in both the primary and secondary markets by alleviating information asymmetries, and avoiding legal liability if they failed to make disclosures (Easterbrook and Fischel 1984). Managers might also face reputational damage and expose themselves and their firms to regulatory and legal action if they do not disclose material information. Gigler and Hemmer (2001) capture some of these forces in a model that shows that managers will voluntarily disclose material information even before a mandatory financial reporting deadlines.

Investors also have an interest in exerting pressure on management to adopt timely disclosure practices because such practices afford protection in an otherwise riskier capital market (Suphap 2003). High quality disclosure also leads to greater market efficiency as more information can be processed by investors and analysts, the cost of redundant data collection efforts is reduced, and capital can be allocated more effectively with improved information (Coffee 1984). In sum, managers and investors have strong mutual incentives to ensure that the firm is disclosing all material information (Coffee 1984).

Any problems with timely information disclosure, if they do exist, may also be isolated to specific instances rather than reflective of broad managerial practice. In spite of high-profile cases of managerial misconduct, recent federal laws expanding the regulatory mandate of the Securities and Exchange Commission (SEC) have been criticized as a questionable and potentially unnecessary regulatory intervention to address an isolated problem (Coates 2007, Hart 2009). Critics claim that these laws are an overreaction to a very small number of bad actors who are not representative of a systemic problem, and that existing regulations already provide remedies to punish (and thus broadly deter) corporate malfeasance. As pointed out by Coates (2007), the criminal prosecutions at Enron, Tyco and Worldcom were all based on laws that had been on the books for decades.

Finally, even if managers had been systematically failing to disclose material information about operational disruptions, enhanced disclosure rules might result in the opposite behavior than they intend, by reducing rather than expanding the dissemination of information. The SEC reported that several respondents to their proposal for fair disclosure rules indicated that firms "would find it so difficult to determine when a disclosure of information would be 'material' (and therefore subject to the regulation) that, rather than face potential liability and other consequences of violating Regulation FD, they would cease *informal* communications with the outside world altogether" (Securities and Exchange Commission 2000).

Despite these regulatory traditions and desires by many stakeholders for disclosure to promote efficient markets, managers actually possess considerable discretion about whether and when to disclose material disruptions. The SEC has declined to articulate a "bright-line standard" identifying what constitutes material information (Securities and Exchange Commission 2000). Since disruptions erode profits and investor confidence, they can reduce firm value in the short run. Managers' pecuniary incentives, including stock options and performance bonuses, can deter them from disclosing such problems. Managers may also be hesitant to disclose problems out of fear that competitors will seek to capitalize on the information, or customers will use it as leverage in future negotiations.

As we describe in Section 3.4.2, the SEC introduced new regulations related to SOX Section 409 which expanded the set of required corporate disclosures and shortened disclosure deadlines. While the new disclosure requirements had little to do with operational disruptions, they forced companies to streamline and formalize their disclosure practices generally. Consequently, management's ability to exercise discretion on whether or not to reveal operational disruptions should be reduced.

Hypothesis 1 *Managers exercise significant discretion in the disclosure of material disruptions and such discretion is alleviated by more formalized corporate disclosure rules.*

3.3.2 Improved Disclosure and the Impact of Disruptions

If managers do not reveal all material disruptions, it may be that they are selecting which disruptions to reveal based on their perception of the impact of such disclosures on the firm's share price. Whether they are influenced to conceal disruptions that are more or less damaging to firm value is not clear ex ante. For instance, managers may have pecuniary incentives in the form of stock options, bonuses and career advancement that may induce them to avoid revealing those disruptions which are likely to have the greatest adverse impact on the firm's stock price. Such disruptions, however, are also apt to be more difficult for the firm to address discreetly, thus providing greater incentive for managers to disclose them and thereby avoid the appearance of obfuscation. Managers may not want to risk losing investor goodwill or other reputational benefits by attempting to hide a material disruption.

There is empirical evidence in the accounting literature suggesting that there is a selection effect in managerial disclosure decisions, but the evidence is conflicting as to whether managers avoid releasing bad news or not.[1] Kothari et al. (2009) analyze the release of earnings forecasts and dividend changes and find that managers delay the release of bad news relative to good news. Skinner (1994), however, provides evidence in the setting of quarterly financial reporting that managers are more likely to preemptively disclose extremely bad earnings information in advance of regular earnings releases as opposed to mildly disappointing earnings information. Earnings information and dividend changes differ from supply chain disruptions not only because they are subject to standardized reporting and third-party auditing but also because their disclosure may be less prone to managerial discretion. It is therefore unclear whether management will behave in a similar fashion for supply chain disruptions.

It is also unclear whether a treatment effect exists between greater disclosure and market returns, and if so, what direction it takes. Prompt disclosure could reduce information asymmetry between firm and investor, creating more goodwill with the investors and alleviating the stock market's response to disruptions. Greater disclosure may also desensitize investors and dilute the informational value of disclosures (Lawrence and Prentice 2006). On the other hand, prompt disclosure gives less opportunity for news to leak out prior to disclosure, resulting in a larger response to the disclosure because it contains new information.

We hypothesize that the dominate effect will be that greater disclosure is associated with a milder market response to disruptions.

Hypothesis 2 *Greater disclosure of disruptions is associated with an amelioration of the impact of such disruptions on firm value.*

3.3.3 Attributing Disruptions to Internal or External Factors

Commonly applied models of determining the value of a firm involve forecasting the firm's future stream of cash flows and discounting those cash flows using an appropriate risk adjusted rate (Brealey et al.

[1] For an overview of the empirical literature on corporate disclosure, see Healy and Palepu (2001).

2011). Such models highlight that disruptions may impact firm value by affecting the cash thrown off by the firm's operations and / or by increasing the riskiness of those cash flows. Prior research has shown that on average disruptions are associated with lower future firm performance, including lower growth in sales and higher growth in costs (Hendricks and Singhal 2005a). If some types of disruptions are associated with comparatively worse future performance or increased risk, it can be expected that they will also have a more negative impact on firm value. This may occur either because a disruption is itself more costly or because the disruption portends riskier operations due to a greater likelihood of future disruptions.

We consider these effects by characterizing disruptions as either internal to the firm, internal to the firm's supply chain, or environmental. One intuitive premise in cross-organizational coordination and control in organizational theory (Powell 1990, Scott and Davis 2007) and more specifically in the operations management literature (Chopra and Meindl 2012, Kok and Graves 2003) is that firms exercise more control over their operations and supply chain than over the environment. Disruptions that are internal to the firm or its supply chain may be perceived as being are at least partially under the firm's presumptive control. Such a disruption may signal to the market that something is wrong with the firm's internal control mechanisms such that future disruptions, and hence either lower cash flows or higher systematic risk, may be more likely. There is some empirical support for such a finding. Hammersley et al. (2008) found that when firms preemptively disclose internal accounting control weaknesses related to financial reporting it elicits a negative price reaction from the stock market.

Disruptions attributed to environmental factors, on the other hand, can be perceived as random or events over which the firm is not expected to be able to exert much control. Consequently, environmental disruptions are less likely than internal disruptions to signal that something is wrong with the firm's internal controls or that the firm's operations are fragile.

Hypothesis 3 *Disruptions that are outside the firm's control will have a milder impact on firm value than will disruptions that are attributed to factors internal to the firm.*

3.4 Data and Empirical Models

3.4.1 Sample

In identifying observations for the analysis, we adopt the Craighead et al. (2007, pg. 132) definition of disruptions as "unplanned and unanticipated events that disrupt the normal flow of goods and materials within a supply chain and, as a consequence, expose firms within the supply chain to operational and financial risks." For instance, in a manufacturing environment, disruptions include events such as an unscheduled plant shutdown, a parts shortage, and a transportation interruption. In a retail environment, disruptions include events such as supplier and logistics failures.

We identify disruptions by reviewing company press releases distributed via the PRNewswire and Business Wire because press releases are widely recognized as a common and effective means for companies to transmit information to shareholders and other constituents in a timely fashion. In issuing its final rule on Regulation FD (Fair Disclosure), the SEC encouraged companies to use press releases as the first step in a three-step process to ensure the broad dissemination of material non-public information.

> *"We believe that issuers could use the following model, which employs a combination of methods of disclosure, for making a planned disclosure of material information, such as a scheduled earnings release. First, issue a press release, distributed through regular channels, containing the information; second, provide adequate notice, by a press release and/or website posting, of a scheduled conference call to discuss the announced results, giving investors both the time and date of the conference call, and instructions on how to access the call; and third, hold the conference call in an open manner, permitting investors to listen in either by telephonic means or through Internet webcasting. By following these steps, an issuer can use the press release to provide the initial broad distribution of the information, and then discuss its release with analysts in the subsequent conference call, without fear that if it should disclose additional material details related to the original disclosure it will be engaging in a selective disclosure of material information. We note that several issuer commenters indicated that many companies already follow this or a similar model for making planned disclosures"* (Securities and Exchange Commission 2000).

The SEC also noted that in many cases self-regulatory organization rules already require companies to issue press releases to announce material developments.

To generate our sample, we apply a search string to the Factiva database of press releases from January 1, 1998, until December 31, 2011. This search string identifies announcements in which the headline or lead paragraph includes such terms as *delay, disruption, interruption, shortage*, or *problem* within 3 words of terms like *component, delivery, parts, shipment, manufacturing, production*, or *operations*. Of the approximately 5.5 million press releases in the Factiva database during our study period, the search string returns approximately 6,900 press releases. We manually reviewed these announcements for relevance. Common reasons why press releases were disqualified in the manual-review stage include that they did not pertain to an actual disruption or pertained to a previously announced disruption. The manual review process yielded 615 press releases representing the first announcement of an actual disruption. From this set of 615 press releases, we linked 577 of them to 447 firms with the requisite financial information for the analysis of whether disruptions are routinely disclosed. Of these, 534 announcements from 425 firms also had the requisite stock price information for the analysis on the impact of increased disclosure on company valuation. Characteristics of the disruption announcements are reported in Table 3.7.1.

Approximately one-third of the disruption announcements include earnings information in the form of updated earnings forecasts or full earnings releases. Simply dropping those announcements that contain contemporaneous earnings information may distort the measured impact on firm value of disruptions. Instead, we seek to use this additional information to examine the impact on firm value of disruptions which exceeds their effect through earnings. In addition, this information allows us to control for the fact that some types of disruptions are simply larger than other types of disruptions, which is particularly important in our test of Hypothesis 3. So that we can robustly control for the impact of earnings information on firm value, we augment each disruption announcement with announcements of that firm's quarterly financial performance for one year before and one year after the disruption date. The final data set includes 3,534 earnings-only announcements, resulting in a total of 4,068 announcement observations. We link the information from the press releases and earnings announcements to firm stock price information from the Center for Research in Security Prices (CRSP) database, firm financial performance information from the Standard and Poor's COMPUSTAT database, and firm earnings expectations from the Institutional Brokers' Estimate System (I/B/E/S) database.

Characteristics of the Announcement

From each announcement we extract the company name, company identifying information, announcement date, earnings information (if provided), and the source of the disruption (for disruption-related announcements). We classify the source of the disruption as either *internal*, *external*, or *environment*. A disruption is classified as *internal* if it is attributed in the announcement to the firm's internal operations, including its staff or facilities. A disruption is classified as *external* if it is attributed to the firm's suppliers, including inbound or outbound logistics and transportation providers. A disruption is classified as *environment* if it is attributed factors outside the firm and its supply chain, including weather, government regulations, natural disasters, and political turmoil. Disruptions are classified by their root cause. For instance, if an earthquake disrupts a firm's critical supplier then the disruption is classified as *environment*. If instead the supplier is disrupted by an mechanical problem at its plant, then the disruption is classified as *external*. Disruption are classified to multiple causes in an isolated number of cases when the announcement makes clear that more than one cause played an important role. We run a robustness test that randomly classifies each of these disruptions to single sources and the inferences from our analysis are unaffected.

