Knightian Uncertainty and Capital Structure: Theory and Evidence

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Abstract

I derive the optimal capital structure of a firm when its manager is ambiguity-averse. My model predicts substantially lower leverage for such firms, in comparison to traditional trade-off models. I use the 1982 Voluntary Restraint Agreement (VRA) on steel import quotas between the U.S. government and the European Community as an exogenous reduction in Knightian uncertainty faced by firms in the U.S. steel industry. Using a difference-in-difference methodology, I find that when uncertainty is resolved, a median firm in the U.S. steel industry increases its market and book leverage by approximately 12% relative to a matched control firm from another industry. The results are not explained away by changes in traditional risk factors or by a change in expected future profitability.

Keywords: Knightian Uncertainty, Optimal Capital Structure, Voluntary Restraint Agreement (VRA), Difference-in-Difference

1   Introduction

> "··· there is no possibility of forming in any way groups of instances of sufficient homogeneity to make possible a quantitative determination of true probability. Business decisions, for example, deal with situations which are far too unique, generally speaking, for any sort of statistical tabulation to have any value for guidance. The concept of objectively measurable probability or chance is simply inapplicable."
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> – (Knight, 1921, p. 231)

According to Knight (1921), risk applies to situations where agents can accurately measure the odds of prospects. Uncertainty (or ambiguity), on the other hand, applies to situations where agents do not have the information necessary to assess probabilities in the first place. For example, an automobile company might forecast that the risk of producing a defective car is exactly one out of 2,000, yet it will not be able to accurately forecast the economic outlook for the automobile industry in 30 years because there are too many unknown factors to calculate. Hence, uncertainty in this sense is common in business decisions.

To financial economists, it is a puzzle that firms take on lower leverage than predicted by trade-off models of capital structure (Miller, 1977; Bradley, Jarrell and Kim, 1984; Graham, 2000). The median corporate market leverage ratio in the United States between 1990 and 2008 is around 20% (Minton and Wruck, 2001; Lemmon and Zender, 2001). The traditional models based on pure risk (not Knightian uncertainty) often predict leverage ratios in excess of 50%, given reasonable exogenous parameters (Berk and DeMarzo, 2008; Frank and Goyal, 2008).

To address this puzzle, I examine the effect of Knightian uncertainty on leverage. I incorporate a manager's ambiguity aversion into a static trade-off model. I derive the optimal capital structure when the manager faces Knightian uncertainty over the firm's future cash flows. My model shows that the amount of uncertainty and the manager's aversion toward it

lead to substantially lower leverage than the traditional counterpart. The intuition is clear. A Knightian manager is unsure about the true distribution of the next period's cash flow. Instead, she maintains a set of distributions (priors) that she thinks are plausible, and displays aversion toward this uncertainty. Her ambiguity aversion causes her to pay more attention to the outcomes of relatively pessimistic priors. Hence, the marginal cost of default increases with both the amount of uncertainty perceived by the manager and her aversion toward it, while the tax benefit of debt decreases. To balance this trade-off, the ambiguity-averse manager takes on considerably lower leverage than she would in the absence of uncertainty.

I show that there is a distinction between the effect of uncertainty and the effect of risk on leverage. A firm's optimal debt does not strictly decrease with risk. As in Bradley et al. (1984), when the firm's cash flow is highly volatile, the manager may want to increase debt to increase the value of tax shields. I show that this is true even when the manger is risk-averse. In contrast, in the presence of ambiguity, an ambiguity-averse but risk-neutral manager strictly decreases debt as the level of ambiguity rises. In particular, I show that an ambiguity-averse but risk-neutral manager takes on strictly less debt than an ambiguity-neutral but risk-averse manager, given a fixed level of risk. Therefore, uncertainty provides a more plausible explanation for firms having low leverage than risk alone.

To empirically test this prediction, I use a difference-in-difference (DID) methodology to estimate the effect of the resolution of uncertainty on leverage. I consider the 1982 Voluntary Restraint Agreement (VRA) on steel import quotas between the U.S. government and the European Community (EC) as an exogenous reduction in the amount of Knightian uncertainty faced by U.S. steel firms. Prior to this agreement, U.S. steel manufacturers faced considerable Knightian uncertainty over the outcomes of antidumping (AD) and countervailing duty (CVD) legal proceedings that they filed against European steel producers. The 1982 VRA resolved the uncertainty confronted by the U.S. steel industry in the pre-VRA period, providing an empirical setting to estimate the effect of the resolution of uncertainty on leverage.

Using the 1982 VRA, the DID panel regression is implemented. In addition to the firm

and time fixed effects, I include the time-varying observed firm characteristics in the panel regression. This is vital because the 1982 VRA not only resolves U.S. steel firms' Knightian uncertainty, but also affects other possible determinants of their leverage, such as future profitability and forward-looking risk of assets. By including the time-varying firm-specific control variables, the DID estimator of the panel regression identifies the effect of uncertainty resolution on the change of U.S. steel firms' leverage as compared to that of matched control firms, after partialing out the other accompanying effects of the 1982 VRA.

The null hypothesis is that when uncertainty is resolved by the 1982 VRA, the average change in leverage is the same for both U.S. steel firms (the treatment) and the matched control firms. The results indicate that when uncertainty is resolved by the 1982 VRA, a median firm in the U.S. steel industry increases its market and book leverage by 11.5% and 12.3%, respectively, relative to a matched control firm from another industry. These results are economically strong and statistically significant. More importantly, the results are not explained away by changes in traditional factors such as forward-looking risk, bankruptcy cost, and future profitability.

I conduct a few placebo tests in which I assume the VRA happens at different times, instead of in 1982. Steel firms and matched control firms respond similarly to the placebo shocks. In addition, following Bertrand, Duflo and Mullainathan (2004), I time-average the data before and after the 1982 VRA shock and run a difference-in-difference analysis on this averaged outcome variable. My results remain robust.

One potential concern is that the U.S. steel firms may have lobbied for the enactment of the 1982 VRA. If leverage (the outcome variable) is a direct reason for the passage of the VRA, this poses a threat to the internal validity of the difference-in-difference (DID) methodology. However, any lobbying by steel firms is likely driven by concerns over profitability rather than issues related to leverage alone. Then, as long as the profitability of a firm is included in the DID panel regression as a firm-specific control variable, the DID estimator identifies the effect of the resolution of uncertainty on a steel firm's leverage. Moreover, the U.S. government

independently had a strong incentive to negotiate the VRA with the EC, even absent any lobbying by steel firms. The U.S. government had a concurrent dispute with the EC over a natural gas pipeline from the Soviet Union to Western Europe (the Trans-Siberian Pipeline). The U.S. government believed that the punitive duties on steel imports would make talks over the pipeline issue even more problematic and impede cooperation with Europe (Moore, 1996). During the Cold War (1947-1991), the U.S. government saw it as a critical security issue (The Weinberger Paper, Pentagon Report, 1981). Therefore, I argue that the 1982 VRA may be treated as exogenous to the leverage of U.S. steel firms.

There is a long-standing body of research that attempts to explain the low-leverage puzzle. A number of recent dynamic trade-off models have been able to predict lower optimal leverage ratios (Goldstein, Ju and Leland, 2001; Morellec, 2004; Strebulaev, 2007). The dynamic trade-off models that incorporate endogenous investment are also able to predict lower optimal leverage ratios (Hennessy and Whited, 2005, 2007; DeAngelo, DeAngelo and Whited, 2011). These models represent an important step toward explaining the low-leverage puzzle. My contribution is to propose a simple model that provides a plausible new reason (a manager's ambiguity aversion) for firms having low leverage. A second contribution of this paper is to present empirical evidence that suggests the effect of uncertainty on leverage is economically and statistically strong, adding to what we know of the empirical determinants of leverage (e.g., Titman and Wessels, 1988; Rajan and Zingales, 1995; Lemmon, Roberts and Zender, 2008). My results suggest that the amount of uncertainty perceived by a firm is an important determinant of leverage.

The Ellsberg paradox (Ellsberg, 1961) illustrates the Knightian distinction between risk and ambiguity. In experiments, agents are typically ambiguity-averse: they prefer a risky bet to an uncertain one.[1] Gilboa and Schmeidler (1989) show that the Ellsberg paradox can be resolved by using multiple priors and a maxmin objective. An ambiguity-averse agent computes expected utility under the worst-case scenario among the priors that he

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[1]Details about the Ellsberg paradox are in Appendix A.

thinks are possible. Klibanoff, Marinacci and Mukerji (2005; henceforth, KMM) extend the multiple priors model to allow smooth preferences toward ambiguity. Their model provides a separation between the attitude toward ambiguity and the amount of the ambiguity itself. In this paper, I use the KMM framework to model the amount of ambiguity perceived by a manager and her aversion toward it.

In Section 2, I begin by providing an outline of the smooth ambiguity aversion model proposed by KMM. Then, I consider a simple static trade-off model of capital structure and incorporate the manager's ambiguity aversion into the model to derive the firm's optimal capital structure. I also consider the relevant comparative statics of the ambiguity-aversion augmented model. In Section 3, I describe the nature and the timing of 1982 VRA, provide the details of the difference-in-difference methodology, as well as the construction of the matched sample. The main empirical results are presented in Section 4. In Section 5, I perform robustness checks for the results. Section 6 concludes.

2 Theory: Trade-off Model with a Manager's Ambiguity Aversion

2.1 Smooth Ambiguity Aversion Preference

In this section, I provide a brief review of KMM's smooth ambiguity aversion model. For clear exposition, I introduce a discrete version of the KMM model. Consider an agent who cares about the realization of a random variable X. The agent is uncertain about the true distribution of X. He maintains $\Pi = \{F_1, \cdots, F_n\}$ as the set of distributions he thinks are plausible as the true distribution for X. It is evident that if Π is a singleton, then there is no ambiguity about the distribution of X. The agent attaches his own subjective belief μ_i to F_i in Π, being the true distribution of the random variable X.

The smooth ambiguity aversion preference is expressed as follows: First, the agent evaluates all possible first-stage expected utilities of X corresponding to a distribution F_i in

Π. He gets a set of the (first-stage) expected utilities, each being indexed by i.

$$\text{Step 1:} \qquad \int u(x)dF_i \qquad \text{each } F_i \in \Pi$$

where $u(\cdot)$ is a usual Bernoulli utility function. Second, the agent transforms each first-stage expected utility by an increasing function $\phi(\cdot)$.

$$\text{Step 2:} \qquad \phi\left(\int u(x)dF_i\right) \qquad \text{each } F_i \in \Pi$$

Finally, the agent obtains the second-stage expectation $V(x)$ by averaging the transformed first-stage expected utilities by his subjective belief μ_i attached to a corresponding F_i in Π for $i = \{1, \cdots, n\}$.

$$\text{Step 3:} \qquad V(x) := \sum_{i=1}^{n} \mu_i \cdot \phi\left(\int u(x)dF_i\right) \tag{1}$$

In this representation, the agent's preference is "an expected utility over expected utilities."

The role of the function $\phi(\cdot)$ in Step 2 is critical. The shape of $\phi(\cdot)$ describes the agent's attitude toward ambiguity, analogous to the attitude toward risk characterized by the shape of utility function $u(\cdot)$. In particular, if $\phi(\cdot)$ is concave, the agent evaluates the final stage expectation of the concave transformed first-stage expected utilities. As with risk aversion, the concave transformation reflects his aversion to ambiguity; he attaches a larger weight to lower first-stage expected utility. If $\phi(\cdot)$ is convex, as with risk seeking, the agent tends to put a higher weight on higher first stage expected utility. Accordingly, he displays ambiguity-seeking behavior. On the other hand, the amount of ambiguity is characterized by the dispersion of the set of priors Π. KMM emphasize that such separation is a distinction of their model from other models, including the multiple priors model.[2]

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[2]In the max-min model, the manager always chooses the worst-case prior in Π. Hence, the dispersion of Π represents both the amount of ambiguity and the attitude toward it. If the manager is infinitely ambiguity-averse, the smooth ambiguity model in effect coincides with the multiple priors model (Klibanoff et al., 2005).

2.2 Trade-off Model with Ambiguity Aversion

2.2.1 The Model

The model is based on a standard trade-off model (Kraus and Litzenberger, 1973; Bradley et al., 1984). The firm's leverage is determined by a single period trade-off between the tax benefit of debt and the deadweight costs of bankruptcy. Investors are assumed to be risk- and ambiguity-neutral. The firm faces a constant marginal tax rate on end-of-period cash flow. If the firm is unable to make the promised debt payments, it incurs deadweight financial distress costs. If the cash flow is negative, due to limited liability, no debt is paid. If the cash flow is positive but not enough to cover the debt payment B, the firm defaults. There is a deadweight loss of kX in the process. When the cash flow is enough for the firm not to default, equity holders receive $(X - B)(1 - \tau)$.

Suppose the firm's next period cash flow (X) has a distribution $F(x)$. Then, the market value of debt is:

$$D(B) = \left(\frac{1}{1+r}\right)\left(\int_0^B x(1-k)\,dF(x) + \int_B^\infty B\,dF(x)\right) \tag{2}$$

and the market value of equity is:

$$E(B) = \left(\frac{1}{1+r}\right)\left(\int_B^\infty (1-\tau)(x-B)\,dF(x)\right), \tag{3}$$

where r is a risk-free rate. The levered firm value is the sum of the market value of equity and the market value of debt:

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\begin{aligned}
V(B) \;=\;& D(B) + E(B) \\[2mm]
=\;& \frac{1}{1+r}\left(\underbrace{\int_0^\infty (1-\tau)x\,dF(x)}_{\text{Unlevered firm value}} - \underbrace{\int_0^B k\,x\,dF(x)}_{\substack{\text{Deadweight loss} \\ \text{due to bankruptcy}}} + \underbrace{\tau\int_B^\infty B\,dF(x) + \tau\int_0^B x\,dF(x)}_{\text{Tax benefit from debt}}\right).
\end{aligned}
$$

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I assume that a manager faces Knightian uncertainty and is averse toward it. However, I assume that she is still risk-neutral.[3] As a Knightian decision maker, the manager is uncertain about the true distribution of cash flow, $F(x)$. Instead, she maintains Π, a set of all possible distributions $\{F_i(x)\}_{i=1}^n$ that she thinks are plausible as the true distribution for the cash flow. She associates the subjective belief μ_i to each $F_i(x)$ in Π. When making a decision about the optimal leverage, the manager considers the expected firm value for each F_i and displays an aversion to ambiguity, characterized by the concave function $\phi(\cdot)$. Because of her ambiguity aversion, she assigns higher weights to firm values with relatively pessimistic priors in Π. Therefore, she makes a lower leverage decision than in the absence of ambiguity. When Π is a singleton, the manager is absolutely sure about the true distribution of cash flow, thereby the model becomes a traditional single-period static trade-off model.

Precisely, the manager chooses the optimal leverage to maximize firm value by applying the smooth ambiguity-averse preference:

$$\max_{B>0} \underbrace{\sum_{i=1}^n \phi(V(B|F_i)) \cdot \mu_i}_{=\mathbb{E}^\mu\left[\phi(V(B|F))\right]}. \tag{4}$$

Here, I slightly abuse the notation. $V(B|F_i)$ is the levered firm value when it takes the debt amount B given a distribution $F_i(x)$ in Π.

The first-order condition is:

$$\mathbb{E}^\mu\left[\phi'(V(B|F))\frac{\partial V(B|F)}{\partial B}\right] = 0. \tag{5}$$

As usual, the optimal debt level B can be obtained by solving (5) for B.

Lemma 1 states that when the ambiguity-averse manager chooses the optimal debt, she

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[3]A manager's risk-neutrality is assumed in order to clearly demonstrate the effect of a manager's uncertainty and her aversion toward it on the leverage decision. The model can be extended, at the cost of computational complexity, to incorporate the risk- *and* ambiguity-averse manager who may take on lower leverage than the risk-neutral and ambiguity-averse manager.

behaves as if she were ambiguity-neutral but pays more attention to relatively pessimistic priors. It is a special case of Proposition 5 of Rigotti, Shannon and Strzalecki (2008).

Lemma 1 (Existence)**.** *The first-order condition* (5) *is equivalent to:*

$$\mathbb{E}^{\mu}\left[\phi'(V(B|F))\frac{\partial}{\partial B}V(B|F)\right] = \mathbb{E}^{\mu^*}\left[\frac{\partial V(B|F)}{\partial B}\right] = 0. \tag{6}$$

Formally, given her subjective belief μ to the set Π of priors, there exists a Radon-Nykodym derivative Z such that:

$$d\mu^* = Z \cdot d\mu, \tag{7}$$

where:

$$Z = \frac{\phi'(V(B|F))}{\mathbb{E}^{\mu}(\phi'(V(B|F)))} \qquad and \qquad \mathbb{E}^{\mu}Z = 1.$$

Proof. See Appendix B.1. □

The belief μ^* is interpreted as an adjusted belief: the subjective belief μ is adjusted by $\phi'(V(B|F))$. I refer to μ^* as an ambiguity-adjusted belief in the following sense. In a case where the manager's subjective belief μ on Π is assumed to be uniform (i.e., she thinks all distributions in Π are equally likely), her ambiguity aversion forces her to put the largest weight on the worst-case prior that yields the highest marginal value $\phi'(\cdot)$. Note that Lemma 1 states the *existence*, not the *uniqueness* of a density Z. I thus obtain the following corollary to Lemma 1.