3.4.2 Relevant Regulatory Events and Definitions

Sarbanes Oxley Section 409

Central to our analysis is the enforcement date of regulations enacted to ensure corporate compliance with the Public Company Accounting Reform and Investor Protection Act, also known as the Sarbanes-Oxley (SOX) Act. Congress passed SOX in July 2002 after a series of notorious corporate scandals involving companies such as Adelphia, Enron, and Worldcom. The SEC formalized a series of additions and changes to existing regulations in response to this new legislation.[2] The regulations of primary interest to us are those intended to comply with the real time disclosure mandate in Section 409 of SOX. This Section requires firms to "disclose to the public on a rapid and current basis such additional information concerning material changes in the financial condition or operations of the issuer" (107th Congress 2002). The SEC issued a final ruling on the new regulations related to Section 409 in March

[2]See "Spotlight on Sarbanes-Oxley Rulemaking and Reports" http://www.sec.gov/spotlight/sarbanes-oxley.htm

2004 that had an effective date of August 23, 2004.

Two aspects of these rules are particularly relevant to our study. First, the SEC shortened the deadline for disclosure of most items on the Form 8-K to four business days after the occurrence of a triggering event, down from five to fifteen days that was previously in place for different types of events.[3] Second, the SEC also introduced new disclosure requirements for a wider range of corporate events, but it did not change the scope for the disclosure of operational and financial results. To accommodate the increase in the number of disclosable events, the SEC introduced a new format for the Form 8-K. Since there were no changes to the disclosure of operational and financial results, however, it retained in Item 2.02 of the new Form 8-K all of the requirements regarding the public announcements of material non-public information of a company's results of operations or financial condition which had been included in former Item 12 of the old Form 8K. The SEC did, however, expand the set of other types events that firms must disclose. For a list of the changes made to the list of events which must be disclosed on the Form 8-K, see Table 3.7.2 in the Appendix.

In making their final ruling, the SEC emphasized that the new regulations provide for better and more timely disclosure of important corporate events, moving towards a system emphasizing current reporting. It also pointed out the presumptive benefits on the markets of faster disclosure, stating that,

> *"Under the prior system, predicated primarily on a periodic reporting system, the securities of a company could be trading on less complete information if an important corporate event has occurred but the company, under no duty to report that event, does not report the event on a timely basis. Such a delay in disclosure permits there to be significant time periods during which important information is not disclosed to the market. These circumstances create opportunity for companies and those with access to non-public information to misuse that information. The amendments adopted today will reduce such opportunities for misuse"* (Securities and Exchange Commission 2004).

The new rules were intended to identify those events which are "unquestionably or presumptively material events that must be disclosed currently," but not to change the threshold for what constitutes a

[3]The SEC introduced the Form 8-K in 1936 and it provides a mechanism for companies to report material corporate events to the SEC on a more current basis than either the Forms 10-K and 10-Q, which are used to file annual and quarterly reports (see http://www.sec.gov/answers/form8k.htm).

material event (Securities and Exchange Commission 2004). The regulation neither sets nor refers to a definition for materiality. In fact, the SEC has consistently avoided developing a bright line rule for materiality and instead has relied on existing case law (Securities and Exchange Commission 2000).

SOX Section 404 and Accelerated Filer Status

Another significant set of regulations, those pertaining to the enforcement of SOX Section 404, took effect nearly concurrent with the regulations related to Section 409. We will take advantage of this happenstance in our analysis to shed some light on whether the relationships we uncover are the result of greater awareness of disruptive events or changes in managerial discretion in reporting those events.

Section 404 of SOX requires the firm's management to include an internal control report with the firm's annual report that affirms "the responsibility of management for establishing and maintaining an adequate internal control structure and procedures for financial reporting," and provides an assessment "of the effectiveness of the internal control structure and procedures of the issuer for financial reporting" (107th Congress 2002). The SEC adopted final rules on June 5, 2003 in response to this section of SOX. These rules require that beginning in with the firm's fiscal year ending on or after July 15, 2004, firms include a report on the company's internal control over financial reporting which includes a statement from management that they acknowledge their responsibility in establishing and maintaining such controls, an assessment of the effectiveness of those controls, a description of the framework use to make that assessment, an evaluation of any changes which would affect those controls, and an attestation on management's assessment from the firm's external auditor (Securities and Exchange Commission 2003).

The cost and effort associated with complying with the new Section 404 requirements is substantial. In a survey of over 250 companies, Ernst and Young found that over 49% undertook significant remediation of core business operations prior to attaining initial compliance, over 60% of companies with annual revenues in excess of $20 billion invested more than 100,000 staff hours in activities related to Section 404, 80% of companies with annual revenues between $5 and $20 billion in invested more than $5 million in initial SOX section 404 compliance, and 50% deployed or intended to deploy an enterprise risk management system within one year of initial compliance (Ernst&Young 2005). The Office of Economic Analysis of the SEC collected survey results from over 2,900 companies and found that the average annual

Section 404 compliance costs exceeded $2.8 million prior to 2007, falling to $2.3 million after 2007 (Office of Economic Analysis 2009). Despite the extensive cost, the new regulations achieved their objective of strengthening internal controls. From a survey of over 8,200 companies, the SEC reports that the most widely reported benefit from Section 404 compliance is improvement in the quality of the respondent company's internal control structure (73% of respondents) (Office of Economic Analysis 2009).

Out of consideration for the cost and effort of compliance, the SEC did not require all companies to comply with these Section 404 regulations at the same time (Securities and Exchange Commission 2003). Instead, only firms designated as accelerated filers had to comply by the original deadline. Accelerated filer status, established by SEC in final rules published in September 2002, was assigned to firms based on the market value of the firm's public float (the portion of the firm's equity that is not held by management or large shareholders) (Securities and Exchange Commission 2002). Domestic firms were designated to have accelerated filer status if they (1) have a public float of at least $75 million as of the last business day of the firm's most recently completed second fiscal quarter, (2) have been subject to the Exchange Act's reporting requirements for at least 12 calendar months, and (3) have previously filed at least one annual report. The effective date of a firm's accelerated filer status began with their annual report after December 15, 2002 and the firms accelerated filer status is reevaluated on an annual basis. Effective December 27, 2005, the SEC updated the definition of accelerated filer such that a firm's designation would change to non-accelerated filer at the end of the fiscal year if the firm's public float was less than $50 million as of the last business day of the firm's most recently completed second fiscal quarter (Securities and Exchange Commission 2005).

Non-accelerated filers were originally required to file the with the annual internal control report with their first fiscal year ending on or after April 15, 2005 (Securities and Exchange Commission 2003). The SEC granted a series of extensions to this compliance deadline, however, and non-accelerated filers were ultimately not required to provide an internal control report until filing an annual report for the first fiscal year ending on or after December 15, 2007, and the auditor's attestation on the internal control report until it filing an annual report for the first fiscal year ending on or after December 15, 2009 (Securities and Exchange Commission 2006, 2008).

Section 404 has direct relevance for our analysis because it excluded a well-defined population from initial compliance. We utilize this fact in our analysis to isolate firms that only improved disclosure mechanisms under Section 409 from those that simultaneously improved control and disclosure mechanisms under Sections 404 and 409. If a lack of awareness of disruptions was the only factor that prevented management from disclosing some disruptions, then this affect should be ameliorated for accelerated filers once the Section 404 regulations went into effect. At that point, accelerated filers should be more likely to disclose disruptions because they are more aware of them. On the other hand, if awareness was the only factor affecting the likelihood of disclosure, then the behavior of non-accelerated filers should should be unchanged.

3.4.3 Measures to Analyze Likelihood of Disruption Disclosure

We first describe the variable needed to assess whether the enforcement Section 409 regulations influences the likelihood that managers will disclose disruptions.

Dependent Variables

Our dependent variable for this portion of the analysis identifies whether or not the firm revealed a disruption in the current quarter. We use a dichotomous dependent variable, *Announced Disruption*, that is collected at the firm-quarter level and set to "1" for those quarters in which the firm announces a disruption, and "0" otherwise. We generate this variable based on a review of the press releases in the Factiva database following the process outlined in Section 3.4.1. In robustness tests, we also employ *Announced Internal*, *Announced External*, or *Announced Environment* as the dependent variable so we may assess whether SOX has a different impact on the disclosure of disruptions that are classified as *internal*, *external*, and *environment* (refer to Section 3.4.1 for the classification process).

Independent Variables

The key independent variable, *Post-SOX Quarter*, identifies whether the quarter is after the start of enforcement of SOX Section 409 (coded "1"), or before enforcement begins (coded "0"). The enforcement date of the SOX Section 409 regulations proxies for our construct of increased formalization of corporate disclosure practices. As pointed out in Section 3.4.2, these regulations did not alter the disclosure requirements for disruptions to the firm's operational performance, nor did the regulations change the threshold for materiality. They did, however, significantly expand the set of non-operational issues that firms must disclose, and reduced the time frame for the filing of an associated Form 8-K from 5 to 15 days (depending on the disclosure) down to 4 days. Complying with these requirements had substantial implications for firm disclosure procedures generally (McGee et al. 2004, Steinberg 2001), because firms had to handle a wider range of disclosures in this shorter time frame. To ensure compliance, firms formalized their disclosure processes and invested in disclosure management infrastructure (Brown and Nasuti 2005a,b, Kaarst-Brown and Kelly 2005). While the new regulations did not impose new disclosure requirements specific to operational issues, the formalization of general disclosure processes may remove managerial discretion for disclosing operational issues. Such formalization involves developing more transparent decision rules, making investments in IT and other infrastructure to administer the new disclosure rules, and increasing the awareness, visibility, and scrutiny of *all* disclosures.

In robustness tests, we separate the effects of Section 404 from those of Section 409 so we may isolate the impact of increased internal control from that of deceased managerial discretion. As described in Section 3.4.2, firms that were classified as accelerated filers had to begin complying with new regulations related to Section 404 of SOX around the same time that they had to comply with regulations related to Section 409 of SOX. We are able to examine the impact of Section 409 compliance separately from Section 404 compliance by comparing the results for non-accelerated filer (NAF) firms (which initially only had to comply with Section 409) to that of accelerated filer (AF) firms (which had to comply with both Sections 404 and 409). We use the dichotomous variable *Accelerated Filer* to identify those firms that are accelerated filers (coded "1") and those firms that are not accelerated filers (coded "0").

Controls

We gather firm financial information, such as the book value of equity, long-term debt, and the market value of equity from the COMPUSTAT database. From this data, we calculate one-quarter lagged values for several financial measures. *Fixed Asset Ratio* is the book value of the firm's property, plant, and equipment divided by its total assets. It provides a measure of how much of a firm's capital is tied up in long term assets. *Debt-to-Equity Ratio* is the book value of the firm's long-term debt divided by market value of its common equity. It measures the amount of leverage the firm has on its balance sheet. *Market-to-Book Ratio* is the market value of the firm's common equity divided by the book value of its common equity. This ratio indicates whether investors believe the firm is worth more or less than the book value of its equity. *Log Sales* is the natural log of quarterly sales (in $M).

3.4.4 Measures to Analyze Disruption Impact

We also assess whether the enforcement of regulations related to Section 409 of SOX influences the impact that a disruption has on the value of the firm's equity.