Corollary 1. *The optimality condition* (6) *becomes:*

$$kB \cdot \mathbb{E}^{\mu^*}[f(B)] = \tau\left(1 - \mathbb{E}^{\mu^*}[F(B)]\right), \tag{8}$$

where $\mathbb{E}^{\mu^*}[f(x)] = \sum_{i=1}^{n}\mu_i^* \cdot f_i(x)$, a mixture of densities $f_i(x)$ with ambiguity adjusted belief μ_i^*.[4]

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[4]When the manager is absolutely sure about the distribution $F(x)$ (i.e., the set Π is a singleton), then the

Proof. See Appendix B.2. ☐

The intuition of Corollary 1 is as follows. The Knightian manager is uncertain about the true probability density ($f(B)$). Instead, she finds the set of densities that she thinks are plausible ($\{f_i(B)\}_{i=1}^{n}$) and averages them with her ambiguity-adjusted belief ($\mathbb{E}^{\mu^*}[f(B)]$). Similarly, she also maintains the set of distributions of the firm being solvent ($\left\{\int_B^\infty f_i(x)dx\right\}_{i=1}^{n} = \{1 - F_i(B)\}_{i=1}^{n}$), then obtains the ambiguity-adjusted distribution of the firm being solvent ($1 - \mathbb{E}^{\mu^*}[F(B)]$). The optimality condition (8) means that the ambiguity-adjusted marginal cost of default and the ambiguity-adjusted marginal tax benefit of debt must be equal.

2.2.2 Comparative Statics of the Optimal Leverage

I next determine two comparative statics of the optimal leverage with respect to the amount of uncertainty perceived by the manager and degree of her aversion toward it.

The amount of uncertainty perceived by the manager is measured by the dispersion of Π. I denote it as δ. In this section, I assume that all distributions in Π are Gaussian and the variance of them is common and known; therefore, the manager is unsure only about the mean of the distribution for the firm's cash flow. Then, the dispersion of Π (i.e., δ) is defined as $\max |\theta_i - \theta_j|$ for all $i \neq j$, where θ_i is the mean parameter of distribution F_i in Π.[5]

Meanwhile, the degree of a manager's ambiguity aversion is characterized by the degree of concavity of $\phi(\cdot)$. Following KMM, I assume that the manager displays constant absolute ambiguity aversion (CAAA). That is,

$$\phi(x) = \begin{cases} 1 - e^{-\alpha x} & \alpha > 0 \\ x & \alpha = 0 \end{cases} \tag{9}$$

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optimality condition (8) becomes the usual first-order condition:

$$\frac{\partial V(B)}{\partial B} = kBf(B) - \tau(1 - F(B)) = 0,$$

because when Π is a singleton, μ becomes degenerate, therefore $f^*(x)$ is $f(x)$.

[5]In general, the dispersion of Π can be characterized by the maximum statistical distance $\mathcal{D}(\cdot||\cdot)$ between any two distributions in Π, $\max \mathcal{D}(F_i||F_j)$ for all $i \neq j$ in $\{1, \cdots, n\}$.

where the parameter α is the coefficient of absolute ambiguity aversion such that:

$$\alpha = -\frac{\phi''(x)}{\phi'(x)}.$$

Similar to the coefficient of risk aversion, α represents the degree of concavity of $\phi(\cdot)$, and therefore represents the degree of the manager's ambiguity aversion.

Proposition 1 states that (a) while keeping the amount of uncertainty fixed, as the manager's ambiguity aversion rises, she may reduce the optimal level of debt, and (b) while keeping the manager's ambiguity aversion fixed, as the amount of uncertainty she faces increases, she may reduce the optimal level of debt.

Proposition 1. *(a) Ceteris paribus, the optimal amount of debt B that satisfies the first-order condition* (8) *decreases with α, the manager's degree of ambiguity aversion. That is,*

$$\frac{\partial B}{\partial \alpha} < 0.$$

(b) Also, the optimal amount of debt B decreases with the amount of uncertainty that the manager perceives. Let the amount of uncertainty be δ. Then,

$$\frac{\partial B}{\partial \delta} < 0.$$

Proof. See Appendix B.3. $\qquad\square$

The intuition is as follows. By Lemma 1 (therefore, Corollary 1), as ambiguity aversion (α) increases, the manager puts higher weight on relatively pessimistic priors in Π. Hence, given an optimal debt level B, as α increases, the ambiguity-adjusted marginal cost of default ($kB \cdot \mathbb{E}^{\mu^*}[f(B)]$) increases, while the ambiguity-adjusted marginal tax benefit of debt ($\tau\left(1 - \mathbb{E}^{\mu^*}[F(B)]\right)$) decreases. To balance this trade-off, the manager must optimally reduce the amount of debt.

Figure 1 illustrates a numerical example of the comparative statics of the optimal leverage

ratio with respect to the manager's degree of ambiguity aversion (Proposition 1-(a)).[6] The optimal leverage ratio is defined as:

$$\text{Leverage ratio} = \frac{B^*}{E(B^*) + B^*}, \tag{10}$$

where B^* is the optimal amount of debt computed from the first-order condition (8), and $E(B^*)$ is the market value of equity at B^* using (3). The computation details are in Appendix C.

Next, as the amount of uncertainty (δ) increases, the pessimistic prior in Π gets worse (i.e., shifted left). According to the optimality condition (8), the ambiguity-adjusted marginal cost of default ($kB\mathbb{E}^{\mu^*}[f(B)]$) increases with δ, while the ambiguity-adjusted marginal tax benefit of debt ($\tau\left(1 - \mathbb{E}^{\mu^*}[F(B)]\right)$) decreases. Therefore, the ambiguity-averse manager must optimally reduce the optimal level of debt to balance this trade-off. Figure 2 illustrates a numerical example of the comparative statics of the optimal leverage ratio with respect to the variation in the amount of uncertainty (Proposition 1-(b)). The computation details are in Appendix C.

In short, from Proposition 1-(b) (see also Figure 2), the effect of uncertainty on leverage is clear. As uncertainty increases, leverage *strictly* decreases.

One can ask whether risk aversion without invoking ambiguity aversion is a sufficient explanation why firms take on low leverage. Qualitatively, the effects of uncertainty and risk on leverage are similar. Because the certainty equivalent of the risk-averse manager decreases with risk, a risk-averse manager also tends to employ lower leverage than a risk-neutral manager. Quantitatively, however, the effect of uncertainty on leverage is higher than that of risk. Moreover, the risk-averse manager's optimal choice of leverage does not strictly decrease with the risk of cash flow. On the other hand, the ambiguity-averse manager's choice of

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[6]The market value of equity $E(B)$ in equation (3) decreases with the level of debt (B) (i.e., $\frac{\partial E(B)}{\partial B} < 0$; thought experiment is: start with unlevered firm, issue debt with promised payment B and buy back equity). Hence, the leverage ratio in equation (10) increases with B. Therefore, there is a one-to-one and onto relation between the comparative statics of the optimal level of debt and those of the optimal leverage ratio.

leverage strictly decreases with uncertainty.

I first show that the optimal level of debt does not strictly decrease with risk, even when the manager is risk-averse.

Proposition 2. *For a risk-averse but ambiguity-neutral manager, there exists a level of risk, $\overline{\sigma}$, such that (i) the optimal debt, B, strictly decreases with risk when the current risk is lower than $\overline{\sigma}$,*

$$\frac{\partial B}{\partial \sigma} < 0 \qquad if \qquad \sigma < \overline{\sigma}$$

(ii) the optimal debt, B, increases or remains the same with increasing risk when the current risk is higher than $\overline{\sigma}$,

$$\frac{\partial B}{\partial \sigma} \geq 0 \qquad if \qquad \sigma \geq \overline{\sigma}$$

Proof. See Appendix B.4. $\overline{\sigma}$ is a solution of the integral equation (B.4) in Appendix B.4.   □

The intuition is as follows. When a firm's cash flow is less volatile, an increase in risk sufficiently increases the marginal cost of default, but decreases the marginal tax benefit at the current optimal level of debt. Therefore, the manager must decrease the optimal level of debt to balance this trade-off. When the cash flow of a firm is highly volatile, the manager is more likely to gamble on the chance of the firm being solvent in the next period. That is, when the present risk is high, the default intensity can decrease with risk. But, the manager can gain an additional tax benefit of debt by adding an additional amount of debt, as long as the firm is still solvent in the next period. Therefore, when the firm's cash flow is highly volatile, the manager may want to increase debt to increase the value of tax shields. Bradley et al. (1984) also point out that when the manager of a firm is risk-neutral, the effect of risk on the optimal level of debt is undetermined. In Proposition 2, I show that it is true even when the manager is risk-averse.

Figure 3 illustrates numerical examples of Proposition 2. The leverage ratio at the optimal level of debt B^* is computed using (10). The middle dotted line in the figure depicts that the risk-averse but ambiguity-neutral manager's optimal leverage ratio does not strictly

decrease with risk after a certain level of risk with the reasonable proportional deadweight cost ($k = 0.4$) and marginal tax rate ($\tau = 0.35$). The computational details to generate Figure 3 are in Appendix C.

I next show that given plausible (and comparable) levels of risk aversion and ambiguity aversion, an ambiguity-averse but risk-neutral manager chooses substantially *lower* optimal leverage than a risk-averse but ambiguity-neutral manager. Figure 3 shows that when the level of volatility of a firm's cash flow is around 0.3, a risk- and ambiguity-neutral manager (the benchmark case) chooses an 85% optimal leverage ratio. In comparison to the benchmark case, an ambiguity-averse but risk-neutral manager whose CAAA coefficient (α) is 2 chooses a 48% optimal leverage ratio. On the other hand, a risk-averse but ambiguity-neutral manager whose constant absolute risk aversion (CARA) coefficient (ρ) is 1 chooses a 70% optimal leverage ratio. Note that Figure 3 illustrates a comparison between optimal leverage ratios chosen by an ambiguity-averse but risk-neutral manager and those chosen by an ambiguity-neutral but risk-averse manager. Appendix D provides the general case.

The comparability between the CAAA coefficient ($\alpha = 2$) and the CARA coefficient ($\rho = 1$) must be justified. The idea is that the ambiguity premium computed as the difference between the certainty equivalent in lieu of a risky bet and the certainty equivalent in lieu of an ambiguous bet must be reasonable (Ju and Miao, 2007; Chen, Ju and Miao, 2013). Camerer (1999) reported that the ambiguity premium is typically on the order of 10% to 20% of the expected value of a bet in the Ellsberg-style experiments (Ju and Miao, 2007). Given the evidence, the choice of a CAAA ambiguity aversion parameter ($\alpha = 2$) turns out to be reasonable with respect to that of the CARA risk aversion parameter ($\rho = 1$). The details are in Appendix A.

3 Evidence: Resolution of Uncertainty on Leverage

Unlike risk, the main difficulty of an empirical study of uncertainty arises from the fact that it is hard to directly measure.[7] Hence, I use a difference-in-difference methodology to estimate the effect of the resolution of uncertainty on leverage. I consider that the 1982 VRA on steel import quotas between the U.S. government and the EC provides an exogenous reduction in the amount of Knightian uncertainty faced by U.S. steel firms. Prior to this agreement, U.S. steel manufacturers faced considerable Knightian uncertainty over the outcomes of AD and CVD legal proceedings that they filed against European steel producers.

Prediction. *By Proposition 1-(b), when uncertainty perceived by U.S. steel firms is resolved by the 1982 VRA, steel firms increase leverage relative to (matched) control firms in the post-VRA period.*

In Section 4, I show that the empirical results indeed support the prediction: When uncertainty is resolved by the 1982 VRA, a median firm in the U.S. steel industry increases its market and book leverage by 11.5% and 12.3%, respectively, relative to a matched control firm from another industry. These results are economically strong and statistically significant. Moreover, the results are not explained away by changes in traditional determinants of leverage including forward-looking risk and future profitability.

In the following section, I provide the details of the nature and the timing of the 1982 VRA.

3.1 1982 VRA Impact on U.S. Steel Imports

In January 1982, U.S. steel companies filed a large number of AD and CVD petitions against European steel producers due to a substantial increase in imports from the EC (February 14,

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[7]In the literature, it is a common practice to calibrate an ambiguity-aversion parameter of a model to match data (see Maenhout (2004), Hansen, Sargent, Turmuhambetova and Williams (2006), Ju and Miao (2007), and references therein). The exceptions include Lee (2012) and Izhakian (2013). In Lee (2012), I propose a new measure of Knightian uncertainty and find that there is an economically sizeable and statistically significant negative relationship between uncertainty and leverage.

1982, *The New York Times*). According to the World Bank's AD/CVD database, on January 11, 1982, major U.S. steel manufacturers including Bethlehem Steel, U.S. Steel, Republic Steel, Inland Steel, Jones and Laughlin Steel, National Steel, and Cyclops Steel filed 33 AD and 61 CVD petitions against eight EC countries.

However, the AD and CVD laws were long and cumbersome for U.S steel firms. These laws require the complainant to do an enormous amount of investigation simply to file a complaint (Range, 1980, p. 283). Once a complaint is filed, the International Trade Administration (ITA) that administers the law has considerable discretion over whether it will pursue the complaint. Even if the ITA agrees to do so, the complainant must go through long and costly procedures (Solomon, 1978, Section 2). Both the formulation and investigation of a complaint are likely to be impeded by the foreign producers reluctance to provide sensitive data to the ITA (Solomon, 1978, footnote 12). And relief, if granted, consists of the imposition of a duty rather than an award of damages to the complainant. Such relief does not necessarily benefit the complainant, because the importer can shift to other foreign producers not subject to the duties (Solomon, 1978, p. 449).

Indeed, the ITA's highly discretionary interpretation of AD and CVD laws results in highly arbitrary injury determinations (Caine, 1981). Part of the reason is that the ITA often lacks the critical information needed to determine the fairness of an exporter's selling price.[8] Accordingly, the ITA is regularly forced to make subjective accounting determinations (Harvard Law Review, 1983; Solomon, 1978). An example of the arbitrariness of this process is provided by the wide disparity between injury determinations calculated by the ITA in its preliminary CVD proceedings and those calculated in its final proceedings in the steel cases. For instance, in June 1982 the margin of subsidy found by the ITA for the British Steel Corporation was 40.4%, but in August 1982 the margin was 20.3% (August 26, 1982,

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[8]For the fair value calculation, it is necessary to make adjustments for differences in the physical characteristics of the merchandise in the markets being compared, differences in the quantities being sold, as well as differences in the circumstances of the sale (the credit terms, grantees, technical assistance, advertising, and services being provided by the seller). In addition, fluctuations in exchange rates must be considered.

The New York Times).[9] Hence, although the steel firms know that the cases will resolve, they are unsure of the likelihood of the outcomes because of the discretionary scope and arbitrariness of the ITA's decision process. Therefore, I suggest that the U.S. steel industry in the pre-VRA period was likely to face a high degree of Knightian uncertainty.

One potential concern is that the intervention-seeking steel industry may have lobbied for the 1982 VRA. One can ask whether or not this is a potential threat to the internal validity of the difference-in-difference methodology. However, I argue that the 1982 VRA is not an event driven by the U.S. steel firms' lobbying because the U.S. government had strong incentives to negotiate the VRA with the EC. It wanted to avoid the open-ended and prohibitive duties on many European steel exports. Complicating matters was a concurrent dispute with the EC over a natural gas pipeline from the Soviet Union to Western Europe (the Trans-Siberian Pipeline) (Moore, 1996).[10]

During the Cold War, the U.S. government worried that the Trans-Siberian Pipeline would make the EC dangerously dependent on Russian energy sources and that the earnings flowing from Western Europe to the Soviet Union would relieve many of the Soviet's economic problems, increasing the Soviet's military strength. Increased Soviet strength was likely to significantly add to the U.S. defense burden (The Weinberger Paper, Pentagon Report, 1981).[11] To impede the growth of the Soviet's military power and economic leverage, the U.S. government strongly opposed the construction of the Trans-Siberian Pipeline. It embargoed U.S. companies' selling supplies for the pipeline's construction and asked their European allies to deny supplying parts for it. Unexpectedly, in mid-1982, Britain and France defied the Reagan Administration's sanctions, insisting that the contract between the Soviet Union and European companies had to be honored (January 11, July 9, August 3, and September 2, 1982,

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[9]In addition, the decisions of laws are not strictly enforceable, if favorable to the complainant. As stated in *The New York Times* (August 5, 1982): "Ian MacGregor, chairman of the British Steel Corporation, insisted that if the American decision to impose stiff duties on steel imports from Common Market countries went into effect, he would take legal action to overturn it."

[10]The Trans-Siberian Pipeline project was first proposed in 1978 and was constructed in 1982-1984. It created a transcontinental gas transportation system from western Ukraine to Central and Western European countries (Hardt, 1982).

[11]Declassified 2004. http://www.margaretthatcher.org/document/110933.