Dependent Variables

We use *Abnormal Return* as our dependent variable to analyze whether the enforcement of SOX 409 changes the impact of disruption announcements on the firm's share price. *Abnormal Return* measures the movement of the firm's stock price relative to an estimated counterfactual and is calculated using an event study methodology. An event study compares the actual return of the firm's stock with an estimate of the return that would have been realized had the announced disruption not occurred. To conduct the event study, we utilize daily stock returns for each company in our data set, which we access through CRSP. We generate the counterfactual estimate using the market returns model summarized below and described in greater detail in MacKinlay (1997) and McWilliams and Siegel (1997).[4] The market returns model expresses the stock return of firm *i*, making announcement *a*, on date *d*, for the event window day *t* as

$$\textit{Firm Return}_{iadt} = \eta_{iad} + \theta_{iad}\textit{Market Return}_{dt} + \varepsilon_{iadt}. \tag{3.1}$$

$\textit{Market Return}_{dt}$ is the market return on date *d* for the event window day *t* using a value-weighted portfolio of all stocks listed in the CRSP database. The announcement date, *a*, is determined as the first trading day in which the stock market can respond to the firm's announcement. Thus, the announcement date is the date the announcement is made, if it occurs either before the U.S. stock markets open or while the

[4] As a robustness check, we also generate the counterfactual using the Fama-French-Carhart 4-factor model (Carhart 1997) and achieve similar results (not presented).

markets are open; otherwise the announcement date is the following trading day. The event window day, t, is measured relative to the announcement date such that $t = 0$ on the announcement date.

To estimate Equation (3.1) we use ordinary least squares (OLS) with a benchmark period of 255 trading days (or approximately 1 year), ending 46 trading days prior to the announcement (or approximately 2 months), i.e. $t = -301, -302, \ldots, -47$. This generates estimated values $\hat{\eta}_{iad}$ and $\hat{\theta}_{iad}$. We then apply these coefficients to actual market-return data in a short event window surrounding the announcement to generate counterfactual estimates of the returns for each stock under the alternative state in which the announcement did not occur. Abnormal returns for the event window are calculated as $\textit{Abnormal Return}_{iad} = \sum_t \textit{Abnormal Return}_{iadt}$, where $\textit{Abnormal Return}_{iadt} = \textit{Firm Return}_{iadt} - (\hat{\eta}_{iad} + \hat{\theta}_{iad}\textit{Market Return}_{dt})$ and $\hat{\eta}_{iad} + \hat{\theta}_{iad}\textit{Market Return}_{dt}$ is the counterfactual expected return for firm i, making announcement a, on date d, for the event window day t. $\textit{Abnormal Return}_{iad}$ (or simply *Abnormal Return* when the context is clear), is calculated by summing the abnormal returns over the desired number of trading days in the event window. To isolate the effect of the announcement, we present our results using a 3-day event window (event window days -1, 0 and 1). This event window is represented with the shorthand notation, (-1, 1) indicating one trading day prior to the announcement date, the trading day of the announcement, and one trading day after the announcement. We also run robustness checks with 5-day (-2, 2), 7-day (-3, 3), 9-day (-4, 4) and 11-day (-5, 5) event windows; the results are not meaningfully different (refer to Section 3.5.2 for a discussion on these results).

One advantage of generating our dependent variable in this way is that it adjusts for market-wide influences on individual stock prices during the event window. By estimating counterfactual returns based on the company's own historical performance we at least partially control for the effects of other unobservable company-specific covariates that may not remain fixed over time, such as growth potential.

Independent Variables

The independent variables that we employ in this portion of the analysis are similar to variables described in Section 3.4.3, except here the variables are dimensioned by firm-announcement-date rather than by firm-quarter-date. *Disruption* is a dummy variable set to "1" if the focal announcement pertains to a disruption and "0" otherwise. We also use *Internal Disruption*, *External Disruption*, and *Environment Disruption* to respectively identify disruptions attributed to factors internal to the firm, to the firm's supply chain, or outside the firm and its supply chain.

We again capture the enforcement of SOX Section 409, but in this case it is dimensioned by the announcement. *Post-SOX* is a dummy variable set to "1" if the announcement is made after the enforcement of Section 409 of SOX and "0" otherwise. We also use *Accelerated Filer* as previously described.

Controls

We again utilize controls for the firm's recent financial performance that were described in Section 3.4.3. To help us uncover whether disruptions impact firm value because they affect the firm's earnings stream, the risk assigned by investors to that earnings stream, or both earnings and risk, we control for the unexpected earnings impact (if any) associated with each announcement. *Earnings Surprise* is the difference between the earnings information released by the firm in conjunction with its announcement and the average of analysts' forecasts for earnings prior to the announcement, divided by the market value of the firm. We collect analyst's earnings forecasts for each company from the I/B/E/S database. *Earnings Surprise* is coded to zero for firms without analyst earnings forecasts. Because there are some extreme outliers for *Earnings Surprise* (primarily due to some firms having very low market values relative to the impact on earnings), we winsorize this variable at 5%. This involves replacing values of *Earnings Surprise* beyond the 2.5th and 97.5th percentile with values at the 2.5th and 97.5th percentile. As detailed in Section 3.5.2, our findings are robust if we do not winsorize *Earnings Surprise*.

3.4.5 Empirical Models

Model to Analyze Disruption Counts

We test for whether managers have been exercising significant discretion in announcing material disruptions by estimating the following model:

$$\textit{Announced Disruption}_{iq} = f(\alpha_i + \beta_1 \cdot \textit{Post-SOX Quarter}_q + \gamma' Z_{iq} + \varepsilon_{iq}). \tag{3.2}$$

The unit of analysis in this model is the firm-quarter. *Announced Disruption* refers to whether firm *i* announced a disruption in quarter q. The coefficient on *Post-SOX Quarter*$_q$ captures the effect of the enforcement of SOX Section 409 on the likelihood that a firm announces a disruption. The vector Z_{iq} includes several controls for other potential determinants of disruptions. We include *Fixed Asset Ratio* and *Debt-to-Equity Ratio* because firms with few liquid assets or with high leverage may be more susceptible to disruptions since the firm has less access to capital that could otherwise cushion normal variations in operational performance. We include *Market-to-Book Ratio* as a proxy for the firm's ability to generate value above the book value of its equity. *Log Sales* is a measure of firm size, which may reflect upon the complexity of the firm and hence its susceptibility to disruption. We include firm-level conditional fixed effects, α_i, to control for unobserved time-invariant factors, such as industry and geographic location, that might influence the likelihood of a disruption announced by a firm. ε_{iq} is the error term.

We recognize that the enforcement date of SOX 409 may not have had an immediate effect on firm behavior. There may instead have been a transition period surrounding the enforcement date during which some firms adopted the spirit of the law's improved disclosure mandate more quickly or slowly than others. To the extent this creates noise in our data, it is a bias against finding a result in our analysis. We also acknowledge that our model is actually a joint test of whether managers exercise discretion in reporting disruptions and whether SOX Section 409 is effective at mitigating this discretion. It may be that managers do exercise such discretion, but SOX Section 409 is a poor remedy to this situation. It may also be that SOX Section 409 would have been effective at removing discretion, but managers were not exercising discretion in the first place. Li et al. (2008) show that SOX was at least perceived by the stock market participants as a means for reducing management's influence on the revelation of *some* types information. It is unclear, however, whether this perception was accurate or whether it applied to the revelation of operational issues. The extent to which SOX is not effective at reducing managerial discretion is also a bias against finding a result in our analysis.

Model to Analyze *Earnings Surprise*

If managers are exercising discretion on disclosing disruptions, they may be doing so based on the perceived impact that the disruption has on earnings. To understand this issue, we look at whether there is a difference in *Earnings Surprise* between the pre- and post-enforcement periods by estimating the following model:

$$\textit{Earnings Surprise}_{ijd} = \alpha + \beta_1 \cdot \textit{Post-SOX}_j + \gamma' Z_{id} + \varepsilon_{ijd}. \tag{3.3}$$

The unit of analysis in this model is the firm-disruption-date. Note that we exclude all non-disruption announcements from this analysis. *Earnings Surprise*$_{ijd}$ is the unexpected change in earnings for firm i making disruption announcement j on date d. *Post-SOX*$_j$ identifies whether disruption announcement j is made after the enforcement of Section 409 of SOX. We also include a vector, Z_{id}, of control variables – *Fixed Asset Ratio*$_{id}$, *Market-to-Book Ratio*$_{id}$, *Debt-to-Equity Ratio*$_{id}$, and *Log Sales*$_{id}$, which might influence the unexpected earnings performance of the firm. α is the intercept and ε_{ijd} is the error term.

Model to Analyze Disruption Impact on Firm Value

We evaluate whether the enforcement of SOX Section 409 causes disruption disclosures to be more or less damaging to firm value by estimating the following model:

$$\begin{aligned} \textit{AbnormalReturn}_{iad} = &\alpha_i + \beta_1 \cdot \textit{Disruption}_{iad} + \beta_2 \cdot \textit{Disruption}_{iad} \times \textit{Post-SOX}_a + \\ &\beta_3 \cdot \textit{Post-SOX}_a + \gamma' Z_{iad} + \varepsilon_{iad}. \end{aligned} \tag{3.4}$$

The unit of analysis is the firm-announcement-date. The subscripting is similar to Equation (3.3) except here we include both disruption and earnings-only announcements, and therefore use subscript a to denote the announcement rather that j to specify the disruption announcement. *Abnormal Return*$_{iad}$ is the abnormal stock movement of firm i after making announcement a on date d. *Disruption*$_{iad}$ identifies whether announcement a made by firm i on date d pertains to a disruption or not. *Post-SOX*$_a$ identifies whether announcement a is made after the enforcement of Section 409 of SOX. The vector Z_{iad} includes control variables *Earnings Surprise*$_{iad}$, *Fixed Asset Ratio*$_{id}$, *Market-to-Book Ratio*$_{id}$, *Debt-to-Equity Ratio*$_{id}$, *Log Sales*$_{id}$, and a complete set of year dummies, *Year*. α_i captures firm fixed effects and ε_{iad} is the error term. By including *Earnings Surprise*$_{iad}$ in the set of controls, we absorb the effect that announcements have through earnings on *Abnormal Return*. This allows us to isolate the effect that disruption announcements have on *Abnormal Return* through their impact on the risk associated with the firm.

Attributing Disruptions to Internal or External Factors

To compare the effects of internal and external disruptions, we modify the model in Equation (3.4) by replacing $Disruption_{iad}$ with $Internal\ Disruption_{iad}$, $External\ Disruption_{iad}$, and $Environment\ Disruption_{iad}$, and interacting these variables with $Post\text{-}SOX_a$. All other features of this model are the same as than in Equation (3.4). The resulting model is,

$$\begin{aligned} AbnormalReturn_{iad} = & \alpha_i + \beta_1 \cdot Internal\ Disruption_{iad} + \beta_2 \cdot External\ Disruption_{iad} + \\ & \beta_3 \cdot Environment\ Disruption_{iad} + \\ & \beta_4 \cdot Internal\ Disruption_{iad} \times Post\text{-}SOX_a + \\ & \beta_5 \cdot External\ Disruption_{iad} \times Post\text{-}SOX_a + \\ & \beta_6 \cdot Environment\ Disruption_{iad} \times Post\text{-}SOX_a + \beta_7 Post\text{-}SOX_a + \\ & \gamma' Z_{iad} + \varepsilon_{iad}. \end{aligned} \tag{3.5}$$

3.5 Results

Table 3.7.3 summarizes the variables used in our analysis of the factors influencing the likelihood of a disruption being announced. Table 3.7.4 provides summary statistics and Table 3.7.5 provides correlations for these variables. All of the measures used in this part of the analysis are available by month from January 1998 until December 2011. Table 3.7.6 summarizes the variables used in the analysis of the impact of announced disruptions. Table 3.7.7 provides summary statistics and Table 3.7.8 provides correlations for these variables.