The New York Times). The U.S. government believed that punitive duties on steel exports would make talks over the pipeline issue even more problematic and impede cooperation on what it viewed as a critical security issue (The Haig Paper, Department of State Report, 1981).[12]

Moreover, a VRA program provides distinct political advantages for the U.S. government over AD/CVD duties or legislative quotas.[13] A VRA program insures that the government would retain control over trade policy decisions. Such discretion would not have been possible if final AD and CVD had been imposed.[14] A VRA program also enables the government to control the timing of protection offered to industry. Unlike AD/CVD, it specifies an expiration date (Caine, 1981).[15] In addition, the free-market Reagan Administration could assert to the public that the government did not impose the tariffs but negotiated the agreement, to retain their free-trade rhetoric. From the Europeans' perspective, they also had an incentive to negotiate with the U.S. According to Viscount Davignon, the Commissioner of Industry for the European Economic Community, "the ceiling is preferable to the duties because the duties would have reduced trade to a trickle and cost thousand of jobs in the Europe" (October 22, 1982, *The New York Times*). These factors strongly induced the U.S. to enter negotiations with the EC for the 1982 VRA (Moore, 1996).

In addition, empirical evidence that the 1982 VRA was driven by the steel firms' lobby is weak. Theoretically, the steel industry has attributes consistent with successful lobbying characteristics: relatively small numbers of actors in the group and loyal unionization. Empirically, however, measures of lobbying power, such as concentration and unionization,

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[12]Declassified 2004. http://www.margaretthatcher.org/document/110934.

[13]The Reagan Administration preferred VRA to legislative quotas. First, VRAs were perceived as less rigid and less permanent than legislative quotas. Second, the Administration feared that, once the Congress gave favorable treatment to one industry, it would be likely to provide comparable benefits to the other industries. Third, a VRA would provide a way of circumventing the General Agreement on Tariffs and Trade's (GATT) prohibition of quotas or would at least reduce the danger of retaliation by other countries under GATT (Lowenfeld, 1983; Harvard Law Review, 1983).

[14]The ITA can impose the final duties without any direct involvement of either the president or any other elected officials (Harvard Law Review, 1983) [see also Anderson (1993) for the empirical evidence].

[15]Duties can remain indefinitely subject to a five-year review. Article 11 of GATT 1994 states "anti-dumping duty shall remain in force only as long as and to the extent necessary to counteract dumping which is causing injury."

are poor explanatory variables for obtaining the government's protection (see Trefler 1993; Markusen 1996). The empirical findings documented in Trefler (1993) refer to general government protections rather than VRAs, in particular. However, whether the steel industry's lobbying was effective for the 1982 VRA is empirically questionable, if theoretically probable. Therefore, I claim the 1982 VRA is exogenous to U.S. steel firms' leverage because it was most likely implemented by the U.S. government.

The VRA for the U.S. steel industry went into effect on October 22, 1982. Its effect was comprehensive and immediate, limiting EC exports to 5.5% of the U.S. market beginning November 1, 1982 (October 22, 1982, *The New York Times*). In return, U.S. firms immediately dropped their unfair trade petitions and agreed to refrain from filing new cases until the VRA expired in January 1986. The VRA allowed U.S. firms to avoid further litigation costs and provided protection against all EC imports rather than a subgroup only (Moore, 1996). The large uncertainty perceived by the U.S. steel industry during the pre-VRA period was immediately resolved by the announcement of the 1982 VRA. In the absence of the VRA, the U.S. steel industry would have gone through cumbersome legal AD and CVD proceedings, whose effective outcomes would be highly uncertain in the Knightian sense.

3.2 Empirical Strategy and Sample Selection

3.2.1 Data

The data set used for the study consists of all nonfinancial firm-year observations in the annual Compustat database from 1971 to 2004. The period between 1978 and 1987 is for the 1982 VRA analysis and other periods are used for the placebo tests. In particular, the period from 1978 to 1982 is designated as the pre-VRA period, while the period from 1983 to 1987 is designated as the post-VRA period. I also require that all firm-year observations have valid data for book assets. All ratios are trimmed at the upper and lower one percentile to mitigate the effect of outliers and eradicate errors in the data. To incorporate the future expected profitability of a firm, I obtain median analyst forecasts of a firm's next-year earnings per

share (EPS) from the IBES database and merge them with the accounting information obtained from the annual Compustat data files.

The variable definitions are in Table 1. The definitions are standard except for the time-varying forward-looking asset volatility. Following Faulkender and Petersen (2006, p. 60), I infer the time-varying asset volatility from the volatility of monthly equity returns. Departing from Faulkender and Petersen, I use the GARCH model to estimate the time-varying volatility of equity returns at a monthly frequency, because the GARCH-based asset volatility estimate is a more accurate forward-looking risk measure than the historical standard deviation approach. The GARCH model emphasizes a recent surprise close to the study event; therefore, it incorporates the realized asset volatility, as well as the forward-looking asset volatility when the 1982 VRA news arrives. The details of measuring the asset volatility using the GARCH model are in Appendix E. Alternatively, in Section 5.2, I measure time-varying forward-looking asset volatility by calculating implied asset volatility using the Merton (1974) model following the procedure of Vassalou and Xing (2004, p. 835) and Bharath and Shumway (2007, p. 1345). The implied asset volatility and GARCH type of asset volatility are often used as measures for forward-looking risk of assets' cash flow.

Distinguishing between the effect of risk and uncertainty is a critical study of this paper. A competing hypothesis against Knightian uncertainty is based on risk: The 1982 VRA reduces a U.S. steel firm's forward-looking asset risk, which completely explains away an increase in a steel firm's leverage in the post-VRA period. If the risk-based competing hypothesis is accurate, after controlling the forward-looking asset risk of a U.S. steel firm, the estimated effect of the resolution of uncertainty in the post-VRA period should be statistically insignificant and/or its economic strength should be negligible. To rule out the risk-based competing hypothesis, a careful measurement of asset volatility is necessary.

3.2.2 Difference-in-Difference

The 1982 VRA is assumed to provide the resolution of uncertainty faced by U.S. steel firms in the pre-VRA period, which is exogenous to the leverage decision of U.S steel producers. Precisely, the difference-in-difference (DID) panel regression used to estimate the effect of the resolution of uncertainty on U.S. steel firms' leverage is:

$$Y_{it} = \alpha_t + \alpha_i + \beta D_{it} + \Gamma' X_{it} + u_{it} , \tag{11}$$

where α_t, α_i, and X_{it} are the firm-specific controls: α_t represents the time fixed effect, α_i the time-invariant firm fixed effect, and X_{it} the time-varying observed firm characteristics. The panel length is 10 years: The period from 1978 to 1982 is designated as the pre-VRA period, while the period from 1983 to 1987 is the post-VRA period. The treatment group includes all U.S. steel producers. Three-digit SIC codes are used to identify the steel manufacturers (331, 332) except firms producing non-ferrous metals, which are not covered under the 1982 VRA. For the control group, I select from non-steel U.S. industries a subset of firms similar to the steel firms in the pre-VRA firm characteristics. I use the standard propensity matching method for the selection of control firms.

The post-VRA (i.e., post-treatment) indicator variable D_{it} takes a value of one if a firm belongs to the U.S. steel industry in the post-VRA period (1983-1987). A vector of time-varying observed firm-specific controls X_{it} includes firm size, profitability, tangibility, market-to-book ratio, time-varying asset volatility, annual stock return, and median analyst's forecast of profitability in year $t + 1$. Y_{it} is the response variable: market leverage and book leverage. The error term u_{it} is allowed to be serially correlated within firms and is possibly heteroscedastic (Bertrand et al. 2004; Petersen 2009).

Selecting firm size, profitability, tangibility, and market-to-book ratio as firm-specific control variables is standard in the empirical capital structure literature (Rajan and Zingales 1995; Fama and French 2002; Leary and Roberts 2005). The rationale to include the other

control variables is as follows. When good news arrives to the stock market, the steel industry's stock prices tend to increase. Market leverage is defined as total debt divided by the sum of total debt and the market value of equity. Hence, an increase in a firm's stock price mechanically decreases its market leverage (Welch, 2004). When protected by the VRA, the U.S. steel industry is expected to be less competitive. Combined with the fact that the VRA provides a fixed term of protection, the future profitability of steel firms likely increases, while the future operating risk of the steel industry likely diminishes in the post-VRA period. To control these level effects, I include firm-specific annualized stock returns, median analyst forecast of next year's profitability, and forward-looking asset volatility as control variables.

Importantly, the 1982 VRA not only resolves U.S. steel firms' uncertainty, but also affects other possible determinants of their leverage. Precisely, the variable D_{it} (i.e., the enactment of the VRA) correlates with X_{it} in the post-VRA period. However, by including the time-varying firm-specific control variables, the estimator $\widehat{\beta}$ of the model in equation (11) identifies the effect of uncertainty resolution on the change of U.S. steel firms' leverage as compared to that of matched control firms, *after partialing out the other accompanying effects of the VRA described above.*

3.2.3 Constructing the Matched Sample

The imbalance and lack of overlap of distributions of the pre-treatment (i.e., the pre-VRA) firm-specific characteristic variables across the two groups are also sources of concern for the correct estimation of the effect of uncertainty resolution provided by the 1982 VRA. One must compare treatment and control groups that are as similar as possible in observable pre-treatment firm characteristics. If the two groups have very different pre-treatment firm characteristics, the prediction of counterfactual for the treatment group will be made using firm information from the control group that looks very different from the treatment group (likewise for the prediction of counterfactual for the control group). Any inferences regarding theses observations would have to rely on modeling assumptions in place of direct support of

the data, which leads to bias of the effect of the treatment on the outcome (Ho, Imai, King and Stuart, 2007, p. 210).[16]

Table 2 presents the comparison of the firm-specific control variables between the treatment and control group in the pre-VRA (i.e., the pre-treatment) period (1978-1982). Pre-match columns indicate that prior to matching, the means of observable pre-VRA firm characteristics in both groups are statistically different at the 5% level. Due to the imbalance of the pre-VRA firm characteristics, a simple comparison of all non-steel firms to all firms in the steel industry is suspect.

The matched sample is constructed using the standard propensity score method (Rosenbaum and Rubin, 1983).[17] In the pre-VRA period, a logit model is estimated with the binary dependent variable, which is an indicator of whether or not a firm belongs to the U.S. steel industry. Asset volatility, market-to-book ratio, annual stock return, and market leverage are the independent variables.[18] Next, I obtain the estimated propensity scores of every firm in the sample from the fitted logit model. Finally, for each firm in the U.S. steel industry, I find up to four nearest non-steel firms in terms of the predicted propensity score with a caliper (i.e., propensity score distance) 0.05 to avoid the extreme counterfactuals.[19] In addition, I restrict the sample to firm-year observations that fall in the overlap between the domains of propensity scores for the treatment and control groups (i.e., common support condition). As a result, there are 41 unique steel-producing firms in the treatment group and 146 matched-control firms.

Post-match columns in Table 2 present the results of the propensity score matching. After matching, based on the sufficiently low t-statistics, the firms in the treatment and control

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[16]See more details in Gelman and Hill (2007, Chapters 9 and 10).

[17]As a robustness check, I alternatively use Mahalanobis-metric direct matching with a caliper of 0.05 to construct the matched sample. The results are robust to this alternate matching method. The details are discussed in Section 5.2 and shown in Table 8.

[18]For a robustness check, as the independent variables, I use a different set of firm characteristics: size, profitability, tangibility, and market-to-book ratio. Table 8 shows that the results are robust to the use of alternative matching variables.

[19]I also use different caliper sizes such as 1.0 and 0.08. The unreported results are robust to these alternative sizes.

groups are statistically similar in terms of the means of each pretreatment firm-characteristic variable: tangibility, firm size, market-to-book ratio, profitability, time-varying volatility of asset, and simulated marginal corporate tax rate available from Graham (2000). The post-matching standard bias column in the table measures the difference in the means of each control variable divided by the standard deviation in the treatment group. Rubin and Thomas (2000) suggest that for reasonable balancing, the absolute standard bias of each covariate should be less than 0.25. Before matching, some of the absolute standard biases of control variables appear to be larger than 0.25. After matching, all absolute standard biases are less than 0.25. I perform the non-parametric test of the null hypothesis as to whether or not the distributions of the propensity scores of the treatment and control group are the same after matching. The substantially high p-value (0.72) suggests to accept the null hypothesis.

Figure 4 illustrates the empirical distributions of each pre-treatment firm characteristic variable across the two groups after matching. As can be seen, those distributions are comparable. In sum, after matching, the firm characteristics in the pre-VRA period are balanced across the treatment and control groups, as desired.

4   Main Results

Table 3 presents the main results of the difference-in-difference (DID) analysis with the matched sample specified in the model in equation (11). The estimated coefficient of $D(i,t)$ (i.e., the DID estimate) in the table represents the estimated effect of resolution of uncertainty on steel firms' leverage relative to matched control firms. All standard errors are computed with clustering at the firm level; thus, they are robust to heteroscedasticity and within-firm serial correlation. In Models 1 and 2, all DID estimates are positive and statistically significant at the 5% level, with sufficiently large t-statistics. That is, steel firms increase their leverage relative to matched control firms when uncertainty is resolved in the post-VRA period.

To gauge the economic strength of the effect of the resolution of uncertainty on leverage, consider a median firm in the steel industry whose market leverage is 0.48 and book leverage

is 0.26 in 1982. The estimated coefficients of D_{it} are 0.055 and 0.032, respectively. Scaling by its leverage, I find that when uncertainty is resolved, a median U.S. steel firm increases its market (book) leverage by $0.055/0.48 = 11.3\%$ ($0.032/0.26 = 12.3\%$) relative to a matched control firm from another industry. These results are economically strong.

By including the firm-specific control variables, effects accompanied by the resolution of uncertainty as a result of the 1982 VRA are absorbed by those control variables. That is, the DID estimator $\hat{\beta}$ of the model in equation (11) measures the effect of the resolution of uncertainty on U.S. steel firms provided by the VRA, after partialing out the other accompanying effects to factors of leverage from the total effect of the VRA on U.S. steel firms' leverage (relative to a matched control firm). Combined with the fact that the DID estimates are statistically significant and economically strong, the effect of the resolution of uncertainty is not explained away by changes in traditional determinants of leverage including forward-looking risk and future profitability.

The signs of estimated coefficients of the control variables in Table 3 appear consistent with standard intuitions. The size and tangibility of firms are positively related to leverage. Profitability enters with a negative sign. The estimated coefficient of median analyst forecast of earnings per share as a proxy for next year's profitability is negative and statistically significant at the 5% level. The negative sign on profitability seems counterintuitive to the standard trade-off theory. However, empirical studies typically find a negative relation between profitability and leverage [see Frank and Goyal (2008) and the references therein]. The market-to-book ratio is negatively related to market leverage; it is consistent with trade-off theories because growth firms lose more of their value when they go into distress. By definition, market leverage is inversely related to an increase in the market value of equity (Welch, 2004). Hence, it seems reasonable that a firm's stock return is also negatively related to its market leverage. Forward-looking asset volatility is also negatively related to leverage. It is also consistent with trade-off theories because firms with more volatile assets will have higher probabilities and expected costs of bankruptcy.

Models 3 and 4 in Table 3 present the results when the excess price-cost margin of a firm (i.e., Modified Lerner index) is included as an additional control variable for the firm-level market power. The modified Lerner index of a firm is computed as the difference between a firm's price-cost margin (i.e., Lerner index) and the average operating profit margin of its industry. The price-cost margin is defined as sales minus cost of goods sold minus selling, general, and administrative expenses divided by total assets (Gaspar and Massa, 2006). The estimated coefficient of the modified Lerner index is positive, although statistically insignificant at the 10% level. When the steel industry is protected by import quotas, these firms face less competition and the price-cost margin of a steel firm increases accordingly. The steel firms facing a less risky environment tend to take on more leverage. Therefore, there is likely a positive relation between the modified Lerner index of a firm and its leverage.

One of the key necessary assumptions for the internal validity of the DID methodology is the parallel-trends assumption (Roberts and Whited, 2011). In the absence of the 1982 VRA, the average change in leverage would have been the same for both the treatment and control groups. Because I never observe the true error terms u_{it} of the model in equation (11), I cannot perform the formal statistical test to ensure the necessary and sufficient conditions for the parallel-trends assumption. However, it is still possible to check the necessary condition by comparing trends in the outcome variable across the treatment and control groups in the pre-treatment period (Roberts and Whited, 2011). Since I have multiple pre-treatment firm-year observations (1979-1982), I can perform a two-sample test to compare the average growth rates (average slopes) of the treatment and matched control groups.

Table 4 presents the results. For example, in the second row, the difference in the means of market-leverage growth rate of the two groups in 1979-1980 is 0.044. The high p-value from the two-sample t-test shows that the difference is statistically insignificant. In addition, the sufficiently high p-value from rank-sum test also shows the distributions between the market-leverage growth rate of the treatment and control groups are statistically indistinguishable. All tests indicate that the average trends of leverage of the treatment and control groups in

the pre-VRA period are statistically similar, based on sufficiently high p-values of both t-tests and rank-sum tests. Statistically, the necessary condition for the parallel-trends assumption appears to be satisfied, as desired.

Figure 5 also depicts that the parallel-trends assumption is satisfied. The figure illustrates the average market-leverage trends of the treated (i.e., U.S. steel firms) and the matched control firms. In the pre-VRA period (1979-1982), the trends across the two groups seems parallel. It is expected from the results of the formal statistical tests presented in Table 4. In the post-VRA period (1983-1987), the two lines diverge noticeably. While the mean market leverage of the matched control group remains stable, that of the treatment group sharply increases. Note that to generate this figure, I require that all firms in the two groups have full firm-year observations in the pre- and post-VRA periods (10 years).

Because the VRA can cause indirect effects on U.S. steel firms' leverage by affecting other determinants of leverage than uncertainty in the post-VRA period (i.e., D_{it} can be correlated with X_{it} in the post-VRA period), one may want to examine the differential between such indirect effects and the effect of the resolution of uncertainty on U.S. steel firms' leverage. Recall that Table 2 shows the pre-VRA firm characteristics of the treatment and the matched control groups are statistically indistinguishable. If the post-VRA firm characteristic variables across the two groups are also statistically indistinguishable, it implies that the VRA seldom affects U.S. steel firms' post-VRA characteristic variables. Therefore, the accompanying indirect effects becomes negligible, in comparison to the effect of the resolution of uncertainty. Precisely, I can test this hypothesis by performing two sample t-tests of whether or not the pre- and post-VRA changes in firm-characteristics between the two groups are statistically indistinguishable.

Table 5 presents the results. Columns (1) and (2) present means and standard deviations of the pre and post changes in the firm characteristic variables. For instance, $\Delta Profitability$ represents the pre- and post-VRA change in profitability. Column (3) presents the results of the two sample t-tests of the null hypothesis as to whether the average changes are

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statistically indistinguishable between the two groups. As can be seen, the sufficiently high p-values suggest to accept the null. Therefore, the 1982 VRA appears to provide a reasonable empirical setting to measure the effect of the resolution of uncertainty on leverage. Although the VRA potentially affects other determinants of U.S. steel firms' leverage than uncertainty in the post-VRA period, such indirect effects appear to be statistically insignificant.[20]

5 Robustness Checks

5.1 Collapsing the Data into Two Periods

Bertrand et al. (2004) suggest that the most conservative way to deal with the within-firm serial correlation of errors is to ignore the time-series information. Following Bertrand et al. (2004), I time-average the data before and after the 1982 VRA and run analysis on the model in equation (11) on this averaged outcome variable in a panel of length 2. That is, the DID model in equation (11) becomes:

$$\Delta Y_i = \beta_0 + \beta D_i + \gamma' \Delta X_i + \Delta u_i.$$

The operator Δ represents the change between the pre and post time-averaged variables. The treatment D_i takes a value of one if a firm belongs to the U.S. steel industry. The estimator $\widehat{\beta}$ estimates the effect of the resolution of uncertainty on the change of U.S. steel firms' leverage as compared to that of a matched control firm, after partialing out the effect of changes in other firm characteristics.

Table 6 reports the results. Compared to the main results in Table 3, in Model 1 for market leverage, the DID estimate ($\widehat{\beta}$) increases from 0.05 to 0.057, while its statistical significance remains similar. In Model 2 for book leverage, the DID estimate decreases from 0.032 to 0.029, and its statistical significance decreases from 0.03 to 0.12 in terms of p-value.

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[20]As a robustness check, in Section 5.4, I perform the subsample analysis to simulate the ideal intervention that would change only the amount of uncertainty confronted by U.S. steel firms. The estimated effect of the resolution of uncertainty on U.S. steel firms' leverage remain statistically significant and economically strong. See the details in Section 5.4.

Models 3 and 4 present the results of similar analyses when the modified Lerner index is employed as an additional control variable. The results of Models 3 and 4 are similar to those of Models 1 and 2.

Losing the statistical significance of the DID estimates in this exercise is expected because collapsing the data into two periods substantially reduces the sample size, while the number of covariates remains the same. As such, I lose a degree of freedom, which leads to the weaker statistical significance of the DID estimates. This aspect is also pointed out in Bertrand et al. (2004).[21] However, the signs of DID estimates are consistent with the main results presented in Table 3, and the magnitude of them is also comparable. The results show that the effect of the resolution of uncertainty provided by the 1982 VRA on a U.S. steel firm's leverage remains economically strong in the most conservative setup.

5.2 Placebo Tests, Alternative Matching Methods, and Alternative Measure of Risk of Assets' Cash Flows

One could ask whether the observed increase in a U.S. steel firm's leverage responding to the resolution of uncertainty is simply random. One way to examine to this question is to generate "placebo shocks," as in Bertrand et al. (2004). Specifically, I conduct three placebo tests in which I pretend the VRA happens, instead of in 1982, at different times: 1979, 1994, and 2002. The results are in Table 7. In the 1979 and 1994 placebo-VRAs, none of the DID estimates is statistically or economically significant, as can be seen from the weak economic strength and the sufficiently small t-statistics. In the 2002 placebo-VRA, all of the DID estimates are statistically insignificant at the 10% level. Although their economic strength seems non-negligible, they enter with a negative sign. As a result, none of the placebo VRAs can generate an economically and statistically effect as significant as that estimated using the actual 1982 VRA shock.

Next, I show that the main results are robust to alternative matching methods. To

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[21]Bertrand et al. (2004) states that "The downside of these procedures (both raw and residual aggregation) is that their power is quite low and diminishes fast with sample size."

begin, I match on the same pretreatment characteristics as shown in Section 3.2.3: the volatility of asset, stock return, market-to-book ratio, and market leverage ratio. Here, I use a Mahalanobis metric to measure the distance between two firms with the chosen characteristics. Each steel firm is matched to the four nearest non-steel firms within a caliper of 0.05.[22] The alternative matching (I) columns in Table 8 present the results of the DID analysis with the matched sample using this matching method. The DID estimates are similar to those presented in Table 3 in terms of statistical and economic significance.

To check the sensitivity of the selection of matching variables, I use a different set of characteristic variables to estimate the propensity scores: tangibility, size, profitability, and market-to-book ratio. As before, each steel firm is matched up to four nearest non-steel firms in terms of the predicted propensity score with a caliper 0.05. The alternative matching (II) columns in Table 8 present the results. All of the DID estimates are economically strong and statistically significant at the 10% level. The economic magnitude and statistical significance of DID estimates are similar to those of the main results in Table 3.

I now demonstrate whether the estimated effect of the resolution of uncertainty on U.S. steel firms' leverage remains robust to an alternative measure of risk of assets' cash flow. Instead of using GARCH, I use implied asset volatility as a proxy for the forward-looking risk of assets' cash flows. I apply the Merton (1974) model to compute the implied volatility, following the procedure of Vassalou and Xing (2004, p. 835) and Bharath and Shumway (2007, p. 1345). Table 9 presents the results, which are close to the main results in Table 3. Precisely, the estimated coefficients of $D(i,t)$ remain close to the main results, in the statistical and economic sense.

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[22]This caliper is chosen following Rubin and Thomas (2000). They advise that in case of Mahalanobis-distance matching, when the variance of linear propensity score in the treatment group is less than twice as large as that in the control group, a caliper of 20% standard deviation of the propensity score of the treatment group removes 98% of the bias in normally distributed covariates. I find that the standard deviation of the linearized propensity scores of the treatment group is 0.27, whereas that of control group is 0.28. Hence, it seems appropriate to use $0.2 \times 0.27 \approx 0.05$ as a caliper.

5.3 Post-VRA Change in the Coefficient of U.S. Steel Firms' Profitability

In the main model in equation (11), I assume that the coefficients Γ of the firm-specific control variables X_{it} are time-invariant across the pre- and post-VRA periods. One could consider that the coefficient of U.S. steel firms' profitability would change in the post-VRA period, and this structural change would explain away the changes in their leverage in the post-VRA period. If that is true, the DID estimator $\widehat{\beta}$ of the extended model,

$$Y_{it} = \alpha_t + \alpha_i + \beta D_{it} + \Gamma' X_{it} + \Theta \cdot D_{it} \times Profitability_{it} + u_{it}, \tag{12}$$

would be statistically insignificant and economically weak. The term $D_{it} \times Profitability_{it}$ represents the interaction between the firms' profitability and the post-VRA indicator. All the other variables are the same as the main model in equation (11).

Table 10 presents the results. The estimated effects of the resolution of uncertainty on both U.S. steel firms' book and market leverage are economically strong and statistically significant at the 1% level. The results reveal that the effect of the resolution of uncertainty on U.S. steel firms' leverage remain robust, even after controlling the structural change in the coefficient of their profitability in the post-VRA period.[23]

5.4 Subsample Analysis: Ideal Intervention that Impacts Only U.S. Steel Firms' Uncertainty

It would provide a perfect empirical setting if we could have a shock that changes *only* the steel firms' uncertainty, but does not affect the other determinants of leverage. The 1982 VAR is not this kind: The 1982 VRA not only resolves U.S. steel firms' uncertainty, but also affects other possible determinants of their leverage. Using a subset of the matched sample, however, I can mimic the situation as if I used the shock that only affects the amount of

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[23]The unreported results are robust to including the following additional interaction variables: (i) interaction between the firms' analysts-median forecast ($Median\ Analyst\ Forecast$) and the post-VRA indicator (D_{it}), and (ii) interaction between the firms' forward-looking risk of assets' cash-flow ($vol(Asset)$) and the post-VRA indicator (D_{it}).

uncertainty faced by U.S. steel firms. I construct a subsample by selecting, *from the matched sample*, the firms whose average change in profitability between the pre- and the post-VRA periods belongs to $(-1\%, 1\%)$. Then, I run similar DID panel regressions as in the main model in equation (11) with the subsample.

Table 11 presents the summary statistics of the subsample and the results of two sample *t*-tests of the null hypothesis as to whether the means of firm characteristics between the treatment and the matched control in the subsample are statistically indistinguishable. The rank-sum tests in the table also present the results of the Wilcoxon rank-sum (non-parametric) test of the null hypothesis if two samples are drawn from the same distribution. As can be seen in Panel A, the pre-VRA firm characteristics between the treatment group and the matched control are not statistically different in the sense of distribution, at the 5% significance level. Panel B shows that the distributions of the post-VRA firm characteristics between the two groups are indistinguishable at the 5% significance level (except for the market-to-book ratio). This implies that the pre-VRA firm characteristics in the subsample are statistically well balanced between the two groups and the enactment of the VRA seldom affects the characteristics of U.S. steel firms (other than their uncertainty), relative to the matched control firms, in the subsample.

Table 12 presents the DID panel regression results using the subsample. The estimated coefficients of the resolution of uncertainty on U.S. steel firms' market leverage (Model 1) and book leverage (Model 2) are economically strong and statistically significant at the 10% level. More importantly, the economic strength of the resolution of uncertainty in the subsample analysis (0.032 for market leverage, 0.037 for book leverage) is indeed comparable to those in the main results (i.e., full sample analysis; 0.055 for market leverage, 0.033 for book leverage) presented in Table 3. Therefore, the 1982 VRA provides a reasonable approximation of the ideal intervention that impacts only the level of U.S. steel firms' uncertainty.

6 Conclusion

This paper shows that the Knightian uncertainty perceived by a manager and her aversion toward it are important drivers of leverage. The model incorporates an ambiguity-averse manager and predicts a substantially lower optimal leverage ratio than its traditional counterpart with risk alone. Quantitatively, the effect of uncertainty on leverage is higher than that of risk. Moreover, a firm's leverage strictly decreases with uncertainty, whereas it does not strictly decrease with risk even when the manager is risk averse. Therefore, I argue that uncertainty provides a more plausible explanation for firms taking on low leverage than risk alone.

I estimate the effect of uncertainty on leverage using the 1982 Voluntary Restraint Agreement (VRA) as an exogenous reduction in U.S. steel firms' Knightian uncertainty. Prior to the 1982 VRA, U.S. steel firms likely confronted high Knightian uncertainty about the likelihood of outcomes of antidumping and countervailing duty legal proceedings. The source of uncertainty was that the International Trade Administration had considerable discretion and often made highly arbitrary injury determinations. I argue that the large uncertainty perceived by the U.S. steel industry during the pre-VRA period was immediately resolved by the enactment of the 1982 VRA. Using a difference-in-difference methodology with the matched sample, I find that when uncertainty is resolved, a median firm in the U.S. steel industry increases its market leverage by 11.5% and its book leverage by 12.3% as compared to a matched control firm from another industry. These results are economically strong and statistically significant. Most importantly, the results are not explained away by changes in traditional factors such as forward-looking risk and future profitability.

The 1982 VRA was implemented by the U.S. government due to its own strong political incentives. Therefore, the internal validity of the difference-in-difference methodology is not threatened by steel firms lobbying for the VRA. I also show that the main results survive various robustness tests including placebo shocks, alternative risk measure and matching methods, structural change in the coefficient of U.S. steel firms' profitability in the post-VRA

period, and the subsample analysis mimicking an ideal shock that impacts only the level of uncertainty.

This paper is, to the best of my knowledge, the first to investigate the effect of Knightian uncertainty on optimal capital structure. It contributes to the capital structure literature by providing a formal model and empirical evidence showing that Knightian uncertainty provides a sensible explanation for firms taking on low leverage, adding to what we know of the empirical determinants of leverage.

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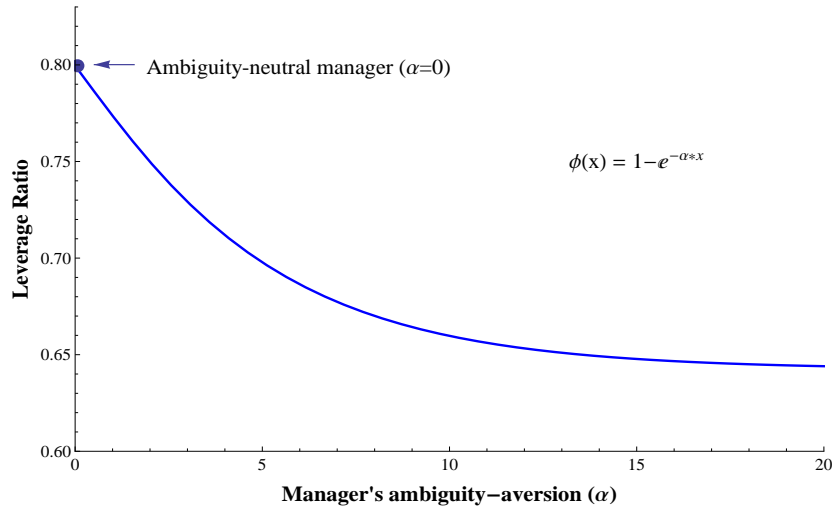
Point A denotes the leverage choice taken by a ambiguity-neutral manager ($\alpha = 0$). The manager is assumed to display the constant absoluteref ambiguity aversion characterized in (9). The set of priors and associated beliefs are set as $\Pi = \{0.7, 1, 1.3\}$ and $\{\mu_i\}_{i=1}^3 = 1/3$. The common and known standard deviation is set as $\sigma = 0.3$, the marginal tax rate $\tau = 0.35$, and the proportional deadweight cost $k = 0.4$. The leverage ratio is defined as $B^*/(E(B^*) + B^*)$ where $E(B^*)$ is the market value of equity at B^* computed using (3).

Figure 1 Optimal leverage ratio when ambiguity aversion parameter α increases
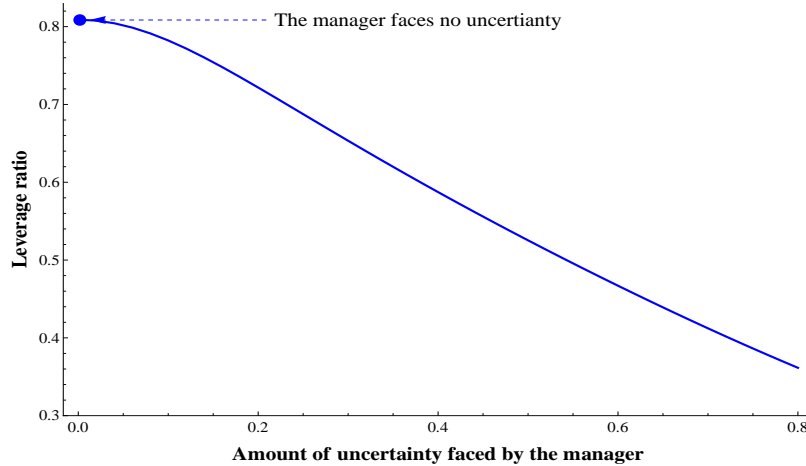
This figure illustrates the optimal leverage ratios when changing the amount of uncertainty perceived by the manager. As the amount of uncertainty increases, the optimal leverage decreases. The manager's ambiguity aversion parameter is fixed as $\alpha = 8$. The other parameters are set as $\tau = 0.35$, $k = 0.4$, and $\sigma = 0.3$.