3.5.1 Management Discretion in Announcing Disruptions

We estimate the model in Equation (3.2) using a conditional fixed effects logistic regression with robust standard errors clustered by firm. The results are reported in Table 3.7.9 as coefficients in column (1) and as odds ratios in Column (2). If, prior to SOX enforcement, managers had been reporting fewer disruptions and if SOX attenuated this practice, we would expect to observe an increased likelihood that managers reveal disruptions after Section 409 enforcement begins. We find that after enforcement of SOX Section 409, the likelihood that firms disclose a disruption increases by a factor of 2.09 ($\beta = 0.74$, $p < 0.01$, odds ratio [OR] = 2.09). This is equivalent to 2.0 percentage point increase in the probability of a disruption disclosure after the enforcement date of Section 409, from the baseline of 2.0 percent to 4.0 percent. These results show that in the aftermath of SOX Section 409 enforcement there is a material and significant increase in the probability that firms announce disruptions.

Mechanisms

Change in the Bar for Disclosure. While we theorize that our results are attributable to managers exercising less discretion in disclosing disruptions, we recognize that there are other possible explanations. One possible alternative explanation for the increased likelihood of disclosure in the post-409 period is that Section 409 lowered the bar for what firms would be required to disclose. We shed some light on this by considering how the likelihood of announced disruptions in the pre- and post-Section 409 periods changes for different types of disruptions. Since external disruptions involve at least two firms (i.e. the firm and the firm's supplier) and possibly more (i.e. other customers of the supplier that are also affected), the firm's management can presumably exercise less discretion in revealing the disruption because one of the other affected parties may elect to reveal it. As such, we would expect that if managerial discretion was playing an important role in the pre-Section 409 period, that the likelihood of a firm announcing an *internal* disruption would increase in the post-Section 409 period, but not necessarily the likelihood of a firm announcing an *external* disruption.

To explore this issue we conduct a sub-sample analysis to separately estimate the probabilities of a firm announcing an internal disruption versus an external disruption. The results are presented in Table 3.7.10. Columns (1) and (2) provide the regression coefficients and odds ratios using the occurrence of an internal disruption announcement as the dependent variable, while columns (3) and (4) provide the regression coefficients and odds ratios using the occurrence of an external disruption as the dependent variable. From columns (1) and (2), after enforcement of SOX Section 409, the likelihood that firms disclose an internal disruption increases by a factor of 2.31 ($\beta = 0.84$, $p < 0.01$, OR = 2.31). This is equivalent to a 2.5 percentage point increase in the probability of a disruption disclosure after the enforcement date of Section 409, from the baseline of 2.0 percent to 4.4 percent. From columns (3) and (4), the change in the likelihood that firms disclose an external disruption, on the other hand, is much smaller and statistically insignificant ($\beta = 0.30$, $p > 0.10$, OR = 1.35). If SOX simply lowered the bar for disclosure we should see an increased likelihood of disclosure for external disruptions as well as the increased likelihood of disclosure for internal disruptions. This result is consistent with managers exercising more discretion on disclosure decisions prior to the enforcement of Section 409, but inconsistent with the alternative explanation that the new regulations lowered the bar for what qualifies as a disclosable disruption.

This aligns with the SEC's stated intent for the new regulations, which they summarized in their final ruling on the regulations, "[These amendments] are intended to provide investors with better and faster disclosure of important corporate events" Securities and Exchange Commission (2004). This intent to make disclosure faster and more accurate is echoed by other scholars. Chan et al. (2008) asserts that "the main objectives of the Sarbanes-Oxley Act of 2002 are to improve the accuracy and reliability of corporate disclosure," while Coates (2007) states that "the primary goal of the Sarbanes-Oxley legislation was to improve audit quality and reduce fraud on a cost-effective basis." In drafting these new regulations, the SEC did not attempt to alter the definition of materiality. In fact, the disclosure of operational issues was unchanged by the regulation (Securities and Exchange Commission 2004).

For completeness, we also display in columns (5) and (6) on Table 3.7.10 the results for the estimation of the likelihood that firms will disclose an environment disruption ($\beta = 0.84$, $p < 0.01$, OR = 2.31). It initially seemed counterintuitive that the coefficient on *Post-SOX Quarter* is positive and significant in this case. The result, however, can be attributed to random misfortune on a global scale. There was a coincidental and significant increase in the number of natural disasters that occurred in the years after the enforcement date of SOX Section 409, including the 2004 Indian Ocean earthquake and tsunami, and four of the five most costly Atlantic hurricanes on record up to that point (Katrina, Ike, Wilma, and Ivan, while the other, Andrew, is outside of our study period). Disasters on a similar scale were absent in the sample period prior to SOX enforcement.

Increased Awareness. Regulations pertaining to Section 404 of SOX had the effect of strengthening firm internal controls (reference Section 3.4.2), and they took effect at approximately the same time as those related to Section 409. Another possible alternative is that these increased requirements on firms to implement stronger internal control systems made managers more aware of disruptions, which then led to greater reporting of those disruptions. To explore this possibility, we take advantage of the fact that not all firms had to comply with Section 404 requirements at the same time. As we point out in Section 3.4.2, firms with a public float less that $75 million were not obligated to even partially comply with these regulations until December 2007, and could delay full compliance until December 2009.

We rerun our analysis using sub-samples for accelerated filers (those that had to comply with Section 404 on time) and non-accelerated filers (those that were not obligated to comply with Section 404). Table 3.7.11 provides the regression results for the estimations associated with these sub-samples. We limit our analysis to observations within six years surrounding the enforcement date of Section 409 so we can exclude the time period when non-accelerated filers had to begin complying with the regulatory provisions associated with Section 404. Columns (1) and (2) of Table 3.7.11 provide the regression coefficients and odds ratios for firms classified as non-accelerated filers. Columns (3) and (4) provide the regression coefficients and odds ratios for firms classified as accelerated filers, and columns (5) and (6) provide the regression coefficients and odds ratios for firms classified as accelerated filers and whose public float is close to the non-accelerated filer threshold. We present results using a public float of $250 million but our results are similar using cutoffs of $200 million and $300 million. The coefficient on *Post-SOX Quarter* for non-accelerated filers remains positive and significant ($\beta = 0.55$, $p < 0.05$, OR = 1.74). This is equivalent to a 2.1 percentage point increase in the probability of a disruption disclosure after the enforcement date of Section 409, from the baseline of 3.0 percent to 5.1 percent. This shows that the increased disclosure of disruptions is not fully explained by compliance to Section 404 regulations, and further supports our assessment that Section 409 regulations had a material impact on firm practices for disclosing operational disruptions.

Robustness Tests

Alternative Sample Windows. We check whether our results differ compared to those that would be obtained if we instead considered alternate time frames around the enforcement date of the Section 409 regulations. We consider 4 years (August 2002 - August 2006), 5 years (February 2002 - February 2007), 6 years (August 2001 - August 2007), 8 years (August 2000 - August 2009), 10 years (August 1999 - August 2009), and all years in the data set (January 1998 - December 2011). Results for these estimations are presented as coefficients in Table 3.7.12. The row of χ^2 statistics in Table 3.7.12 test the equivalency of the coefficients on *Post-409 Quarter* between that obtained using the full sample (our base case), and that obtained using the other time frames. Our inferences are unchanged if we use any of the alternative time frames.

3.5.2 Improved Disclosure and Abnormal Returns

We estimate the model in Equation (3.4) using OLS with firm-level fixed effects and robust standard errors clustered by firm. The results are presented in Column (1) of Table 3.7.13. If in the pre-enforcement period managers disproportionately under-reported disruptions that were less (more) damaging to firm value, we should observe that the average impact of a disruption on firm stock price is more (less) damaging in that period than in the post-enforcement period. The coefficient on *Disruption* is negative and significant ($\beta =$ -7.65, SE 0.93, $p < 0.01$), while the coefficient on *Disruption* $\times$ *Post-SOX* is positive and significant ($\beta =$ 4.79, SE 1.06, $p < 0.01$). The coefficient on this interaction term shows that there is a statistically significant positive difference in the impact on abnormal returns in the post-enforcement period compared to the pre-enforcement period. This provides support for Hypothesis 2.

Including *Earnings Surprise* in the original models serves to partial out the impact of earnings information separately from that of disruptions. We approximate the total effect of disruptions, including the impact of the disruption on short-term earnings, by excluding *Earnings Surprise*. The results, presented in in Column (2) of Table 3.7.13, are substantively similar. The coefficient on *Disruption* is negative and significant ($\beta =$ -7.35, SE 0.92, $p < 0.01$), while the coefficient on *Disruption* $\times$ *Post-SOX* is positive and significant ($\beta =$ 4.58, SE 1.06, $p < 0.01$). This implies that the market is not responding to the direct impact that the disruption has on earnings, but rather the impact that the disruption has on the perceived risk of the firm.

Mechanisms

Increased Awareness. We again consider whether the contemporaneous enforcement of the internal control provisions in SOX (Section 404) is responsible for our result. In this alternative line of reasoning, improved internal controls either made firms more aware of material disruptions that had a smaller impact on the firm's stock price, or allowed firms to mitigate the impact of disruptions. To explore this alternative explanation, we add *Accelerated Filer* to our specification and interact it with *Disruption*, *Post-SOX*, and *Disruptions*×*Post-SOX*. The results of our estimation are presented in Column (1) of Table 3.7.14. *Disruption*×*Post-SOX* isolates the impact of Section 409 on non-accelerated filers that are immune from Section 404 compliance. The coefficient on this term is positive and significant ($\beta = 8.91$, SE 3.42, $p < 0.01$), which supports that improved internal control is not fully responsible for the amelioration of abnormal returns after the enforcement of Section 409. We reach a similar conclusion if we limit our sample only to non-accelerated filers and accelerated filers with public floats close the the non-accelerated filer status threshold. We present results in Column (2) of Table 3.7.14 using a public float of $250 million but our results are similar using cutoffs of $200 million and $300 million. The coefficient on *Disruption*×*Post-SOX* is again positive and significant ($\beta = 8.32$, SE 3.52, $p < 0.01$), which also supports the conclusion that the change in managerial discretion from Section 409 regulations is driving our results rather than improved internal control.

News Leakage. A second potential explanation for our results is that the news of disruptions leaks out to the market prior to management's formal announcement and this influences our main results. As mentioned in Section 3.4.2, however, Section 409 mandated shorter deadlines for the disclosure of material information. Since news is less likely to leak when disclosure is prompt, news leakage is more likely a bias against our result. To examine the impact of news leakage, we compare our main results using an event window of (-1, 1) to the results obtained by using event windows of (-3, 1), (-7, 1), and (-10, 1). The results of this analysis are presented in Columns (1) - (4) of Table 3.7.15. To test for differences in the pre-enforcement period, we run a Wald test comparing the coefficient on *Disruption* in Column (1) (our base model) to that in Columns (2) - (4). There is a statistically significant difference comparing windows (-1, 1) and (-7,1) ($\beta = -2.01$, Wald χ^2 8.37, $p < 0.01$), as well as comparing comparing windows (-1, 1) and (-10,1) ($\beta = -1.94$, Wald χ^2 7.08, $p < 0.01$). This provides support that the market did respond to disruptions prior to their announcement in the pre-enforcement period, but as expected, this is a bias against our results. To test for differences in the post-enforcement period, we run a Wald test comparing the linear combination of the coefficients on *Disruption* plus *Disruption times Post-SOX* in Column (1) to that in Columns (2) - (4). There is not a statistically significant difference across any of these comparisons. These results indicate that our findings may be conservative since, by using a 3-day event window, we are not capturing some of the pre-announcement market response in the pre-enforcement period. This finding also provides additional support that Section 409 had a material influence on corporate disclosure practices.