Figure 2 Optimal leverage ratio when the amount of uncertainty increases.
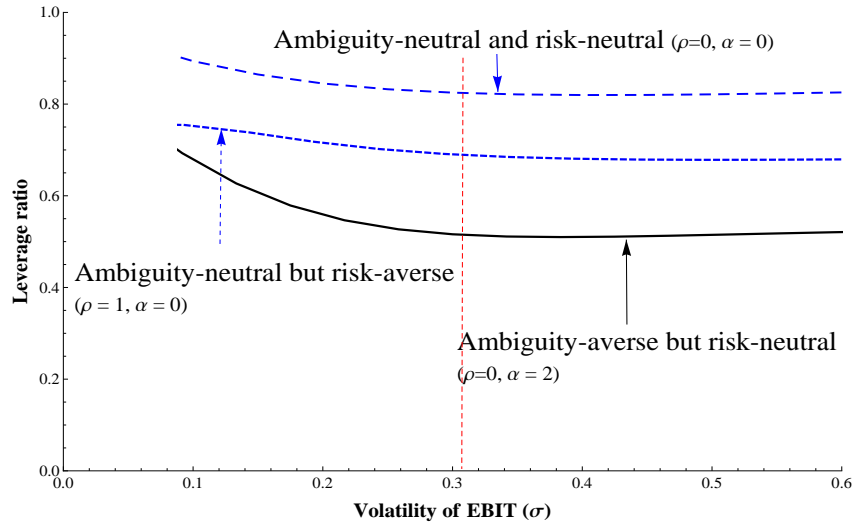
This figure presents the comparative statics of optimal leverage with respect to the risk of a firm's cash flow. The (top) dashed line represents the case where a manager is risk- and ambiguity-neutral. The dotted line represents the optimal leverage decisions when the manager is risk-averse but ambiguity-neutral when the degree of manager's risk aversion (ρ) is 1. The solid line denotes the optimal leverages when the manager is ambiguity-averse but risk-neutral - that is, $\alpha = 2$ and $\rho = 0$. Note that the amount of Knightian uncertainty faced by the managers is set as amount of uncertaity$/\sigma = 2$, the marginal corporate tax rate and proportional bankruptcy cost as $\tau = 0.35$ and $k = 0.4$ for this figure.

Figure 3 Comparison of the optimal leverage between the ambiguity-neutral but risk-averse manager and the ambiguity-averse but risk-neutral manager

(a) Market-to-Book Ratio

(b) Annual Stock Return

(c) Market Leverage

(d) Firm Size

(e) Asset Volatility

(f) Profitability
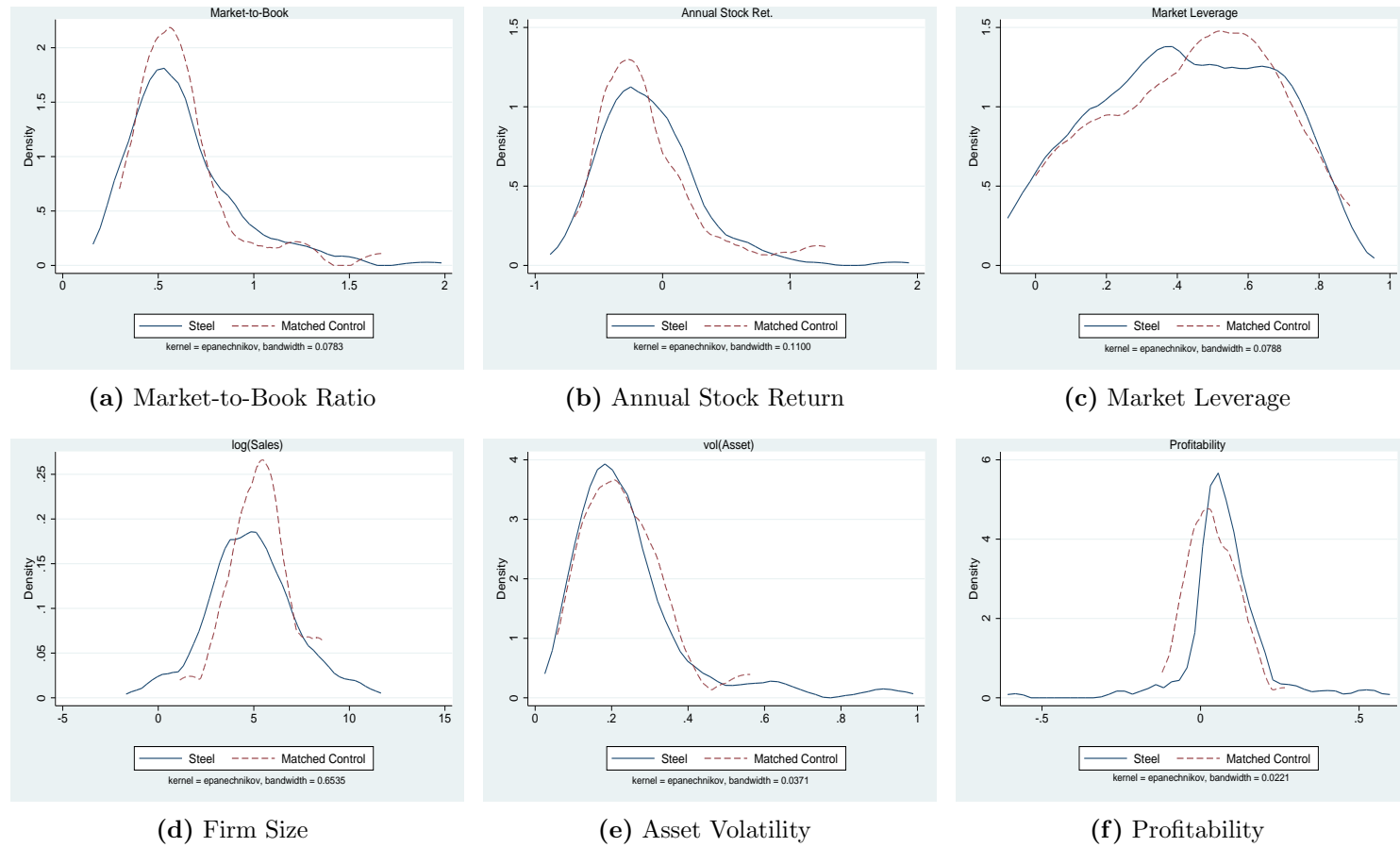
The solid lines represent the estimated Epanechnikov kernel densities of each pretreatment firm-specific controls of the treatment group (U.S. steel manufacturers), the dashed lines denote those of the matched control group.

Figure 4 Post-matching balance of the pre-VRA firm-characteristic variables

Checking Parallel-Trends (Market Leverage)
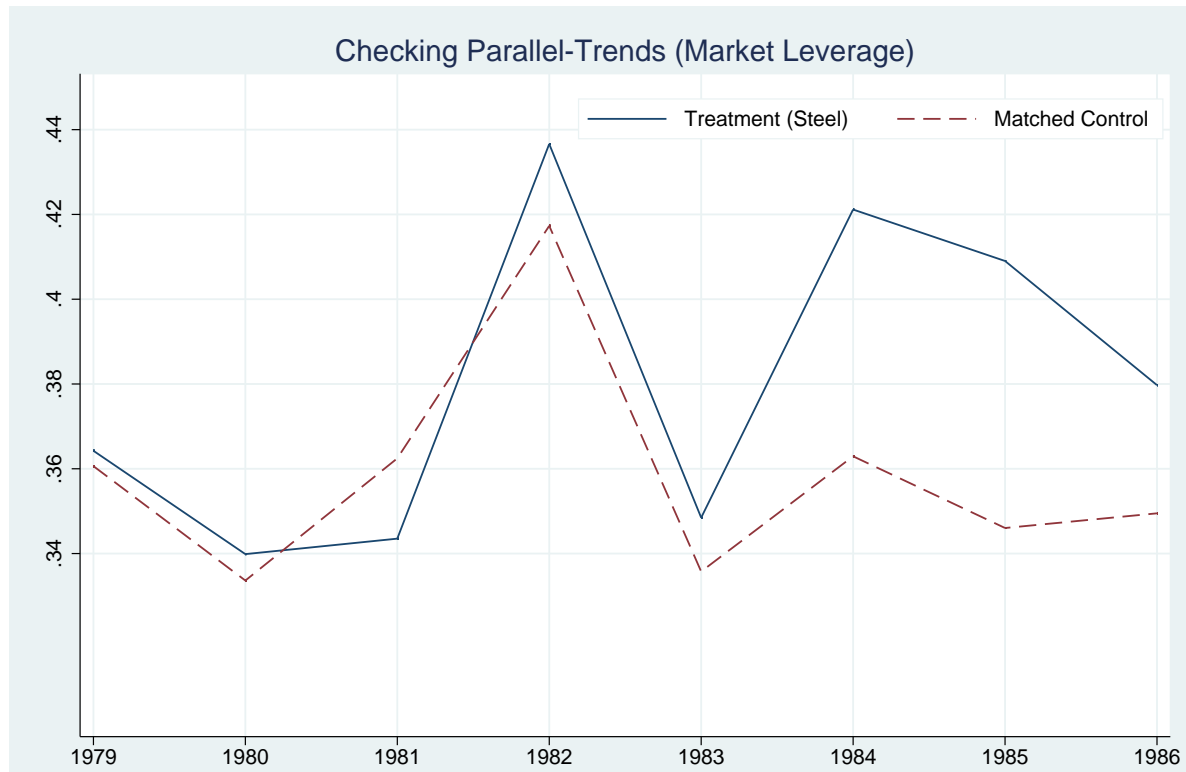
This figure provides the graphical examination of parallel-trends assumption for market leverage. If the parallel-trends holds, the pre-treatment trends across the treatment and control groups are parallel. The figure illustrates the market-leverage trend of the treatment group (U.S. steel industry) and that of the matched control group using the standard four nearest propensity score matching. The pre-VRA period is the period between 1978 and 1982 and the post-VRA period is the period between 1983 and 1987. The pre-VRA trends across the two groups appear parallel, whereas the market-leverage trend of the treatment seems to diverge from that of the matched control group in the post-VRA era. This implies that in the pre-VRA period, the parallel-trends assumption is met.

Figure 5 The pre- and post-trends of the treatment and the matched control groups

Table 1 Variable Definitions

Variables	Definitions
Book Equity	Stockholders Equity + Deferred Taxes and Investment Tax Credit - Preferred Stock (PSTKQ) [if PSTKQ is missing, then use Preferred Stock Redemption Value (PSTKRQ)]
Total Debt	(Long-term debt) + (Short-term debt)
Market Equity	Common Shares Outstanding × Closing Price
Market Leverage	Total Debt / Market Value of Asset
Book Leverage	Total Debt / Total Asset
Market-to-Book	(Market Equity + Total Debt + Preferred Stock - Deferred taxes and investment tax credits) / Total Asset
Firm Size	log(Sales [millions of dollars (henceforth, MM$)])
Tangibility	Plant Property and Equipment / Total Asset
Profitability	Earnings Before Interest, Taxes, Depreciation and Amortization / Total Asset
Investment	Capital expenditure / the beginning period Total Asset
Marginal Tax Rate (MTR)	Simulated Marginal Tax Rate available in Graham (1996)
Lerner index (Operating Profit Margin)	(Sales - Cost of Goods Sold - Selling Expense)/Total Asset
Modified Lerner index	Difference between a firm's Lerner index and the Lerner index of its industry.
vol(Asset)[GARCH]	Volatility of a firm's assets' cash flow using GARCH model. The details are available in Appendix E.
vol(Asset)[Implied]	Volatility of a firm's assets' cash flow using the Merton (1974) model following the procedure of Vassalou and Xing (2004, p. 835) and Bharath and Shumway (2007, p. 1345).

Table 2 Comparison of the Pre-VRA Firm-specific Control Variables between the Treatment (U.S. Steel Industry) and Control Groups Before and After Propensity Score Matching

This table presents the results of two sample tests to compare the means of the pretreatment firm-specific controls between the treatment and matched control groups before and after the propensity score matching described in Section 3.2.3. The standard bias of each variable measures a standardized differences in mean: the difference in means of each control variable of the treated and control group divided by the standard deviation of the treatment group, $(\overline{X}_T - \overline{X}_C)/\overline{\sigma}_T$. The bottom table presents the result of the Wilcoxon rank-sum test of the null hypothesis whether the distributions of the estimated propensity scores of the treatment and control group are same after matching.

| | Pre-Matching | | | | | Post-Matching | | | | |
| | Mean | | Std. Bias | Two sample t-test | | Mean | | Std. Bias | Two sample t-test | |
Variables	Treated	Control	$\frac{(\overline{X}_T - \overline{X}_C)}{\overline{\sigma}_T}$	t-stats	p-val	Treated	Control	$\frac{(\overline{X}_T - \overline{X}_C)}{\overline{\sigma}_T}$	t-stats	p-val
Market Leverage	0.44	0.29	0.62	3.86	0.00	0.44	0.43	0.02	0.11	0.92
Book Leverage	0.26	0.25	0.06	0.34	0.73	0.26	0.27	-0.05	-0.24	0.81
Cash/Asset	0.08	0.12	-0.32	-1.68	0.09	0.08	0.08	-0.03	-0.15	0.89
Tangibility	0.45	0.36	0.50	2.74	0.01	0.45	0.37	0.46	2.00	0.05
Firm Size	5.35	4.26	0.55	2.99	0.00	5.35	4.91	0.22	0.99	0.33
Mkt-to-Book	0.62	1.33	-0.63	-2.81	0.01	0.62	0.62	0.01	0.11	0.91
Profitability	0.04	-0.02	0.07	0.32	0.75	0.04	0.08	-0.05	-1.62	0.11
vol(Asset)[GARCH]	0.23	0.36	-0.78	-3.91	0.00	0.23	0.24	-0.04	-0.20	0.84
Annual Stock Ret.	-0.12	0.23	-0.67	-3.66	0.00	-0.12	-0.12	0.00	0.01	0.99
Marginal Tax rate	0.40	0.41	-0.10	-0.13	0.90	0.40	0.42	-0.20	-1.04	0.30

Two-sample Wilcoxon rank-sum (Mann-Whitney) test

H_0: Distributions of estimated propensity score of the treatment and the matched control group are same

p-val = 0.719

Table 3 Main Results: Difference-in-Differences with the Matched Sample

This table presents the main results of difference-in-difference (DID) analysis with the matched sample specified in (11). The outcome variable is market and book leverage. The treatment group is the U.S. steel industry. The matched control firms are constructed using the standard propensity score matching. Each firm in the steel industry is matched up to the nearest four non-steel firms in terms of its estimated propensity score. The post-treatment variable $D(i,t) = 1$ if a firm belongs to the U.S. steel industry (the treatment group) and is in the post-VRA period (1983-1987). The estimated coefficient of $D(i,t)$ (i.e., the DID estimate) represents the estimated effect of resolution of uncertainty on steel firms' leverage relative to matched control firms. The definitions of other variables are in Table 1. $vol(Asset)[GARCH]$ represents the forward-looking asset volatility using the GARCH model. All regressions include firm and year fixed effects. Standard errors are computed with clustering at the firm level, thus robust to heteroscedasticity and within-firm serial correlation. The t-statistics of the coefficient estimates are reported in parentheses. Statistical significance at the 10%, 5%, and 1% levels are denoted by *, **, and ***, respectively.

	Model 1 Market Lev.	Model 2 Book Lev.	Model 3 Market Lev.	Model 4 Book Lev.
D(i,t)	0.055***	0.032**	0.046**	0.028*
	(3.034)	(2.158)	(2.510)	(1.921)
Profitability	-0.116	-0.045	-0.107	-0.042
	(-1.399)	(-0.651)	(-1.194)	(-0.634)
Tangibility	0.299***	0.222***	0.252***	0.204***
	(3.979)	(3.471)	(3.635)	(3.397)
Firm Size	0.033	0.022	0.048**	0.029*
	(1.585)	(1.363)	(2.581)	(1.741)
Market-to-Book	-0.010	0.094**	-0.003	0.096***
	(-0.384)	(2.614)	(-0.160)	(2.831)
Med. Analyst For.	-0.021***	-0.006**	-0.020***	-0.005
	(-4.208)	(-2.008)	(-4.000)	(-1.539)
vol(Asset)[GARCH]	-1.281***	-0.817***	-1.374***	-0.905***
	(-8.099)	(-7.864)	(-9.599)	(-8.429)
Annual Stock Ret.	-0.014	0.005	-0.010	0.011
	(-1.338)	(0.568)	(-0.874)	(1.216)
Modified Lerner Index			0.102	0.100
			(1.570)	(1.550)
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Within R^2	0.671	0.442	0.691	0.475
Num. of Obs.	735	735	693	693

Table 4 Necessary Condition for Parallel-Trends Assumption in the Pre-VRA Period
This table presents the results of checking the necessary condition of the parallel-trends assumption. The columns in (1) and (2) show the means and standard deviations of the leverage growth rate of the treatment and matched control group in the pre-VRA period (1978-1982). The columns in (3) show the results of the two-sample t-test to explore whether the means of leverage growth rate of the treatment and matched control group are statistically different. The column in (4) reports the results of the Wilcoxon rank-sum test of the null hypothesis if two samples are drawn from the same distributions.

	(1) Treatment		(2) Matched Control		(3) Two Sample Test			(4) Rank-Sum
Growth Rate	Mean	Std	Mean	Std	Diff	t-stats	p-val	p-val
ML (1978-1979)	0.198	0.686	0.037	0.534	-0.161	-1.453	0.148	0.214
ML (1979-1980)	0.206	1.501	0.249	2.088	0.044	0.115	0.908	0.745
ML (1980-1981)	0.040	0.391	0.324	1.569	0.284	1.074	0.284	0.189
ML (1981-1982)	0.605	2.141	0.388	1.179	-0.217	-0.830	0.408	0.654
BL (1978-1979)	0.153	0.639	0.066	0.587	-0.087	-0.754	0.452	0.822
BL (1979-1980)	0.291	1.593	0.265	2.016	-0.026	-0.071	0.944	0.552
BL (1980-1981)	-0.036	0.247	0.277	2.344	0.313	0.798	0.426	0.246
BL (1981-1982)	0.358	1.303	0.178	0.812	-0.180	-1.055	0.293	0.118

Table 5 Two sample tests for the Average Changes Between Pre and Post Firm-specific Control Variables across Treatment and Matched Control Groups

This table presents the summary statistics of the differences between pre and post firm-specific control variables across the treatment and matched control groups. For example, $\Delta Profitability$ represents the change between pre- and post-profitability. The columns in (1) present the mean and standard deviation of $\Delta Profitability$ in the treated group, whereas the columns in (2) those in the matched control group. The columns in (3) and (4) present the results of a two-sample test of means and a rank-sum test between two groups. $Diff$ presents the difference between the mean of the treated and that of the matched control. To construct the matched control group, I use the standard propensity score matching described in Section 3.2.3. The variable definitions are in Table 1.

	(1) Treated		(2) Matched Control		(3) Two Sample t-test			(4) Rank-Sum
Pre- & Post-VRA changes in firm characteristics	Mean	Std	Mean	Std	Diff	t-stats	p-val	p-val
Δ Profitability	-0.041	0.086	-0.055	0.258	0.014	-0.538	0.591	0.247
Δ Tangibility	0.006	0.083	0.009	0.085	-0.003	0.196	0.846	0.259
Δ Firm Size	0.072	0.347	0.158	0.425	-0.086	1.279	0.205	0.199
Δ Mkt-to-Book	0.017	0.285	0.035	0.355	-0.018	0.321	0.749	0.626
Δ vol(Asset)[GARCH]	0.000	0.047	-0.002	0.122	0.002	-0.184	0.854	0.745
Δ Annual Stock Ret.	0.088	0.280	0.097	0.392	-0.009	0.151	0.880	0.823
Δ Marginal Tax Rate	-0.058	0.082	-0.036	0.071	-0.022	1.403	0.168	0.177

Table 6 Collapsing the Data into Two Periods (à la Bertrand et al., 2004)

This table presents the results of the difference-in-difference (DID) estimator ignoring time series information proposed by Bertrand et al. (2004). Following Bertrand et al., I time-average the data before and after the 1982 VRA and run analysis (11) on this averaged outcome variable in a panel of length 2. That is, the DID model (11) becomes $\Delta Y_i = \beta_0 + \beta D_i + \gamma' \Delta X_i + \Delta u_i$. Δ represents the change between pre- and post-variables. The treatment $D(i) = 1$ if a firm belongs to the U.S. steel industry. β represents the DID estimator: the effect of resolution of uncertainty on the change of leverage. As Bertrand et al. (2004) suggest, this is the most conservative way robust to the within-firm serial correlation of errors. The t-statistics are reported in parentheses. All standard errors are robust to heteroscedasticity. Statistical significance at the 10%, 5%, and 1% levels are denoted by *, **, and ***, respectively.

	Model 1 Δ Market Lev.	Model 2 Δ Book Lev.	Model 3 Δ Market Lev.	Model 4 Δ Book Lev.
D(i)	0.057***	0.029	0.061***	0.036*
	(2.642)	(1.562)	(2.721)	(1.889)
Δ Profitability	-0.018	0.126	0.377	0.420
	(-0.070)	(0.566)	(0.959)	(1.137)
Δ Market-to-Book	0.029	0.175***	-0.004	0.164***
	(0.544)	(3.517)	(-0.073)	(3.137)
Δ Tangibility	0.523***	0.374***	0.480***	0.381***
	(3.584)	(3.014)	(3.455)	(3.256)
Δ Firm Size	-0.011	-0.021	0.008	-0.023
	(-0.301)	(-0.729)	(0.236)	(-0.691)
Δ Med. Anal. Forecast	-0.032***	-0.016**	-0.034***	-0.016**
	(-3.497)	(-2.511)	(-3.676)	(-2.335)
Δ vol(Asset)[GARCH]	-1.478***	-1.113***	-1.464***	-1.151***
	(-6.846)	(-8.956)	(-5.926)	(-7.666)
Δ Annual Stock Ret.	0.048	0.083***	0.045	0.082***
	(1.177)	(2.798)	(1.132)	(2.819)
Δ Modified Lerner Index			0.418	0.429
			(1.213)	(1.244)
Constant	-0.051***	-0.018	-0.039**	-0.011
	(-3.129)	(-1.465)	(-2.175)	(-0.723)
Adj. R^2	0.690	0.595	0.679	0.604
Num. of Obs.	93	93	87	87

Table 7 Difference-in-Difference Panel Regressions with the Placebo Shocks at 1979, 1993, and 2001

This table presents the results of tests with placebo-VRAs had they taken place in 1979, 1993 or 2001 instead of 1982. In each test, I use the difference-in-difference methodology with the propensity score-based matched sample the same as Section 3.2.3. In all tests, none of the DID estimates (i.e., the estimated coefficients of $D(i,t)$) is statistically significantly positive, according to the sufficiently small t-statistics. The definitions of other variables are in Table 1. $vol(Asset)[GARCH]$ represents the forward looking asset volatility using GARCH model. Standard errors are computed with clustering at the firm level, thus robust to heteroscedasticity and within-firm serial correlation. The t-statistics are reported in parentheses. Statistical significance at the 10%, 5%, and 1% levels are denoted by *, **, and ***, respectively.

	1979 Placebo Shock		1993 Placebo Shock		2001 Placebo Shock	
	Market Lev.	Book Lev.	Market Lev.	Book Lev.	Market Lev.	Book Lev.
D(i,t)	0.005	0.003	0.018	0.003	-0.023	-0.033
	(0.262)	(0.247)	(0.893)	(0.182)	(-0.713)	(-1.497)
Profitability	-0.819***	-0.357***	0.020	0.035	-0.053	-0.144
	(-7.191)	(-3.045)	(0.190)	(0.474)	(-0.307)	(-1.198)
Tangibility	0.080	0.163**	0.136*	0.098	0.024	0.166*
	(0.999)	(2.032)	(1.750)	(1.599)	(0.240)	(1.887)
Firm Size	0.105***	0.079***	0.032	0.050**	0.043	0.052*
	(4.120)	(3.084)	(1.461)	(2.506)	(1.205)	(1.806)
Market-to-Book	-0.050**	0.031	-0.070***	0.010	-0.062*	0.062**
	(-2.200)	(1.454)	(-3.738)	(0.684)	(-1.925)	(2.417)
Med. Analyst For.	0.000	-0.000**	-0.020***	-0.012**	-0.009**	-0.003
	(0.055)	(-2.356)	(-3.610)	(-2.085)	(-2.178)	(-1.101)
vol(Asset)[GARCH]	-0.879***	-0.499***	-0.838***	-0.562***	-0.833***	-0.478***
	(-6.056)	(-5.746)	(-6.855)	(-5.708)	(-8.808)	(-6.508)
Annual Stock Ret.	-0.009	0.016**	-0.001	0.017*	-0.021*	0.008
	(-0.843)	(2.400)	(-0.096)	(1.930)	(-1.719)	(0.760)
Firm & Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Within R^2	0.641	0.399	0.585	0.380	0.690	0.447
Num. of Obs.	691	691	950	950	436	436

Table 8 Difference-in-Difference with Alternative Matching Methods

This table presents the results of the difference-in-difference with the matched sample using alternative matching methods: (i) Mahalanobis metric matching with a caliper 0.05, and (ii) propensity score matching with the different set of matching variables. As before, the treatment group is the U.S. steel industry. The outcome variables are market and book leverage ratio. Case (i) Mahalanobis metric matching with a caliper 0.05: I take each firm in the U.S. steel industry and match it up to the four nearest non-steel firms in terms of the Mahalanobis metric instead of the propensity score distance. The firm characteristics that I match on are the same as in Section 3.2.3. Case (ii) the propensity score matching with the different set of matching variables: I match on the firm size, tangibility, profitability, and market-to-book ratio. The unreported results indicate that both alternative matching methods are successful in balancing the pretreatment firm characteristics. All standard errors are computed with clustering at the firm level. The t-statistics are reported in parentheses. Statistical significance at the 10%, 5%, and 1% levels are denoted by *, **, and ***, respectively.

	Alternative Matching (I)		Alternative Matching (II)	
	Market Leverage	Book Leverage	Market Leverage	Book Leverage
D(i,t)	0.050***	0.027**	0.058***	0.029*
	(2.609)	(1.986)	(3.086)	(1.909)
Profitability	-0.178***	-0.075	-0.181**	-0.170***
	(-2.991)	(-1.146)	(-2.014)	(-2.935)
Tangibility	0.114	0.029	0.167**	0.091
	(1.472)	(0.347)	(2.165)	(1.375)
Firm Size	0.040	0.039*	0.021	0.031*
	(1.239)	(1.770)	(1.029)	(1.793)
Market-to-Book	-0.059*	0.096**	-0.065***	0.086***
	(-1.955)	(2.543)	(-2.834)	(3.954)
vol(Asset)[GARCH]	-0.768***	-0.470***	-1.229***	-0.634***
	(-3.520)	(-3.162)	(-12.112)	(-7.992)
Annual Stock Ret.	-0.026***	-0.001	-0.002	0.001
	(-2.814)	(-0.115)	(-0.251)	(0.192)
Med. Analyst For.	-0.032***	-0.017***	-0.002	-0.001
	(-5.142)	(-3.874)	(-0.333)	(-0.208)
Firm & Year fixed effects	Yes	Yes	Yes	Yes
Within-in R^2	0.614	0.285	0.693	0.421
Number of Obs.	899	899	682	682

Table 9 Difference-in-Differences with the Matched Sample using Implied Volatility

This table presents the results of difference-in-difference (DID) analysis with the matched sample using an alternative measure of the risk of assets' cash flows. The outcome variable is market and book leverage. The treatment group is the U.S. steel industry. The matched control firms are constructed using the standard propensity score matching. Each firm in the steel industry is matched up to the nearest four non-steel firms in terms of its estimated propensity score. The post-treatment variable $D(i,t) = 1$ if a firm belongs to the U.S. steel industry (the treatment group) and is in the post-VRA period (1983-1987). The estimated coefficient of $D(i,t)$ (i.e., the DID estimate) represents the estimated effect of resolution of uncertainty on steel firms' leverage relative to matched control firms. The definitions of other variables are in Table 1. In stead of using the GARCH model (see Table 3), $vol(Asset)[Implied]$ represents implied asset volatility using Merton's model following Bharath and Shumway (2007). All regressions include firm and year fixed effects. Standard errors are computed with clustering at the firm level, thus they are robust to heteroscedasticity and within-firm serial correlation. The t-statistics of the coefficient estimates are reported in parentheses. Statistical significance at the 10%, 5%, and 1% levels are denoted by *, **, and ***, respectively.

	Model 1 Market Leverage	Model 2 Book Leverage	Model 3 Market Leverage	Model 4 Book Leverage
D(i,t)	0.057**	0.033*	0.052*	0.033
	(2.098)	(1.657)	(1.892)	(1.637)
Med. Analyst For.	-0.035***	-0.015***	-0.037***	-0.016***
	(-4.706)	(-3.172)	(-4.860)	(-3.768)
Profitability	-0.128	-0.060	-0.107	-0.058
	(-1.164)	(-0.639)	(-1.034)	(-0.712)
Tangibility	0.392***	0.301***	0.390***	0.330***
	(3.376)	(3.633)	(3.382)	(3.779)
Firm Size	0.087***	0.062**	0.108***	0.072***
	(2.662)	(2.525)	(3.598)	(3.296)
Market-to-Book	-0.075***	0.048	-0.064**	0.055
	(-2.657)	(1.234)	(-2.219)	(1.446)
vol(Asset)[Implied]	-0.019	-0.026	-0.006	-0.021
	(-0.609)	(-0.965)	(-0.143)	(-0.689)
Annual Stock Ret.	-0.073***	-0.029**	-0.068***	-0.025*
	(-6.286)	(-2.423)	(-5.825)	(-1.956)
Modified Lerner Index			0.005	-0.024
			(0.216)	(-0.901)
Firm & Year fixed effects	Yes	Yes	Yes	Yes
Within R^2	0.405	0.191	0.409	0.209
Number of Obs.	674	674	640	640

Table 10 Post-VRA Change in the Coefficient of U.S. steel Firms' Profitability
This table presents the results of difference-in-difference (DID) analysis with the matched sample allowing the structural changes in the coefficients of U.S. steel (the treated) firms' characteristic variables specified in (12). The outcome variable is either market or book leverage. The treatment group is the U.S. steel industry. The matched control firms are constructed using standard propensity score matching. Each firm in the steel industry is matched up to the four nearest non-steel firms from the other industries in terms of its estimated propensity score. The post-treatment variable $D(i,t) = 1$ if a firm belongs to the U.S. steel firms (the treated) and is in the post-VRA period (1983-1987). $D(i,t) \times Profitability$ represent the interaction between the firms' profitability and the post-VRA indicator. The estimated coefficient of $D(i,t)$ represents the estimated effect of resolution of uncertainty on steel firms' leverage relative to matched control firms. The definitions of other variables are in Table 1. All regressions include firm and year fixed effects. Standard errors are computed with clustering at the firm level, thus robust to heteroscedasticity and within-firm serial correlation. The t-statistics of the coefficient estimates are reported in parentheses. Statistical significance at the 10%, 5%, and 1% levels are denoted by *, **, and ***, respectively.

	Model 1 Market Lev.	Model 2 Book Lev.	Model 3 Market Lev.	Model 4 Book Lev.
D(i,t)	0.060***	0.045***	0.057***	0.045***
	(3.165)	(2.625)	(2.976)	(2.667)
D(i,t)× Profitability	-0.075	-0.210	-0.136	-0.233
	(-0.431)	(-1.076)	(-0.769)	(-1.191)
Med. Analyst For.	-0.021***	-0.006**	-0.021***	-0.006*
	(-4.210)	(-2.017)	(-4.235)	(-1.939)
Profitability	-0.109	-0.025	-0.085	-0.022
	(-1.255)	(-0.360)	(-0.966)	(-0.327)
Tangibility	0.295***	0.211***	0.284***	0.229***
	(3.881)	(3.245)	(3.693)	(3.385)
Firm Size	0.034	0.025	0.047**	0.029*
	(1.610)	(1.633)	(2.423)	(1.812)
Market-to-Book	-0.010	0.094**	0.003	0.102***
	(-0.390)	(2.607)	(0.119)	(2.710)
vol(Asset)[GARCH]	-1.281***	-0.819***	-1.349***	-0.878***
	(-8.090)	(-7.862)	(-9.700)	(-8.458)
Annual Stock Ret.	-0.014	0.005	-0.013	0.007
	(-1.342)	(0.551)	(-1.200)	(0.771)
Modified Lerner Index			0.008	-0.026
			(0.326)	(-0.813)
Firm & Year fixed effects	Yes	Yes	Yes	Yes
Within R^2	0.671	0.445	0.683	0.466
Number of Obs.	735	735	693	693

Table 11 Subsample Analysis: Summary Statistics

This table presents the summary statistics of the subsample. I construct the subsample by selecting from the matched sample the firms whose average change in profitability between pre- and post-VRA period belongs to $(-1\%, 1\%)$.

Panel A: Pre-VRA

	Treated		Matched Control		Two Sample t-test			Rank-Sum	
	Mean	Std	Mean	Std	Diff	t-stats	p-val	z-val	p-val
Tangibility	0.414	0.106	0.415	0.195	0.000	0.009	0.992	-0.240	0.811
Firm Size	4.557	0.915	5.315	1.832	-0.758	1.995	0.054	1.723	0.085
Profitability	0.092	0.065	0.082	0.057	0.010	-0.503	0.622	-0.313	0.754
Mkt-to-Book	0.529	0.156	0.749	0.576	-0.219	2.262	0.028	1.644	0.100
vol(Asset)[GARCH]	0.216	0.064	0.221	0.095	-0.004	0.181	0.858	-0.505	0.614
Annual Stock Ret.	0.028	0.331	0.046	0.347	-0.018	0.162	0.873	0.313	0.754

Panel B: Post-VRA

	Treated		Matched Control		Two Sample t-test			Rank-Sum	
	Mean	Std	Mean	Std	Diff	t-stats	p-val	z-val	p-val
Tangibility	0.391	0.124	0.412	0.214	-0.021	0.416	0.681	0.183	0.855
Firm Size	4.640	0.955	5.520	1.776	-0.880	2.215	0.034	1.776	0.076
Profitability	0.109	0.046	0.096	0.055	0.013	-0.767	0.453	-0.680	0.497
Mkt-to-Book	0.600	0.131	0.789	0.288	-0.189	3.135	0.003	2.519	0.012
vol(Asset)[GARCH]	0.249	0.069	0.246	0.112	0.004	-0.138	0.891	-0.639	0.523
Annual Stock Ret.	0.299	0.410	0.149	0.541	0.151	-1.006	0.326	-1.535	0.125

Table 12 Subsample Analysis: DID with the Matched Sample

This table presents the results of difference-in-difference panel regression with the subsample. I construct the subsample by selecting from the matched sample the firms whose average change in profitability between pre- and post-VRA period belongs to $(-1\%, 1\%)$. See the summary statistics of the subsample in Table 11. The outcome variable is market and book leverage. The post-treatment variable $D(i, t) = 1$ if a firm belongs to the U.S. steel firms (the treatment group) and is in the post-VRA period (1983-1987). The estimated coefficient of $D(i, t)$ represents the estimated effect of the resolution of uncertainty on steel firms' leverage relative to matched control firms. The definitions of other variables are in Table 1. All regressions include firm and year fixed effects. Standard errors are computed with clustering at the firm level, thus robust to heteroscedasticity and within-firm serial correlation. The t-statistics of the coefficient estimates are reported in parentheses. Statistical significance at the 10%, 5%, and 1% levels are denoted by *, **, and ***, respectively.