Other Contemporaneous Causes. While we are unable to entirely eliminate the possibility that our results are due to some other unrecognized and contemporaneous factor, we do take steps to guard against such a contingency. First, the dependent variable we use to analyze the impact of disruptions on the firm's stock price, *Abnormal Return*, is developed using relationships between each firm's security price and contemporaneous market conditions. If general stock market conditions change over time it should not influence our results, provided these changes do not systematically affect the relationship between our sample firms' stock prices and the market benchmark. There is no reason to suspect that this would be the case. In addition, we include *Year* dummies in our models estimating the impact on the firm's share price.

Robustness Tests

Alternative Sample Windows. We also run robustness test to determine whether our results differ compared to those that would be obtained if we instead considered alternate time frames around the enforcement date of the new regulations – 4 years (August 2002 - August 2006), 5 years (February 2002 - February 2007), 6 years (August 2001 - August 2007), 8 years (August 2000 - August 2009), 10 years (August 1999 - August 2009), and all years in the data set (January 1998 - December 2011). Results for the estimation of the impact of disruption announcements on the firm's share price are presented in Table 3.7.16. The first row of χ^2 pre-409 statistics in Table 3.7.16 test the equivalency of the coefficient on *Disruption* between that obtained using all years in the data set surrounding the enforcement of SOX Section 409 (our base case for this part of the analysis), and that obtained using the other time frames. The second row of χ^2 pre-409 statistics in Table 3.7.16 test the equivalency of the linear combination of the coefficients on *Disruption* and *Disruption* × *Post-SOX* between that obtained using all years in the data set surrounding the enforcement of SOX Section 409 and that obtained using the other time frames. Neither set of χ^2 test statistics provide evidence that the differences are statistically significant.

Alternative Calculations of *Abnormal Return*. To confirm that our results are not driven by the method we employ to calculate *Abnormal Return*, we run the analysis by instead using 5-day, 7-day, 9-day and 11-day event windows surrounding the announcement dates. These results are presented in Table 3.7.17. In each case we achieve results with similar inferences to those found using a 3-day event window.

We also consider different estimation periods for for the calculation of *Abnormal Return*, namely 200 days, 150 days and 100 days (not presented). Considering shorter estimation periods gives some confidence that the value of *Abnormal Return* is not driven by stale relationships between the firm's share price and the market index. Our results do not substantively change if we use any of these alternative estimation periods.

We calculate *Abnormal Return* utilizing the Fama-French-Carhart 4-factor model to identify the counterfactual values used in the calculation of *Abnormal Return* (not presented). The results are similar to those using the market model to calculate *Abnormal Return*.

Vulnerability to Outliers. Because some of our financial variables exhibit skew, we run robustness tests after winsorizing the data to ensure that the results are not driven by extreme outliers. Winsorizing contains the impact of outlying data values by replacing those values with values that are at a specified percentile in the data distribution. For instance, winsorizing *Earnings Surprise* at 5 percent involves replacing those values of *Earnings Surprise* that are below the 2.5 percent and above the 97.5 percent tails of the distribution for this variable with values that are at the 2.5 percent and 97.5 percent of the distribution respectively. This data-transformation process is similar to trimming, except that trimming discards the outlying data entirely. Our main findings do not change in any meaningful way for the variables of interest in any of the hypotheses when the financial moderators and financial controls are (1) not winsorized, (2) winsorized at 2.5 percent, or (3) winsorized at 5 percent (not presented).

Multiple Disruptions. Seventy-seven of the 425 firms in our data experience more than one disruption during our study period. To confirm whether our results are driven by firms with multiple disruptions, we update all of our models to include a dummy variable, *Precendent*, that is set to "1" for any disruption that is not the first for the firm in the data set (not presented). Adding this control does not change our results in any meaningful way and the coefficient on this control is consistently small and insignificant.

3.5.3 Attributing Disruptions to Internal Versus External Factors

We next consider whether the market impact of disruptions is aggravated by disruptions that are attributed to factors beyond the firm's control compared to factors over which the firm should reasonably exert some control. We estimate the model in Equation (3.5) using OLS with firm-level fixed effects and robust standard errors clustered by firm. Column (1) in Table 3.7.18 presents the results. The coefficient on *Internal Disruption* is negative and statistically significant ($\beta =$ -8.93, SE 1.26, $p < 0.01$) while the coefficient on *Environment Disruption* is negative and not statistically significant ($\beta =$ -2.06, SE 1.88, $p > 0.10$). To test Hypothesis 3 in the pre-enforcement period, we conduct a Wald test on the difference between these two coefficients and find that it is negative and statistically significant ($\beta =$ -6.87, Wald χ^2 8.74, $p < 0.01$). We test whether this difference persists in the post-enforcement period by also including the coefficients for *Internal Disruption*$\times$*Post-SOX* ($\beta = 4.48$, SE 1.52, $p < 0.01$) and *Environment Disruption*$\times$*Post-SOX* ($\beta = 0.80$, SE 2.04, $p > 0.10$) in our Wald test. We again find that the difference between the impact of internal and environmental disruptions is negative and statistically significant ($\beta =$ -3.19, Wald χ^2 6.72, $p < 0.01$). These results provide evidence that in both the pre- and post-enforcement periods investors punish firms substantially more for the occurrence of disruptions that are within the firm's control compared to those that are due to outside forces.

We re-estimate the models in Equation (3.5) after excluding *Earnings Surprise* to approximate the total effect of disruptions, including the impact of the disruption on short-term earnings. The results, presented in in Column (2) of Table 3.7.18, are substantively similar to those including *Earnings Surprise*. This implies that the market is not responding to the direct earning impact, but rather the impact that the disruptions have on the perceived risk of the firm. A Wald test provides evidence that internal disruptions have a larger impact than environment disruption on abnormal returns in the pre-enforcement period ($\beta =$ -6.92, Wald χ^2 8.96, $p < 0.01$) and the post-enforcement period ($\beta =$ -3.06, Wald χ^2 6.08, $p < 0.05$). The inference remains that investors punish firms substantially more for the occurrence of disruptions that are within the firm's control compared to those that are due to outside forces.

Mechanisms

Differential Response Timing. A potential alternative explanation for the larger negative impact on firm value of internal disruptions announcements compared to environmental disruption announcements is that environmental disruptions are more visible to the investing public and news may be incorporated into the price of the firm's securities before management makes a formal announcement. To examine this possibility we calculate *Abnormal Return* based on different event windows which include more time prior to the official announcement of the disruption. We present the results for this analysis in Table 3.7.19. Column (1) provides our main results using an 3-day event window which covers the trading day before the announcement through the trading day after the announcement, (-1, 1). Results using extended event windows are presented in Columns (2) through (5). These event windows include 3, 5, 7 and 10 trading days before the announcement, (-3, 1), (-5, 1), (-7, 1) and (-10, 1). For each of the extended event windows, the estimated impact of an internal disruption is significantly greater than that of an environmental disruption in both the pre- and post-SOX Section 409 enforcement periods. This is contrary to what one would expect if the market was responding to environmental disruption announcements sooner than internal disruption announcements. The coefficient calculations at the bottom of the table show that the difference between internal and environmental disruptions is consistently larger for longer event windows than it is in our focal event window of (-1, 1) in both the pre- and post-enforcement periods. The statistical significance of the difference does degrade as the event window is extended because the calculation of *Abnormal Returns* includes more noise with a longer event window.

Competitive Effects. Another possible explanation of our finding for Hypothesis 3 is that environmental disruptions can sometimes affect a large geographic area. If an industry is concentrated then the firm and its competitors will both be affected by the disruption and the market response for such environmental disruptions will be muted. We limit this influence in our base analysis by calculating the counterfactual for *Abnormal Returns* using a broad market index rather than industry indices. We also run a robustness test after removing disruptions to firms in geographically concentrated industries. The industries that we exclude are electronics (SIC 3600 - 3699), automotive (SIC 3711-3714), and aerospace (SIC 3720-3729). The results are presented in Column (1) of Table 3.7.20 and continue to provide support for Hypothesis 3.

Differential Earnings Impact. We guard against the possibility that disruptions may impact the firm's market value differently because they are simply lower magnitude or have a smaller direct effect on the firm's earnings. For instance, environmental disruptions in general could have a lower impact on firm value because firms may be more likely to suffer insurable losses from such disruptions. In all of our tests on *Abnormal Returns* we account for the possibility of a differential earnings impact by including the *Earnings Surprise* control in our specifications.

Robustness Tests

We run the same battery of robustness tests that we describe in 3.5.2, including using alternative sample windows, alternative calculations of *Abnormal Return*, winsorizing outlying independent variables, and controlling for multiple disruptions by individual firms (not presented). The main inferences from our analysis continue to hold under these robustness tests.

3.6 Limitations and Extensions

The questions we seek to answer are potentially susceptible to endogeneity issues. Indeed, it is this possibility for endogeneity that has been least explored in the existing literature on this topic, and our effort to address it marks an important component of our findings. To that end, we have identified a natural experiment (the change in disclosure regulations) that helps us to address some of the potential endogeneity that all research on this topic is susceptible to, namely the propensity of some firms to hide emerging disruptions. Our research makes a valuable contribution by addressing these unexplored associations.

As with other large-sample empirical studies of disruptions we cite, our analysis is hampered by incomplete information about the economic magnitude of disruptions; few disruption announcements disclose such information consistently. We make and important step in addressing this deficiency by including the *Earnings Surprise* control variable, but a data source that more consistently reports on the magnitude of disruptions would be helpful and might generate additional insights.

Another limitation to our study is that we cannot eliminate the possibility that other unmeasured contemporaneous forces are driving the increase in disruption announcements and the market's response. In addition to the robustness tests identified above, we sought to validate our results by interviewing current and former executives of publicly traded firms about their disclosure practices pertaining to operational disruptions. The feedback we received aligns with our theory that managers did, in fact, refrain from disclosing material disruptions if they could "manage it within the quarter." For instance, the President of a large supermarket chain acknowledged "[we] would really weigh the pros and cons [of making an announcement], since you don't want to prematurely spook the market." The CEO and Chairman of a major electronics distributor made the same point more colorfully: "Firms will be hesitant to pull their pants down in public unless they are forced to do it." The interviews support the view that, prior to Section 409 enforcement, managers avoided announcing disruptions generally, but felt compelled to announce those that were so large as to make them difficult to address privately. The increased formalization of disclosure practices as a result of SOX regulations curtailed this practice. Post-enforcement announcements, by contrast, include disruptions material enough to warrant disclosure but that might not have otherwise been announced had management retained more discretion.

3.7 Discussion and Managerial Implications

We estimate the firms twice as likely to disclose supply chain disruption announcements following the enforcement date of SOX Section 409. The average impact of a disruption on the firm's share price is reduced from -7.7 percentage points to -2.9 after the enforcement of Section 409 of SOX. We provide considerable evidence that managers exercised consideration discretion in reporting material disruptions and that Section 409 enforcement tempered their predisposition to underreport disruptions that are less damaging but still consequential to the firm's operations under the SOX guidelines.

We also show that the impact of a disruption on firm value depends heavily on whether or not the disruption is attributed to factors under the firm's control in both the pre- and post-Section 409 enforcement period. In the pre-Section 409 period, the average impact on the firm's stock price is -8.9 percentage points for an internal disruption and -2.1 percentage points for disruptions attributed to the environment. These values drop to -4.4 percentage points and -1.3 percentage points in the post-Section 409 period. Given that the median daily return was -0.05 percentage points for the observations in our database that did not involve a disruption, the results from our analysis are economically significant.

We draw two insights from these results. First, disruptions that are under the firm's control are much more damaging to firm value than those not under the firm's control, even after accounting for their impact on current earnings. While this difference persists in both the pre- and post-enforcement period, it is reduced in the post-enforcement period. Second, and relatedly, the enforcement of Section 409 reduced the impact of internal disruptions on the firm's stock price more than that of environmental disruptions. This difference persists (and actually becomes more pronounced) after accounting for the possibility that the stock market responds to environmental disruptions before the firm officially announces them. This difference can reasonably be explained by management's ability to avoid revealing internal disruptions compared to environmental disruptions since the latter are more likely to be observable by external parties.

The impact of disruptions on firm value can vary widely, but there are clearly instances when disruptions have a devastating effect. We have shown that the type of disruption matters in identifying the magnitude of a disruption's impact on a firm's share price. Disruptions attributed to factors within the firm or its supply chain are far more damaging than disruptions attributed to factors in the environment. It is important for managers and investors alike to recognize the types of disruptions and the firm characteristics that contribute disproportionately to more undesirable outcomes. Countermeasures to mitigate the risk of disruptions have a cost, and insights into the types of disruptions that represent the greatest risk to company value will help managers assess whether the company is investing appropriately to mitigate the most material risks.

Table 3.7.1: Sample summary

	Disruptions		Earnings-Only	
Year	**Frequency**	**Percent**	**Frequency**	**Percent**
1997			65	1.8
1998	43	8.1	162	4.6
1999	38	7.1	234	6.6
2000	34	6.4	192	5.4
2001	31	5.8	179	5.1
2002	24	4.5	183	5.2
2003	16	3.0	160	4.5
2004	46	8.6	269	7.6
2005	70	13.1	354	10.0
2006	39	7.3	365	10.3
2007	36	6.7	332	9.4
2008	74	13.9	342	9.7
2009	25	4.7	308	8.7
2010	33	6.2	225	6.4
2011	25	4.7	164	4.6
Total	534	100	3534	100
	Disruptions		**Earnings-Only**	
Current Quarter Sales	**Frequency**	**Percent**	**Frequency**	**Percent**
Current Quarter Sales $<$ 100M	219	41.0	1123	31.8
Sales $\geq$ 100M and $<$ 500M	155	29.0	1199	33.9
Sales $\geq$ 500M and $<$ 2000M	99	18.5	786	22.2
Sales $\geq$ 2000M	53	9.9	386	10.9
Sales unknown	8	1.5	40	1.1
Total	534	100	3534	100

Table 3.7.2: Description of Form 8-K Items

Item Description	Status
Section 1 - Registrant Business and Operations	
Item 1.01 Entry into a Material Definitive Agreement	New
Item 1.02 Termination of a Material Definitive Agreement	New
Item 1.03 Bankruptcy or Receivership	Unchanged
Section 2 - Financial Information	
Item 2.01 Completion of Acquisition or Disposition of Assets	Largely Unchanged
Item 2.02 Results of Operations and Financial Condition	Unchanged
Item 2.03 Creation of a Direct or Off-Balance Sheet Obligation	New
Item 2.04 Events That Accelerate or Increase a Direct or Off-Balance Sheet Obligation	New
Item 2.05 Costs Associated with Exit or Disposal Activities	New
Item 2.06 Material Impairments	New
Section 3 - Securities and Trading Markets	
Item 3.01 Notice of Delisting or Transfer of Listing	New
Item 3.02 Unregistered Sales of Equity Securities	Previously on 10Q/K
Item 3.03 Material Modifications to Rights of Security Holders	Previously on 10Q/K
Section 4 - Matters Related to Accountants and Financial Statements	
Item 4.01 Changes in Registrant's Certifying Accountant	Unchanged
Item 4.02 Non-Reliance on Previously Issued Financial Statements	New
Section 5 - Corporate Governance and Management	
Item 5.01 Changes in Control of Registrant	Largely Unchanged
Item 5.02 Departure, Election or Appointment of Directors or Principal Officers	Expanded
Item 5.03 Amendments to Articles of Incorporation or Bylaws; Change in Fiscal Year	Expanded
Item 5.04 Suspension of Trading Under Registrant's Employee Benefit Plans	Expanded
Item 5.05 Amendments to or Waiver of the Registrant's Code of Ethics	Unchanged
Section 7 - Regulation FD	
Item 7.01 Regulation FD Disclosure	Unchanged
Section 8 - Other Events	
Item 8.01 Other Events	Unchanged

continued on the next page

Table 3.7.2 – continued from previous page

Item Description	Status
Section 9 - Financial Statements and Exhibits	
Item 9.01 Financial Statements and Exhibits	Largely Unchanged

Note : *Table developed based on information contained in the SEC final ruling, "Additional Form 8-K Disclosure Requirements and Acceleration of Filing Date (Final Rule)", Federal Register. 69: 15594-15629.*

Table 3.7.3: Description of Variables Used in the Analysis of the Likelihood of a Disruption Announcement

Variable	Description
Announced Disruption	Supply chain disruption was announced by the firm
Announced Internal	Disruption attributed to factors internal to the firm's operations was announced by the firm
Announced External	Disruption attributed to factors external to the firm but within its supply chain was announced by the firm
Announced Environment	Disruption attributed to factors in the environment was announced by the firm
Post-SOX Quarter	Period is before the enforcement quarter of the SOX Section 409
Accelerated Filer	Indicator identifying whether the firm has accelerated filing status in the quarter of the announcement
Earnings Surprise	The difference between the earnings per share provided in the announcement and the average of the analysts' forecast.
Debt-to-Equity Ratio	The book value of the firm's long-term debt divided by market value of its common equity, lagged one quarter
Market-to-Book Ratio	The market value of the firm's common equity divided by the book value of its common equity, lagged one quarter
Fixed Assets Ratio	The ratio of property, plant, and equipment divided by total assets, lagged one quarter
Log Sales	The natural log of quarterly sales (in $M), lagged one quarter

Table 3.7.4: Summary Statistics for Variables Used in the Analysis of the Likelihood of a Disruption Announcement

Variable	Mean	Std. Dev.	Min.	Max.	N
Announced Disruption	0.03	0.16	0	1	22066
Announced Internal	0.01	0.12	0	1	22066
Announced External	0.01	0.08	0	1	22066
Announced Environment	0.01	0.08	0	1	22066
Post-Sox Quarter	0.48	0.5	0	1	22066
Accelerated Filer	0.78	0.42	0	1	20430
Debt-to-Equity Ratio	0.58	1.35	0	10.32	22066
Market-to-Book Ratio	2.42	3.45	-7.48	23.82	22066
Fixed Assets Ratio	0.34	0.25	0	0.92	22066
Log Sales	4.67	2.29	-0.18	11.6	22066

Table 3.7.5: Correlations for Variables Used in the Analysis of the Likelihood of a Disruption Announcement

Variables	Announced Disruption	Announced Internal	Announced External	Announced Environment	Post-Sox Quarter	Accelerated Filer	Debt-to-Equity Ratio	Market-to-Book Ratio	Fixed Assets Ratio	Log Sales
Announced Disruption	1.00									
Announced Internal	0.73	1.00								
Announced External	0.47	0.03	1.00							
Announced Environment	0.52	0.02	0.03	1.00						
Post-Sox Quarter	0.04	0.03	0.00	0.04	1.00					
Accelerated Filer	0.01	0.00	0.00	0.02	0.11	1.00				
Debt-to-Equity Ratio	-0.02	-0.01	-0.01	-0.01	-0.02	-0.13	1.00			
Market-to-Book Ratio	0.02	0.01	0.01	0.01	-0.02	0.09	-0.15	1.00		
Fixed Assets Ratio	0.01	0.00	-0.03	0.03	-0.00	0.16	0.13	-0.02	1.00	
Log Sales	0.01	0.00	-0.01	0.03	0.17	0.57	0.13	-0.01	0.27	1.00

Table 3.7.6: Description of Variables Used in the Analysis of the Impact of Disruptions on the Firm's Stock Price

Variable	Description
Abnormal Return	Excess return on the firm's common stock
Disruption	Indicator identifying a supply chain disruption
Internal Disruption	Indicator identifying a disruption attributed to factors internal to the firm's operations
External Disruption	Indicator identifying a disruption attributed to factors external to the firm but within its supply chain
Environment Disruption	Indicator identifying a disruption attributed to factors in the environment
Post-SOX	Announcement occurring on or before the enforcement date of the SOX Section 409, August 23, 2004
Accelerated Filer	Indicator identifying whether the firm has accelerated filing status at the time of the announcement
Earnings Surprise	The difference between the earnings per share in the announcement and the average of the analysts' forecast.
Debt-to-Equity Ratio	The book value of the firm's long-term debt divided by market value of its common equity, lagged one quarter
Market-to-Book Ratio	The market value of the firm's common equity divided by the book value of its common equity, lagged one quarter
Fixed Assets Ratio	The ratio of property, plant, and equipment divided by total assets, lagged one quarter
Log Sales	The natural log of quarterly sales (in $M), lagged one quarter

Table 3.7.7: Summary Statistics for Variables Used in the Analysis of the Impact of Disruptions on the Firm's Stock Price

Variable	Mean	Std. Dev.	Min.	Max.	N
Abnormal Return	-0.85	9.51	-66.77	72.34	4068
Disruption	0.13	0.34	0	1	4068
Internal Disruption	0.07	0.26	0	1	4068
External Disruption	0.03	0.17	0	1	4068
Environment Disruption	0.04	0.19	0	1	4068
Post-Sox	0.62	0.49	0	1	4068
Accelerated Filer	0.9	0.3	0	1	4068
Earnings Surprise	0	0.01	-0.05	0.01	4068
Debt-to-Equity Ratio	0.41	0.67	0	4.76	4068
Market-to-Book Ratio	2.88	3.07	-1.26	21.1	4068
Fixed Assets Ratio	0.35	0.24	0	0.89	4068
Log Sales	5.26	2.02	0	11.26	4068

Table 3.7.8: Correlations for Variables Used in the Analysis of the Impact of Disruptions on the Firm's Stock Price

Variables	Abnormal Return	Disruption	Internal Disruption	External Disruption	Environment Disruption	Post-Sox	Accelerated Filer	Earnings Surprise	Debt-to-Equity Ratio	Market-to-Book Ratio	Fixed Assets Ratio	Log Sales
Abnormal Return	1.00											
Disruption	-0.16	1.00										
Internal Disruption	-0.15	0.71	1.00									
External Disruption	-0.08	0.45	-0.01	1.00								
Environment Disruption	-0.04	0.49	-0.02	0.01	1.00							
Post-Sox	0.02	0.00	-0.01	-0.04	0.05	1.00						
Accelerated Filer	-0.02	-0.11	-0.11	-0.05	-0.00	0.21	1.00					
Earnings Surprise	0.12	0.03	0.01	0.02	0.03	0.06	0.21	1.00				
Debt-to-Equity Ratio	0.05	-0.01	0.02	-0.02	-0.02	-0.09	-0.08	-0.08	1.00			
Market-to-Book Ratio	-0.04	-0.00	-0.01	0.01	0.01	0.01	0.09	0.07	-0.13	1.00		
Fixed Assets Ratio	0.03	-0.01	-0.02	-0.07	0.05	0.15	0.11	0.03	0.19	-0.05	1.00	
Log Sales	0.07	-0.08	-0.07	-0.07	0.01	0.29	0.39	0.16	0.17	0.03	0.27	1.00

Table 3.7.9: Estimating the likelihood of a disruption announcement.