	Model 1 Market Leverage	Model 2 Book Leverage
D(i,t)	0.032*	0.037**
	(1.980)	(2.844)
Profitability	-0.184	0.068
	(-1.435)	(0.692)
Tangibility	0.269	0.274
	(0.829)	(1.412)
log(Asset)	0.011	0.004
	(0.145)	(0.073)
Market-to-Book	0.063	0.037
	(1.357)	(1.142)
vol(asset)[GARCH]	-1.520***	-0.859***
	(-5.792)	(-4.662)
Annual Stock Ret.	-0.034*	0.026
	(-1.942)	(1.757)
Firm fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Within R^2	0.759	0.581
Number of Obs.	122	122

Appendix

A Ellsberg Paradox and Reasonable Ambiguity Aversion

Agents are given the opportunity to bet on the draw of a ball from one of two urns. Urn A has 50 red and 50 black balls, while urn B has 100 balls in an unknown mix of red and black. First, the agents are offered a choice between two bets: (a) \$1 if the ball drawn from urn A is red and nothing if it is black, or (b) \$1 if the ball drawn from urn B is red and nothing if it is black. In the first experiment, the agents generally prefer the first bet over the second. Therefore, the predicted probability of drawing red in urn B must be strictly less than 0.5. Next, the agents are offered a choice between two new bets: (a) \$1 if the ball drawn from urn A is black and nothing if it is red, (b) \$1 if the ball drawn from urn B is black and nothing if it is red. Again the first bet has been generally preferred in experiments. It implies that the predicted probability of drawing black in urn B must be less than 0.5 (i.e., the predicted probability of picking red in urn B must be strictly higher than 0.5). Indeed, this probability assessment is inconsistent since one cannot simultaneously assign to the event "red from urn B" a probability that is strictly less and also more than 0.5. Ellsberg (1961) interprets this behavior as an aversion to the ambiguity about the odds for urn B. Therefore, the agents prefer to bet on events with known odds than on events with ambiguous odds. This phenomenon is referred to as ambiguity aversion (Ellsberg, 1961).

Now assume that the risk-averse agent displays the constant absolute risk aversion (CARA) $u(x) = 1 - e^{-\rho x}$ and the ambiguity-averse agent displays the constant absolute ambiguity aversion (CAAA) $\phi(x) = 1 - e^{-\alpha x}$. Suppose that the agent knows the distribution of red and black balls in urn A is (1/2,1/2). When she evaluates a "risky" bet on urn A, given the CARA coefficient ($\rho = 1$), her certainty equivalent is equal to

$$u^{-1}\left(\frac{1}{2}u(1) + \frac{1}{2}u(0)\right) = 0.38. \tag{A.1}$$

The agent believes that there are two possible equally likely distributions: her set of priors $\Pi = \{(0,1),(1,0)\}$ and associated belief $\mu = (1/2, 1/2)$. However, she is averse to this uncertainty and displays CAAA. When she evaluates an "ambiguous" bet on urn B, her non-ambiguity equivalent – the payoff amount she would accept in lieu of the ambiguous situation – can be computed as, given the CAAA coefficient $\alpha = 2$,

$$\phi^{-1}\left(\frac{1}{2}\phi(u^{-1}(1 \cdot u(1) + 0 \cdot u(0))) + \frac{1}{2}\phi(u^{-1}(0 \cdot u(1) + 1 \cdot u(0)))\right)$$
$$= \phi^{-1}\left(\frac{1}{2}\phi(1) + \frac{1}{2}\phi(0)\right) = 0.28. \tag{A.2}$$

The difference between the certainty equivalent (A.1) and the non-ambiguity equivalent (A.2) is a measure of the ambiguity premium (Klibanoff et al., 2005; Ju and Miao, 2007). Camerer (1999) reported that the ambiguity premium is typically on the order of 10% - 20% of the expected value of a bet in the behavioral setting. Therefore, the choice of CAAA ambiguity aversion parameter ($\alpha = 2$) seems reasonable with respect to the CARA risk aversion parameter ($\rho = 1$).

B Proofs

B.1 Proof of Lemma 1

Proof. Assume Π is compact so that I can interchange differentiation and integration.[24]

$$\mathbb{E}^{\mu}\left[\phi^{'}(V(B|F))V_B(B|F)\right] = \mathbb{E}^{\mu}(\phi^{'}(V(B|F))) \cdot \mathbb{E}^{\mu}\left[\frac{\phi^{'}(V(B|F))}{\mathbb{E}^{\mu}(\phi^{'}(V(B|F)))}\frac{\partial V(B|F)}{\partial B}\right].$$

Since,

$$\mathbb{E}^{\mu}\left[\frac{\phi^{'}(V(B|F))}{\mathbb{E}^{\mu}\phi^{'}(V(B|F))}\right] = 1.$$

I can define $Z = \frac{\phi^{'}(V(B|F))}{\mathbb{E}^{\mu}\phi^{'}(V(B|F))}$ as the density (Radon-Nykodym derivative) of μ^* with respect to μ. That is,

$$d\mu^* = \frac{\phi^{'}(V(B|F))}{\mathbb{E}^{\mu}(\phi^{'}(V(B|F)))} \cdot d\mu.$$

Thus, the first order condition can be rewritten as:

$$\mathbb{E}^{\mu^*}[V_B(B|F))] = \int_{\Pi} V_B(B|F)d\mu^*(F) = 0.$$

$\square$

B.2 Proof of Corollary 1

Proof. Assume a finite dimensional parameter space Θ. Any parametric setting, $\Pi := \{F(\cdot|\theta)\}_{\theta \in \Theta}$, therefore Π is fully indexed by θ. Assume also Π is compact.

The first order condition is:

$$\int_{\Pi} \phi'(V(B|\theta))\frac{\partial V(B|\theta)}{\partial B}d\mu(\theta)$$

$$= \int_{\Pi} \phi'(V(B|\theta))\left(kBf(B|\theta) - \tau\int_B^{\infty} f(x)dx\right)d\mu(\theta)$$

$$= kB\int_{\Pi} f(B|\theta)\phi'(V(B|\theta))d\mu(\theta) - \tau\int_{\Pi}\phi'(V(B|\theta))\left(\int_{[B,\infty]} f(x|\theta)dx\right)d\mu(\theta)$$

$$= kB\int_{\Pi} f(B|\theta)\phi'(V(B|\theta))d\mu(\theta) - \tau\int_{\Pi}\phi'(V(B|\theta))\left(1 - F(B|\theta)\right)d\mu(\theta)$$

$$= kB\int_{\Pi} f(B|\theta)\frac{\phi'(V(B,\theta))}{\int_{\Pi}\phi'(V(B,\theta))d\mu(\theta)}d\mu(\theta) - \tau\left(1 - \int_{\Pi}F(B|\theta)\frac{\phi'(V(B|\theta))}{\int_{\Pi}\phi'(V(B,\theta))d\mu(\theta)}d\mu(\theta)\right)$$

$$= kB\int_{\Pi} f(B|\theta)d\mu^*(\theta) - \tau\left(1 - \int_{\Pi}F(B|\theta)d\mu^*(\theta)\right)$$

$$= kB\,\mathbb{E}^{\mu^*}[f(B)] - \tau\left(1 - \mathbb{E}^{\mu^*}[F(B)]\right) = 0.$$

---

[24]In a case where Π is not compact, I use the Lebesgue dominated convergence theorem. Provided there exists a integrable function g such that $|\Phi'(\cdot)| < g(\cdot)$, I can interchange integration and differentiation (Folland, 1999).

That is, the manager balances the trade-off between the ambiguity-adjusted marginal tax benefit of debt and ambiguity-adjusted marginal default cost of debt.

In addition, the sufficient condition for the optimality holds. To see this, obtain the second-order condition:

$$\frac{\partial}{\partial B}\left(\int_{\Pi}\phi'(V(B|\theta))\frac{\partial V(B|\theta)}{\partial B}d\mu(\theta)\right)$$

$$= \int_{\Pi}\left(\phi''(V(B|\theta))\frac{\partial V(B|\theta)}{\partial B} + \phi'(V(B|\theta))\frac{\partial^2 V(B|\theta)}{\partial B^2}\right)d\mu(\theta)$$

$$= \int_{\Pi}-\alpha\phi'(V(B|\theta))\frac{\partial V(B|\theta)}{\partial B}d\mu(\theta) + \int_{\Pi}\phi'(V(B|\theta))\frac{\partial^2 V(B|\theta)}{\partial B^2}d\mu(\theta)$$

$$= \int_{\Pi}\phi'(V(B|\theta))(-kf(B|\theta) - kBf'(B|\theta) - \tau f(B|\theta))d\mu(\theta) < 0\,.$$

In the second line, I use the property of CAAA such that $\phi''(x) = -\alpha\phi'(x)$, then the first term vanishes due to the FOC. The last line evidently holds because $\phi'(V) > 0$ and $B < \theta$. $\qquad\square$

B.3 Proof of Proposition 1

Proof. Let $G(\alpha, B, \Pi) = \int_{\Pi}\phi'(V(B|\theta))\frac{\partial V(B|\theta)}{\partial B}d\mu(\theta) = 0$. Since the sufficient condition for the optimality of B holds (i.e., $\frac{\partial G}{\partial B} < 0$), by the implicit function theorem, it is enough to show $\frac{\partial G}{\partial \alpha} < 0$. Because $\phi'(x) = \alpha e^{-\alpha x}$ and $\frac{\partial}{\partial \alpha}\phi'(x) = \frac{1}{\alpha}\phi'(x) - \phi'(x)x$,

$$\frac{\partial G}{\partial \alpha} = \int_{\Pi}\left(\frac{1}{\alpha}\phi'(V(B|\theta)) - \phi'(V(B|\theta))V(B|\theta)\right)(-kBf(B) + \tau(1 - F(B)))d\mu(\theta)$$

$$= -\int_{\Pi}\phi'(V(B|\theta))V(B|\theta)(-kBf(B) + \tau(1 - F(B)))d\mu(\theta) < 0\,.$$

In the first line, I use the FOC (8). The first term of the second line also vanishes because of FOC. Observe $V(B,\theta) > 0$ and $V'(B,\theta) > 0$ for all θ in Π. Therefore, the last line is valid.

Next, let the reference parameter be θ_0 and the amount of uncertainty be δ. Accordingly, the set of priors is defined as $\Pi = [\overline{\theta}, \underline{\theta}]$, where $\overline{\theta} = \theta_0 + \delta$ and $\underline{\theta} = \theta_0 - \delta$. Assume the manager puts the uniform belief $\mu(d\theta) = \frac{1}{2\delta}d\theta$ on Π. Then, at the optimal B satisfying (8),

$$\frac{\partial}{\partial \delta}\left(\int_{\theta_0-\delta}^{\theta_0+\delta}(-kBf(B|\theta) + \tau\overline{F}(B|\theta))\phi'(V(B|\theta))\frac{1}{2\delta}d\theta\right)$$

$$= (-kBf(B|\overline{\theta}) + \tau\overline{F}(B|\overline{\theta}))\phi'(V(B|\overline{\theta})) + (-kBf(B|\underline{\theta}) + \tau\overline{F}(B|\underline{\theta}))\phi'(V(B|\underline{\theta}))$$

$$-\frac{1}{\delta}\int_{\Pi}(-kBf(B|\theta) + \tau\overline{F}(B|\theta))\phi'(V(B|\theta))\frac{1}{2\delta}d\theta < 0,$$

where $\overline{F}(B|\theta) = 1 - F(B|\theta)$. At the optimal B that satisfies (8), the last term in the second line vanishes due to the FOC, and $-kBf(B|\overline{\theta}) + \tau\overline{F}(B|\overline{\theta}) > 0$ and $-kBf(B|\underline{\theta}) + \tau\overline{F}(B|\underline{\theta}) < 0$. Finally, observe $\phi'(v)$ is (exponentially) a monotone decreasing function and $V(B|\underline{\theta}) < V(B|\overline{\theta})$, where $\underline{\theta} < \overline{\theta}$. Therefore, the last line is valid. $\qquad\square$

B.4   Proof of Proposition 2

Lemma B.1. *When a (risk-averse) manager faces uncertainty, the ambiguity-neutral manager combines the uncertainty about the distribution and risk of the distribution into the variance of a new density. Precisely, let* $\Pi = \{F(\cdot|\theta)\}_{\theta \in \Theta}$ *be the compact set of prior and* μ *associated belief over* Π. *Then, there exists a density* $\widehat{f}$ *given by:*

$$\widehat{f}(x) = \int_{\Pi} f(x|\theta) d\mu(\theta)\,,$$

such that

$$\int_{\Pi} \left(\int_{\underline{x}}^{\overline{x}} u(x) f(x|\theta) dx \right) d\mu(\theta) = \int_{\underline{x}}^{\overline{x}} u(x) \widehat{f}(x) dx\,.$$

That is, an ambiguity-neutral manager acts behaviorally the same as a Bayesian manager who puts the prior $\mu(d\theta)$ *on the parameter of* $f(x|\theta)$.

Proof. By Fubini's theorem,

$$\int_{\Pi} \left(\int_{\underline{x}}^{\overline{x}} u(x) f(x|\theta) dx \right) d\mu(\theta) = \int_{\underline{x}}^{\overline{x}} u(x) \left(\int_{\Pi} f(x|\theta) d\mu(\theta) \right) dx = \int_{\underline{x}}^{\overline{x}} u(x) \widehat{f}(x) dx$$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ □

Proof of Proposition 2. According to Lemma B.1, in the presence of uncertainty, a risk-averse but ambiguity-neutral manger constructs the new compounding distribution $\widehat{f}(x)$ by combining the uncertainty with risk of the distribution. For the simplicity of notation, use $f(x)$ instead of $\widehat{f}(x)$.

The risk-averse but ambiguity-neutral manager's optimality condition for B is:

$$f(B)(u(B) - u(B(1-k))) = \tau \int_{B}^{\infty} u'((1-\tau)x + \tau B) f(x) dx, \tag{B.1}$$

where $u(\cdot)$ is CARA utility function such that $u'(x) > 0$, $u''(x) < 0$ and $\alpha = -u''/u'$. Because $u(x)$ is continuous and differentiable on $[(1-k)B, B]$, by the mean value theorem there exists $B_0 \in [(1-k)B, B]$ such that:

$$kB\, u'(B_0)\, f(B) = \int_{B}^{\infty} u'((1-\tau)x + \tau B) f(x) dx\,. \tag{B.2}$$

Let

$$G(B, \sigma) = -kB\, u'(B_0)\, f(B) + \int_{B}^{\infty} u'((1-\tau)x + \tau B) f(x) dx = 0\,. \tag{B.3}$$

Then, by the implicit function theorem,

$$\frac{\partial B}{\partial \sigma} = -\frac{\frac{\partial G}{\partial \sigma}}{\frac{\partial G}{\partial B}}\,.$$

From (B.3):

$$-\frac{\partial G}{\partial B} = k\, u'(B_0) f(B) + k\, B\, u'(B_0) \frac{\partial f(B)}{\partial B} + \tau\, u'(B) - \tau^2 \int_{B}^{\infty} u''((1-\tau)x + \tau B) f(x) dx > 0$$

and

$$\frac{\partial G}{\partial \sigma} = -k\, B\, u'(B_0)\frac{\partial f(B)}{\partial \sigma} + \tau \frac{\partial}{\partial \sigma}\int_B^\infty u'((1-\tau)x+\tau B)f(x)dx. \tag{B.4}$$

Since $u'(t) > 0$ for all $t \in [B,\infty]$:

$$\frac{\partial G}{\partial \sigma} < -k\, B\, u'(B_0)\frac{\partial f(B)}{\partial \sigma} + \sup_{t\in[B,\infty)} u'((1-\tau)x+\tau B)\cdot\frac{\partial}{\partial \sigma}\int_B^\infty f(x)dx\,.$$

Assuming $B < \mathbb{E}X = \theta$, $\frac{\partial}{\partial \sigma}\left(\int_B^\infty f(x)dx\right) < 0$ for all $0 < \sigma < +\infty$. Hence, (i) if:

$$\frac{\partial f(B)}{\partial \sigma} > 0 \Longleftrightarrow \sigma < \theta - B\,,$$

then combining with $-\frac{\partial G}{\partial B} > 0$:

$$\frac{\partial G}{\partial \sigma} < 0 \Longleftrightarrow \frac{\partial B}{\partial \sigma} < 0\,.$$

Otherwise, let a solution of equation (B.4) be $\bar{\sigma}$. Then, if $\theta - B < \sigma < \bar{\sigma}$,

$$\frac{\partial G}{\partial \sigma} < 0 \Longleftrightarrow \frac{\partial B}{\partial \sigma} < 0\,,$$

but (ii) if $\sigma \geq \bar{\sigma}$, then:

$$\frac{\partial G}{\partial \sigma} \geq 0 \Longleftrightarrow \frac{\partial B}{\partial \sigma} \geq 0\,.$$

$\square$

C Numerical Examples: Optimal Leverage Ratio

In this section, I provide the computational details to generate Figures 1, 2, and 3.