	Dependent Variable: *Announced Disruption*	
	Coefficient	Odds Ratio
	(1)	(2)
Post-SOX Quarter	0.74**	2.09**
	[0.12]	[0.24]
Debt-to-Equity Ratio	-0.22**	0.80**
	[0.06]	[0.05]
Market-to-Book Ratio	0.03*	1.03*
	[0.01]	[0.01]
Fixed Assets Ratio	0.53	1.70
	[0.41]	[0.70]
Log Sales	0.08	1.09
	[0.07]	[0.08]
Observations	22,066	22,066
Number of Firms	447	447
Number of Disruptions	577	577
Pseudo R^2	0.02	0.02
Mean, pre-409	0.019	0.019
Mean, post-409	0.034	0.034

Notes: Conditional fixed effects logistic estimation. Robust standard errors clustered by firm in brackets.
** $p<0.01$, * $p<0.05$, + $p<0.1$

Table 3.7.10: Estimating the likelihood of a disruption announcement by disruption type.

	Dependent Variable:					
	Announced Internal		*Announced External*		*Announced Environment*	
	Coefficient	Odds Ratio	Coefficient	Odds Ratio	Coefficient	Odds Ratio
	(1)	(2)	(3)	(4)	(5)	(6)
Post-SOX Quarter	0.84**	2.31**	0.30	1.35	0.84**	2.31**
	[0.17]	[0.38]	[0.21]	[0.29]	[0.22]	[0.50]
Debt-to-Equity Ratio	-0.16*	0.86*	-0.30	0.74	-0.39*	0.68*
	[0.06]	[0.05]	[0.20]	[0.14]	[0.16]	[0.11]
Market-to-Book Ratio	0.03+	1.03+	0.03	1.03	0.03	1.03
	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]
Fixed Assets Ratio	1.32*	3.74*	0.72	2.06	-0.89	0.41
	[0.65]	[2.45]	[0.88]	[1.82]	[0.63]	[0.26]
Log Sales	-0.01	0.99	-0.00	1.00	0.49**	1.62**
	[0.08]	[0.08]	[0.14]	[0.14]	[0.13]	[0.21]
Observations	12,035		5,897		7,107	
Number of Firms	247		119		136	
Number of Disruptions	350		164		198	
Pseudo R^2	0.023		0.007		0.051	
Mean, pre-409	0.020		0.021		0.012	
Mean, post-409	0.032		0.024		0.032	

Notes: Conditional fixed effects logistic estimation. Robust standard errors clustered by firm in brackets. ** $p<0.01$, * $p<0.05$, + $p<0.10$

Table 3.7.11: Estimating the likelihood of a disruption announcement by accelerated filer status.

	Dependent Variable: Announced Disruption					
	Non-Accelerated Filers		*Accelerated Filers*		*Accelerated Filers, $250M*	
	Coefficient	Odds Ratio	Coefficient	Odds Ratio	Coefficient	Odds Ratio
	(1)	(2)	(3)	(4)	(5)	(6)
Post-SOX Quarter	0.55*	1.74*	0.67**	1.96**	0.39	1.48
	[0.28]	[0.48]	[0.13]	[0.26]	[0.32]	[0.48]
Debt-to-Equity Ratio	-0.22*	0.80*	-0.21*	0.81*	-0.00	1.00
	[0.09]	[0.07]	[0.09]	[0.07]	[0.15]	[0.15]
Market-to-Book Ratio	0.04*	1.05*	0.02	1.02	0.04	1.05
	[0.02]	[0.02]	[0.01]	[0.01]	[0.04]	[0.05]
Fixed Assets Ratio	2.80+	16.47+	-0.56	0.57	-1.48	0.23
	[1.63]	[26.80]	[0.68]	[0.38]	[1.50]	[0.34]
Log Sales	0.56+	1.76+	0.16+	1.17+	0.30	1.35
	[0.30]	[0.53]	[0.09]	[0.10]	[0.25]	[0.34]
Observations	3,101	3,101	14,977	14,977	1,594	1,594
Number of Firms	89.000	89.000	347.000	347.000	77.000	77.000
Number of Disruptions	104.000	104.000	448.000	448.000	82.000	82.000
Pseudo R^2	0.029	0.029	0.019	0.019	0.012	0.012
Mean, pre-409	0.030	0.030	0.021	0.021	0.047	0.047
Mean, post-409	0.039	0.039	0.038	0.038	0.057	0.057
χ^2			0.158		0.145	
P-value			0.691		0.703	

Notes: Conditional fixed effects logistic estimation. Robust standard errors clustered by firm in brackets. The χ^2 statistic tests the equivalency of the coefficient on *Post-SOX Quarter* across models (1) and (2), and models (1) and (3). ** $p<0.01$, * $p<0.05$, + $p<0.10$

Table 3.7.12: Estimating the likelihood of a disruption announcement using different estimation periods.

	Dependent Variable: *Announced Disruption*					
	All Years	4 Years	5 Years	6 Years	8 Years	10 Years
	(1)	(2)	(3)	(4)	(5)	(6)
Post-SOX Quarter	0.74**	0.96**	0.95**	0.75**	0.77**	0.78**
	[0.12]	[0.20]	[0.18]	[0.16]	[0.14]	[0.12]
Debt-to-Equity Ratio	-0.22**	-0.00	-0.08	-0.09	-0.17*	-0.29**
	[0.06]	[0.09]	[0.07]	[0.07]	[0.07]	[0.08]
Market-to-Book Ratio	0.03*	0.06*	0.04+	0.03+	0.04**	0.04**
	[0.01]	[0.03]	[0.02]	[0.02]	[0.02]	[0.01]
Fixed Assets Ratio	0.53	0.22	1.01	1.16	1.37*	1.14*
	[0.41]	[0.90]	[0.81]	[0.75]	[0.61]	[0.51]
Log Sales	0.08	0.00	-0.02	0.04	0.05	0.02
	[0.07]	[0.19]	[0.16]	[0.11]	[0.12]	[0.09]
Observations	22,066	2,676	3,795	5,096	8,570	12,675
Number of Firms	447	163	189	215	287	357
Number of Disruptions	577	178	214	249	347	441
Pseudo R^2	0.023	0.042	0.038	0.026	0.029	0.030
Mean, pre-409	0.019	0.038	0.034	0.032	0.027	0.024
Mean, post-409	0.034	0.094	0.080	0.066	0.054	0.046
χ^2	2.044	2.044	2.459	0.009	0.102	0.445
P-value	0.153	0.153	0.117	0.926	0.749	0.505

Notes: Estimated with conditional fixed-effects logistic regression. Robust standard errors clustered by firm in brackets. Results are presented as coefficients rather than odds ratios. The χ^2 statistic tests the equivalency of the coefficient on *Post-SOX Quarter* across models (1) and (2), (1) and (3), (1) and (4), (1) and (5), and (1) and (6). The results in each column omit firms for which there are no disruptions reported in the adjusted sample periods. ** $p<0.01$, * $p<0.05$, + $p<0.1$

Table 3.7.13: Estimating the impact of disruptions on firm abnormal stock returns before and after SOX Section 409 enforcement.

	Dependent Variable: *Abnormal Return*	
	(1)	(2)
Disruption × *Post-SOX*	4.79**	4.58**
	[1.06]	[1.06]
Disruption	-7.65**	-7.35**
	[0.93]	[0.92]
Post-SOX	0.36	0.38
	[1.23]	[1.22]
Earnings Surprise	108.80**	
	[20.81]	
Debt-to-Equity Ratio	1.58**	1.44**
	[0.43]	[0.44]
Market-to-Book Ratio	-0.32**	-0.30**
	[0.10]	[0.10]
Fixed Assets Ratio	0.96	0.46
	[2.18]	[2.26]
Log of lagged sales	-0.10	-0.13
	[0.32]	[0.34]
Constant	0.42	0.39
	[2.04]	[2.11]
Observations	4,068	4,068
Number of Firms	425	425
Number of Disruptions	534	534
R^2	0.06	0.04
Mean, pre-409	-7.13	-7.13
Mean, post-409	-3.41	-3.41

Notes: Ordinary least squares estimation with firm-level fixed effects. Robust standard errors clustered by firm in brackets. Other included controls – a complete set of *Year* dummies. ** p<0.01, * p<0.05, + p<0.10

Table 3.7.14: Estimating the impact on stock returns of announced disruptions by accelerated filer status.

		Dependent Variable: *Abnormal Return*	
		(1)	(2)
(A)	*Disruption* × *Post-SOX*	8.91**	8.32*
		[3.42]	[3.52]
(B)	*Disruption* × *Post-SOX* × *Accelerated Filer*	-4.96	-7.76
		[3.59]	[4.91]
	Disruption	-9.95**	-9.91**
		[2.26]	[2.27]
	Post-SOX	2.84	5.41
		[2.46]	[4.11]
	Accelerated Filer	-3.09**	-2.13+
		[1.16]	[1.27]
	Disruption × *Accelerated Filer*	2.85	1.85
		[2.48]	[3.09]
	Post-SOX × *Accelerated Filer*	-2.70	-4.72+
		[2.03]	[2.45]
	Constant	3.10	3.52
		[2.37]	[5.91]
	Observations	4,068	1,011
	Number of Firms	425	156
	Number of Disruptions	534	179
	Number AF Disruptions	434	79
	Number NAF Disruptions	100	100
	R^2	0.07	0.11
	Mean, pre-409	-7.13	-7.74
	Mean, post-409	-3.41	-4.52
	Coeff on (A)+(B)	3.95	0.56
	Wald: (A)+(B)=0?	12.11**	0.03

Notes: Ordinary least squares estimation with firm-level fixed effects. Robust standard errors clustered by firm in brackets. Model (1) includes all observations. Model(2) includes only observations with a public float $\leq$ 250M. Included controls – *Earnings Surprise, Fixed Asset Ratio, Market-to-Book Ratio, Debt-to-Equity Ratio, Log Sales*, and a complete set of year dummies, *Year*. Wald tests report *F* statistics. ** $p<0.01$, * $p<0.05$, + $p<0.10$

Table 3.7.15: Estimating the impact on stock returns of announced disruptions after including more pre-announcement days in the calculation of *Abnormal Returns*.

	Dependent Variable: *Abnormal Return*			
	W(-1,1)	W(-3,1)	W(-7,1)	W(-10,1)
	(1)	(2)	(3)	(4)
Disruption	-7.65**	-8.40**	-9.66**	-9.61**
	[0.93]	[1.13]	[1.25]	[1.28]
Disruption × *Post-SOX*	4.79**	5.06**	6.11**	6.04**
	[1.06]	[1.30]	[1.48]	[1.55]
Post-SOX	0.36	-1.10	-1.77	-2.35
	[1.23]	[1.32]	[1.50]	[1.71]
Constant	0.42	2.57	3.33	3.81
	[2.04]	[2.54]	[3.48]	[4.12]
Observations	4,068	4,069	4,069	4,100
Number of Firms	425	425	425	425
Number of Disruptions	534	534	534	534
R^2	0.06	0.06	0.06	0.06
Mean, pre-409	-7.13	-7.88	-9.22	-9.35
Mean, post-409	-3.41	-3.97	-4.31	-4.73
χ^2, pre-409		2.60	8.37	7.08
P-value, pre-409		0.11	0.00	0.01
χ^2, post-409		2.01	1.92	1.52
P-value, post-409		0.16	0.17	0.22

Notes: Ordinary least squares estimation with firm-level fixed effects. Robust standard errors clustered by firm in brackets. The *Abnormal Return* dependent variable in column (1) uses a (-1,1) event window, column (2) uses a (-3,1) event window, column (3) uses a (-7,1) event window, and column (4) uses a (-10,1) event window. Included controls – *Earnings Surprise*, *Fixed Asset Ratio*, *Market-to-Book Ratio*, *Debt-to-Equity Ratio*, *Log Sales*, and a complete set of year dummies, *Year*. The pre-409 χ^2 statistic tests the equivalency of the coefficient on *Disruption* across models (1) and (2), (1) and (3), and (1) and (4). The post-409 χ^2 statistic tests the equivalency of the coefficient on *Disruption* + *Disruption*×*Post-SOX*. ** $p<0.01$, * $p<0.05$, + $p<0.10$

Table 3.7.16: Estimating the impact on stock returns of announced disruptions using different estimation periods.

	Dependent Variable: *Abnormal Return*					
	AllYears	10 Years	8 Years	6 Years	5 Years	4 Years
	(1)	(2)	(3)	(4)	(5)	(6)
Disruption	-7.65**	-7.49**	-7.17**	-6.25**	-5.89**	-6.14**
	[0.93]	[1.11]	[1.35]	[1.42]	[1.59]	[1.84]
Disruption × *Post-SOX*	4.79**	4.24**	3.99**	3.30*	3.20+	3.45
	[1.06]	[1.31]	[1.49]	[1.60]	[1.81]	[2.11]
Post-SOX	0.36	0.48	0.54	0.59	0.71	0.72
	[1.23]	[1.24]	[1.26]	[1.28]	[1.27]	[1.28]
Constant	0.42	2.42	1.49	3.64	10.91+	5.48
	[2.04]	[3.27]	[4.61]	[6.33]	[6.23]	[5.45]
Observations	4,068	3,084	2,425	1,778	1,527	1,262
R^2	0.06	0.05	0.06	0.06	0.06	0.05
Number of Firms	425	339	273	208	183	157
Number of Disruptions	534	404	318	229	196	166
Mean, pre-409	-7.13	-7.20	-6.53	-5.26	-5.75	-5.18
Mean, post-409	-3.41	-3.70	-3.62	-3.22	-3.15	-2.95
χ^2, pre-409		0.08	0.35	1.56	1.75	0.98
P-value, pre-409		0.78	0.55	0.21	0.19	0.32
χ^2, post-409		2.52	0.53	0.02	0.07	0.06
P-value, post-409		0.11	0.47	0.89	0.79	0.81

Notes: Ordinary least squares estimation with firm-level fixed effects. Robust standard errors clustered by firm in brackets. Included controls – *Earnings Surprise*, *Fixed Asset Ratio*, *Market-to-Book Ratio*, *Debt-to-Equity Ratio*, *Log Sales*, and a complete set of year dummies, *Year*. Wald tests report *F* statistics. The pre-409 χ^2 statistic tests the equivalency of the coefficient on *Disruption* across models (1) and (2), (1) and (3), (1) and (4), (1) and (5), and (1) and (6). The post-409 χ^2 statistic tests the equivalency of the coefficient on *Disruption* + *Disruption*×*Post-SOX*. ** $p<0.01$, * $p<0.05$, + $p<0.10$

Table 3.7.17: Estimating the impact on stock returns of announced disruptions after expanding the event window in the calculation of *Abnormal Returns*.

	Dependent Variable: *Abnormal Return*				
	W(-1,1)	W(-2,2)	W(-3,3)	W(-4,4)	W(-5,5)
	(1)	(2)	(3)	(4)	(5)
Disruption	-7.65**	-8.07**	-9.01**	-10.42**	-10.05**
	[0.93]	[1.05]	[1.26]	[1.27]	[1.33]
Disruption × *Post-SOX*	4.79**	4.64**	5.33**	6.66**	6.00**
	[1.06]	[1.23]	[1.44]	[1.52]	[1.61]
Post-SOX	0.36	-0.54	-1.29	-1.54	-1.13
	[1.23]	[1.45]	[1.59]	[1.83]	[1.86]
Constant	0.42	0.09	1.76	2.20	2.45
	[2.04]	[2.36]	[2.63]	[3.21]	[3.97]
Observations	4,068	4,069	4,069	4,069	4,069
R^2	0.06	0.06	0.06	0.06	0.05
Number of Firms	425	425	425	425	425
Number of Disruptions	534	534	534	534	534
Mean, pre-409	-7.13	-7.56	-8.22	-9.48	-8.88
Mean, post-409	-3.41	-4.26	-4.45	-4.45	-4.49

Notes: Ordinary least squares estimation with firm-level fixed effects. Robust standard errors clustered by firm in brackets. The *Abnormal Return* dependent variable in column (1) uses a (-1,1) event window, column (2) uses a (-2,2), column (3) uses a (-3,3), column (4) uses a (-4,4), and column (5) uses a (-5,5). Included controls – *Earnings Surprise, Fixed Asset Ratio, Market-to-Book Ratio, Debt-to-Equity Ratio, Log Sales,* and a complete set of year dummies, *Year*. Wald tests report *F* statistics. ** $p<0.01$, * $p<0.05$, + $p<0.10$

Table 3.7.18: Estimating the impact of different types of disruptions on firm abnormal stock returns before and after SOX Section 409 enforcement.

		Dependent Variable: *Abnormal Return*	
		(1)	(2)
(A)	*Internal Disruption* × *Post-SOX*	4.48**	4.37**
		[1.52]	[1.50]
	External Disruption × *Post-SOX*	4.93*	4.83*
		[2.23]	[2.26]
(B)	*Environment Disruption* × *Post-SOX*	0.80	0.51
		[2.04]	[2.05]
(C)	*Internal Disruption*	-8.93**	-8.69**
		[1.26]	[1.23]
	External Disruption	-6.75**	-6.45**
		[1.65]	[1.65]
(D)	*Environment Disruption*	-2.06	-1.77
		[1.88]	[1.90]
	Post-SOX	0.33	0.34
		[1.22]	[1.21]
	Constant	0.61	0.59
		[2.07]	[2.14]
	Observations	4,068	4,068
	Number of Firms	425	425
	Number of Disruptions	534	534
	R^2	0.06	0.05
	Mean, pre-409	-7.13	-7.13
	Mean, post-409	-3.41	-3.41
	Wald: (C)-(D)=0?	8.74**	8.96**
	Wald: (A)+(C)-(B)-(D)=0?	6.72**	6.08*

Notes: Ordinary least squares estimation with firm-level fixed effects. Robust standard errors clustered by firm in brackets. *Earnings Surprise*, *Fixed Asset Ratio*, *Market-to-Book Ratio*, *Debt-to-Equity Ratio*, *Log Sales*, and a complete set of year dummies, *Year*. Wald tests report *F* statistics. ** p<0.01, * p<0.05, + p<0.10

Table 3.7.19: Estimating the impact on stock returns of announced disruptions by disruption type after including more pre-announcement days in the calculation of *Abnormal Returns*.

		Dependent Variable: *Abnormal Return*				
		W(-1,1)	W(-3,1)	W(-5,1)	W(-7,1)	W(-10,1)
		(1)	(2)	(3)	(4)	(5)
(A)	*Internal Disruption* × *Post-SOX*	4.48**	4.56*	5.10**	6.11**	5.78*
		[1.52]	[1.93]	[1.95]	[2.25]	[2.27]
	External Disruption × *Post-SOX*	4.93*	6.06*	5.75*	5.60+	4.84
		[2.23]	[2.70]	[2.91]	[3.13]	[3.23]
(B)	*Environment Disruption* × *Post-SOX*	0.80	0.56	-0.10	0.64	2.47
		[2.04]	[2.34]	[2.31]	[2.81]	[2.76]
(C)	*Internal Disruption*	-8.93**	-10.27**	-10.72**	-11.33**	-10.85**
		[1.26]	[1.56]	[1.54]	[1.77]	[1.73]
	External Disruption	-6.75**	-7.64**	-8.55**	-8.75**	-8.65**
		[1.65]	[2.18]	[2.36]	[2.53]	[2.58]
(D)	*Environment Disruption*	-2.06	-1.43	-1.68	-2.33	-3.83
		[1.88]	[2.17]	[2.09]	[2.58]	[2.50]
	Post-SOX	0.33	-1.20	-0.94	-1.78	-2.38
		[1.22]	[1.31]	[1.37]	[1.50]	[1.71]
	Constant	0.61	2.91	1.94	3.52	3.92
		[2.07]	[2.55]	[3.11]	[3.48]	[4.13]
	Observations	4,068	4,069	4,069	4,069	4,100
	Number of Firms	425	425	425	425	425
	Number of Disruptions	534	534	534	534	534
	R^2	0.06	0.07	0.07	0.07	0.06
	Mean, pre-409	-7.13	-7.88	-8.17	-9.22	-9.35
	Mean, post-409	-3.41	-3.97	-4.42	-4.31	-4.73
	Coeff on (C)-(D)	-6.87	-8.85	-9.04	-9.00	-7.02
	Wald: (C)-(D)=0?	8.74**	10.58**	12.01**	9.30**	5.59*
	Coeff on (A)+(C)-(B)-(D)	-3.19	-4.84	-3.83	-3.52	-3.70
	Wald: (A)+(C)-(B)-(D)=0?	6.72**	10.02**	5.45*	3.61+	3.41+

Notes: Ordinary least squares estimation with firm-level fixed effects. Robust standard errors clustered by firm in brackets. The *Abnormal Return* dependent variable in column (1) uses a (-1,1) event window, column (2) uses a (-3,1) event window, column (3) uses a (-5,1) event window, column (4) uses a (-7,1) event window, column (5) uses a (-10,1) event window. Included controls – *Earnings Surprise, Fixed Asset Ratio, Market-to-Book Ratio, Debt-to-Equity Ratio, Log Sales,* and a complete set of year dummies, *Year*. Wald tests report *F* statistics. ** $p<0.01$, * $p<0.05$, + $p<0.10$

Table 3.7.20: Estimating the impact on stock returns of announced disruptions by disruption type after excluding concentrated industries.

		Dependent Variable: *Abnormal Return*
		(1)
(A)	*Internal Disruption* × *Post-SOX*	3.73*
		[1.64]
	External Disruption × *Post-SOX*	3.19
		[2.28]
(B)	*Environment Disruption* × *Post-SOX*	0.93
		[2.05]
(C)	*Internal Disruption*	-8.41**
		[1.36]
	External Disruption	-5.40**
		[1.83]
(D)	*Environment Disruption*	-2.37
		[1.89]
	Post-SOX	-0.37
		[1.36]
	Constant	0.57
		[2.16]
	Observations	3,394
	Number of Firms	354
	Number of Disruptions	442.00
	R^2	0.06
	Mean, pre-409	-6.77
	Mean, post-409	-3.29
	Coeff on (C)-(D)	-6.04
	Wald: (C)-(D)=0?	6.96**
	Coeff on (A)+(C)-(B)-(D)	-3.24
	Wald: (A)+(C)-(B)-(D)=0?	5.88*

Notes: Ordinary least squares estimation with firm-level fixed effects. Robust standard errors clustered by firm in brackets. Included controls – *Earnings Surprise*, *Fixed Asset Ratio*, *Market-to-Book Ratio*, *Debt-to-Equity Ratio*, *Log Sales*, and a complete set of year dummies, *Year*. The analysis excludes firms in SIC 3600 - 3699, 3711-3714, and 3720-3729. Wald tests report *F* statistics. ** $p<0.01$, * $p<0.05$, + $p<0.10$

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Colophon

THIS THESIS WAS TYPESET using LaTeX, originally developed by Leslie Lamport and based on Donald Knuth's TeX. The body text is set in 11 point Arno Pro, designed by Robert Slimbach in the style of book types from the Aldine Press in Venice, and issued by Adobe in 2007. A template, which can be used to format a PhD thesis with this look and feel, has been released under the permissive MIT (X11) license, and can be found online at github.com/suchow/ or from the author at suchow@post.harvard.edu. Man, was it a pain to use!