C.1 Ambiguity-Averse but Risk-Neutral Manager

To compute the optimal debt of the ambiguity-augmented model, I make the following assumptions:

1. The Knightian manager is risk-neutral and knows $X \sim N(\theta,\sigma^2)$. She is certain about variance σ^2, but uncertain about mean θ. Instead, she collects all candidates of distribution $F_i(x)$ for X and constructs $\Pi = \{F_i(x)\}_{i=1}^n$.

2. Suppose all distributions $\{F_i(x)\}_{i=1}^n$ are Gaussian distributions with a known and common standard deviation σ. Then $F_i(x) = F(x;\theta_i,\sigma)$ is fully indexed by θ_i when σ is known. The set Π is assumed to be finite, so I can write $\Pi = \{\theta_i\}_{i=1}^N$ without loss of any information.

3. The manager's attitude toward ambiguity is characterized by the constant absolute ambiguity aversion (CAAA) function as in equation (9) in Definition 1.

4. The dispersion of Π, denoted as $||\Pi||$, represents the amount of uncertainty the manager faces. Under assumption 2,
$$\Pi = \{\theta_{min},\cdots,\theta_{max}\}, \qquad \theta_{min} < \theta_{max}.$$
Then, the length of the interval $|\theta_{max} - \theta_{min}|$ can be a representation of $||\Pi||$. A larger $||\Pi||$ implies that the manager believes that the true mean belongs to a larger interval (i.e., she confronts higher uncertainty). Fixing the average of $\{\theta_i\}_{i=1}^n$, as $||\Pi||$ increases, the lowest

possible mean θ_{min} decreases. Although θ_{max} also increases as $\|\Pi\|$ increases, the manager's ambiguity aversion forces her to pay higher attention to the worst case $(\theta_{\min})$ than the best (θ_{max}).

5. N, the number of possible priors, is assumed to be 3 and the firm's volatility σ is 0.3. The manager believes all three priors in $\|\Pi\|$ are equally likely. That is,

$$\Pi = \{\theta_1, \theta_2, \theta_3\}, \quad \sigma = 0.3, \quad \text{and} \quad \mu(\theta_i) = \frac{1}{3}, \quad \text{where} \quad i = 1, 2, 3 \tag{C.1}$$

such that $\|\Pi\| = |\theta_1 - \theta_3|$.

6. The optimal leverage ratio is defined as:

$$\text{Levarage ratio} = \frac{B^*}{E(B^*) + B^*}, \tag{C.2}$$

where B^* is the optimal amount of debt computed from a relevant first-order condition, and $E(B^*)$ is market value of equity at B^* using in equation (3).

Under these assumptions, the ambiguity-averse manager chooses the optimal debt level to satisfy:

$$\max_{B>0} \sum_{i=1}^{3} \mu(\theta_i) \cdot \phi(V(B, \theta_i)) \tag{C.3}$$

with respect to (9), (C.1) and

$$V(B, \theta_i) = \left(\frac{1}{1+r}\right) \left(\int_0^B x(1-k) \, f(x; \theta_i, \sigma) dx + \int_B^{\infty} \left((1-\tau)x + \tau B\right) f(x; \theta_i, \sigma) dx\right),$$

where $f(x; \theta_i, \sigma)$ is the normal density with mean $\theta_i \in \Pi$ and a known standard deviation σ.

According to Proposition 1, the first-order condition of equation (C.3) is:

$$\sum_{i=1}^{3} \mu^*(\theta_i) \frac{\partial V(B, \theta_i)}{\partial B} = 0, \tag{C.4}$$

where the ambiguity-adjusted belief is:

$$\mu^*(\theta_i) \equiv \frac{\mu(\theta_i)\phi'(V(B, \theta_i))}{\sum_j^3 \mu(\theta_j)\phi'(V(B, \theta_j))}.$$

Then the optimal leverage B satisfies:

$$kBf^*(B) = \tau(1 - F^*(B)),$$

where $f^* = \sum_i^3 \mu^*(\theta_i) f(x|\theta_i)$ is a mixture of normal densities $f(x|\theta_i)$ with ambiguity-adjusted belief $\mu^*(\theta_i)$. It is a discrete counterpart of Corollary 1.

For the numerical computations, I set the marginal corporate tax rate as $\tau = 0.35$ and the proportional deadweight cost of default as $k = 0.4$. The particular choice of tax rates are applicable to the 1990 - 2009 period following the 1986 Tax Reform Act (Graham, 2000). I also fix the set of

priors and associated belief as:

$$\Pi = \{0.7, 1, 1, 3\} \qquad \mu(\theta_i) = \frac{1}{3} \qquad i = 1, 2, 3 \, , \tag{C.5}$$

such that the amount of uncertainty is fixed as $\|\Pi\| = 0.3$. The other parameters are set as before: $\sigma = 0.3$, $\tau = 0.35$, and $k = 0.4$. I now change only the manager's degree of ambiguity aversion (α) and numerically compute the optimal leverage decisions of the ambiguity-aversion augmented model with varying α. Figure 1 illustrates the results. As expected, the result is consistent with Proposition 1. As the manager's ambiguity aversion increases (α rises), she takes on less leverage. In Figure 1, the ambiguity-averse manager ($\alpha = 8$) takes substantially less leverage (0.64) than the ambiguity-neutral manager (0.80).

I turn to compute the optimal leverage ratio with respect to the amount of uncertainty perceived by the manager. I specify the set of priors as $\Pi = \left\{1 - \frac{u}{2}, 1, 1 + \frac{u}{2}\right\}$ such that the amount of manager's ambiguity $\|\Pi\| = u$. For this simulation, I fix the degree of the manager's ambiguity aversion as $\alpha = 8$, and set $\tau = 0.35$ and $k = 0.4$. I change only the amount of uncertainty $\|\Pi\|$ from 0 to 0.8, and numerically determine the optimal leverage decisions of the ambiguity-aversion augmented model with varying $\|\Pi\|$. Figure 2 presents the numerical results. Point A in the figure represents the optimal leverage decision when the manager faces no uncertainty about the distribution of cash flow. As can be seen, the manager who faces the amount of uncertainty $\|\Pi\| = 0.3$, 30% dispersion from the reference mean ($\theta_2 = 1$), takes on substantially less debt (0.61) than the manager who faces no uncertainty (0.83).

C.2 Risk-Averse but Ambiguity-Neutral Manager

I first characterize a manager's risk aversion as the CARA:

$$u(x) = 1 - e^{-\rho x} \qquad \text{where } \rho > 0 \, , \tag{C.6}$$

and the coefficient of absolute risk aversion is $-u''(x)/u'(x) = \rho$. The risk-averse but ambiguity-neutral manager's optimal amount of debt (B) is then computed using the first order condition (B.1):

$$f(B)(u(B) - u(B(1 - k))) = \tau \int_B^\infty u'((1 - \tau)x + \tau B)f(x)dx.$$

The leverage ratio is computed using equation (C.2). It is evident that the optimal level of debt when the manager is risk-neutral (and ambiguity-neutral) can be computed using the first-order condition (B.1) by setting $u(x) = x$.

Figure 3 presents the results. The top dashed line in the figure represents the manager's optimal leverage ratios with an increase in risk when she is ambiguity- and risk-neutral. The middle dotted line represents the optimal leverage ratios when the manager is risk-averse but ambiguity-neutral. The bottom solid line represents the optimal leverage ratios when the manager is risk-neutral but ambiguity-averse. Note that the risk-neutral but ambiguity-averse manager's optimal leverage ratios are computed by the procedure described in Appendix C.1. In addition, I set the (exogenous) tax and proportional bankruptcy parameters as $\tau = 0.35$ and $k = 0.4$.

D Optimal Leverage: Ambiguity-Averse Manager v.s. Risk-Averse Manager

Consider two managers. Manager "A" is risk-neutral but ambiguity-averse with CAAA preference. Manager "R" is risk-averse with CARA preference, but is ambiguity-neutral. Since, at the given level of σ, there is one-to-one mapping between the level of debt and the leverage ratio, Proposition D.1 states that given a fixed level of risk, the leverage ratio of manager "A" is strictly less than that of manager "R," if and only if the following condition (D.6) is satisfied.

Proposition D.1. *For a given level of risk, the optimal debt of manager "A," is strictly less than that of manager "R," if and only if, the amount of uncertainty perceived by the managers (δ), the level of the risk of the firm's cash flow (σ), the coefficient of absolute ambiguity aversion (α) of the manager "A," and the coefficient of absolute risk aversion (ρ) of the manager "R" satisfy condition (D.6).*

Proof. Assume Π is compact. Let the optimal leverage taken by the risk-averse but ambiguity-neutral manager be B_R, which then satisfies the first-order condition:

$$G_R(B_R) = -KB_R u'(B_0) \int_\Pi f(B_R|\theta)d\mu(\theta) + \tau \int_\Pi \int_{B_R}^{\bar{x}} u'((1-\tau)x+\tau B_R)f(x|\theta)dxd\mu(\theta) = 0, \ \ (D.1)$$

where $B_0 \in [(1-k)B_R, B_R]$ defined in equation (B.2) in Appendix B.4.

Let the optimal leverage taken by the risk-neutral but ambiguity-averse manager be B_A, which then satisfies the first-order condition:

$$G_A(B_A) = -kB \int_\Pi \phi'(V(B_A|\theta))f(B_A|\theta)d\mu(\theta) + \tau \int_\Pi \phi(V(B_A|\theta)) \int_{B_R}^{\bar{x}} f(x|\theta)dxd\mu(\theta) = 0. \ \ (D.2)$$

Assuming $B < \theta$, $\frac{\partial G_R}{\partial B} < 0$ and $\frac{\partial G_A}{\partial B} < 0$. That is, $G_R(B)$ and $G_A(B)$ are monotonically decreasing in B.

Since $G_A(B)$ is a monotone decreasing function of B, it is sufficient to show that $G_A(B_R) < 0$ in order to prove $B_A < B_R$.

$$G_A(B_R) = -kB_R \int_\Pi \phi'(V(B_R|\theta))f(B_R|\theta)d\mu(\theta) + \tau \int_\Pi \phi'(V(B_R|\theta)) \left(\int_{B_R}^\infty f(x|\theta)dx \right) d\mu(\theta).$$

By the mean value theorem, there exists a $\theta_1 \in \Pi$ such that:

$$G_A(B_R) = -kB_R\phi'(V(B_R|\theta_1)) \int_\Pi f(B_R|\theta)d\mu(\theta) + \tau \int_\Pi \phi'(V(B_R|\theta)) \left(\int_{B_R}^\infty f(x|\theta)dx \right) d\mu(\theta). \ \ (D.3)$$

According to (D.1),

$$kB_R \int_\Pi f(B_R|\theta)d\mu(\theta) = \tau \int_{B_R}^\infty \frac{u'((1-\tau)x+\tau B_R)}{u'(B_0)} \left(\int_\Pi f(x|\theta)d\mu(\theta) \right) dx.$$

Plug this into (D.3),

$$
\begin{aligned}
G_A(B_R) &= -\tau\phi'(V(B_R|\theta_1))\int_{B_R}^{\infty}\frac{u'((1-\tau)x+\tau B_R)}{u'(B_0)}\left(\int_{\Pi}f(x|\theta)d\mu(\theta)\right)dx \\
&\quad +\tau\int_{\Pi}\phi'(V(B_R|\theta))\left(\int_{B_R}^{\infty}f(x|\theta)dx\right)d\mu(\theta) \\
&= \left(-\phi'(V(B_R|\theta_1))\frac{u'((1-\tau)x_0+\tau B_R)}{u'(B_0)}+\phi'(V(B_R|\theta_2))\right) \\
&\quad \times\int_{\Pi}\left(\int_{B_R}^{\infty}f(x|\theta)dx\right)d\mu(\theta),
\end{aligned}
\tag{D.4}
$$

where $\theta_2 \in \Pi$ and $x_0 \in [B_R, \overline{x}]$. I use the mean value theorem twice in the last line.

According to (D.4), for any given B_R, $B_A < B_R$, if and only if:

$$
\frac{u'((1-\tau)x_0+\tau B_R)}{u'(B_0)} > \frac{\phi'(V(B_R|\theta_2))}{\phi'(V(B_R|\theta_1))}.
\tag{D.5}
$$

Assuming $\phi(\cdot)$ is the CAAA and $u(\cdot)$ is the CARA preference, the inequality (D.5) is equivalent to:

$$
\rho((1-\tau)x_0+\tau B_R-B_0) < \alpha(V(B_R|\theta_2)-V(B_R|\theta_1)),
\tag{D.6}
$$

where α is the coefficient of CAAA, and ρ is the coefficient of CARA. $\qquad\square$

Note that the condition (D.6) is more likely satisfied (keeping all the other things fixed) if (i) the ambiguity aversion (α) is higher than risk aversion (ρ), and if (ii) the dispersion of Π (i.e., $\|\theta_1 - \theta_2\| = \delta$) is higher relative to risk (σ). It is because a decrease in σ decreases $x_0 \in [B_R, \overline{x}]$ and increases $B_0 \in [(1-k)B_R, B_R]$, which makes the left-hand side of the condition (D.6) decrease.

E Measuring Asset Volatility using GARCH

Since the asset value or asset volatility of a firm can rarely be observed, I estimate the asset volatility of a firm implied from the volatility of the observed equity return process. Specifically, following Faulkender and Petersen (2006), I estimate asset volatility by multiplying the equity volatility by the equity-asset ratio. The formula for asset volatility at time t is:

$$
\sigma_{V_t} = \sqrt{\left(\frac{E_t}{V_t}\right)^2\sigma_{E_t}^2 + \left(\frac{D_t}{V_t}\right)^2\sigma_{D_t}^2 + 2\left(\frac{D_t}{V_t}\right)\left(\frac{E_t}{V_t}\right)\rho\,\sigma_{D_t}\sigma_{E_t}},
\tag{E.1}
$$

where V is the market value of the asset, E the market value of equity, D the total debt, σ_D the volatility of debt, and ρ the correlation coefficient between debt and equity. Assuming $\sigma_D = 0$, I have:

$$
\sigma_{V_t} = \frac{E_t}{V_t}\sigma_{E_t}.
\tag{E.2}
$$

Comparing with equation (E.1), the approximation in equation (E.2) understates the true asset volatility except for the all equity firm.[25] Also, the magnitude of error increases with the debt-

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[25]Alternatively, the Merton formula provides the approximation of the volatility of an asset such as:

$$
\sigma_{V_t} = \frac{\partial V/V}{\partial E/E}\sigma_{E_t} = \frac{1}{\Delta(\sigma_{V_t})}\frac{E}{V}\sigma_{E_t}
$$

to-asset ratio. However, the difference-in-difference analysis also relies on the change of control variables. Hence, this type of measurement error will be mitigated.

The GARCH model is used to estimate the time-varying equity volatility. That is, tomorrow's volatility is predicted to be a weighted average of the (i) long run average variance, (ii) today's volatility (forecasted from yesterday), and (iii) the news effect (today's squared equity return).

$$r_{it} = \epsilon_{it}\sqrt{\sigma_{E,it}} \qquad \epsilon_{it} \sim N(0,1), \tag{E.3}$$

$$\sigma_{E,it} = \underbrace{c_i}_{(i)} + b_i \underbrace{\sigma_{E,it-1}}_{(ii)} + a_i \underbrace{r_{it-1}^2}_{(iii)}, \tag{E.4}$$

so that a firm i's conditional equity volatility at time t given information $t-1$,

$$r_{it}|\mathcal{F}_{t-1} \sim N(0, \sigma_{E,it}). \tag{E.5}$$

The GARCH-based volatility estimate is a more accurate time-varying risk measure compared to the historical standard deviation approach. According to (E.3), the GARCH model emphasizes a surprise close to the event for study, therefore it incorporates the realized, as well as the forward-looking risk of an asset when the 1982-VRA news arrives.

---

where $\Delta(\sigma_{V_t})$ is the option's delta. Faulkender and Petersen (2006) report that this alternative does not affect the results when running a capital structure panel regression.