Risk Management:

Evidence from Oil Price Hedging in Highway Procurement

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Abstract

There is little empirical evidence about risk management heterogeneity across firm types. I evaluate a policy that shifts oil price risk in highway procurement from the private sector to the government, reducing the cost of hedging to zero. In a triple-differences design using data from Kansas and Iowa, I show that firms value hedging oil price risk between the auction and commencement of work. Consistent with the prediction that hedging is more valuable for financially constrained firms, I find higher risk premiums in private vis-à-vis public firms and in smaller vis-à-vis larger firms. I also find that family ownership and a lack of diversification are associated with higher risk premiums. Competition is highly imperfect in this industry. Monopoly power in product markets, together with market frictions in derivative hedging, may limit the pass-through of risk to financial markets, and thus prevent efficient allocation of risk.

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1 Introduction

There are rich theoretical predictions of how nonlinearities in firm costs or other characteristics may lead to corporate risk management (e.g. Smith and Stulz 1985). Empirical tests have yielded some evidence that hedging against cash flow volatility is more valuable to more constrained firms (e.g. Vickery 2008, Haushalter 2000) and is associated with increased firm value (e.g. Mackay and Moeller 2007, Nance et al. 1993).[1] Other relationships are more contested or less well studied, in part because the literature has often relied on cross-sectional data, survey data, and data exclusively from publicly traded firms. Further, the risk in question can be correlated with determinants of firm value, especially demand. Last, risk management may be conflated with speculative activity when financial derivatives measure hedging. This paper exploits a natural experiment in a panel setting to assess the value to firms of relaxing constraints on risk management. It then examines how risk management varies by firm ownership, size, and diversification.

Highway procurement is a useful context to study risk management. Paving firms take on oil price risk in the period between a government auction of the project and commencement of work, and government highway "demand" is plausibly exogenous to oil price and other market risks. I use detailed procurement auction data from Iowa and Kansas between 1998 and 2012 to assess the impact of oil price volatility on firm bids to pave asphalt ("blacktop") roads, whose primary component is bitumen, an oil product. This industry is economically important; the U.S. spends around $150 billion annually on public highway construction and maintenance, of which about 85% goes to asphalt roads (CBO 2011).

Many U.S. state governments have recently shifted oil price risk from contractors to Departments of Transportation. These policies emerged from a belief - to my knowledge untested - that firms charge large risk premiums in oil-intensive projects, despite oil's near-zero CAPM-implied beta. In 2006 Kansas implemented such a risk removal for bitumen, but Iowa has never done so. The difference between the two otherwise observably similar states is apparently due to bureaucratic preference. After the policy, firms in Kansas were automatically fully hedged.

In a triple-differences design, I test the effect of additional oil price volatility on bids

[1] On the other hand, Rampini et al. (2014) show that more financial constraints may lead to less hedging in practice, and Brown et al. (2003) do not find that hedging improves performance. Additional work on benefits of hedging includes Carter et al. (2006) and Cornaggia (2013). On tax convexity, Graham and Smith (1999) and Graham and Rogers (2002) find opposing results. Guay and Kothari (2003), Stulz (1996) and Haushalter (2000) find greater hedging by larger firms (using derivatives). Panousi and Papanikolaou (2012) and Tufano (1996) find a positive relationship between manager ownership of the firm and effective risk aversion.

for bitumen in Kansas compared to Iowa after relative to before the policy. I show that a 100% increase in historical volatility leads bitumen bids in Kansas to be 16% lower than in Iowa after relative to before the policy. This effect is robust to a variety of tests, including placebo, falsification with non-oil bid items, alternative volatility metrics, and measures to address potential serial correlation in the variables. Fully hedged firm bids are much less sensitive to oil price volatility, suggesting that firms place a high value on hedging.

Hedging a diversifiable risk is worthwhile only if market imperfections cause cash flow variability to be costly to the firm (Stulz 1996). Froot, Scharfstein and Stein (1993, henceforth FSS) show that financially constrained firms are most likely to hedge when cash flows are negatively correlated with investment opportunities. My setting conforms to this situation; highway contractors are not paid until work is well underway, but must fund labor, materials and equipment costs at the beginning of the construction season. They tend to be cash flow constrained precisely when they are most exposed to oil price risk. In Rampini and Viswanathan's (2010, 2013, henceforth RV) model, constrained firms value hedging more but must weigh its benefits against those of current investment. I show that highway paving firms place a large value on being fully hedged, consistent with risk aversion among constrained firms in both FSS and RV.

Idiosyncratic volatility should not have a measurable effect on bids if firms hedge in financial markets. Interviews with executives of the firms in my data indicate that only the largest, publicly traded firms regularly hedge using oil futures or options. A lack of sophistication, basis risk, economies of scale in hedging, information costs, and the opportunity cost of capital dedicated to hedging are reasons not to hedge in financial markets. Imperfect competition in the industry prevents firms with higher hedging costs from being priced out of the market.[2] Monopoly power in product markets may impede efficient allocation of risk to financial markets, instead leading firms to pass higher risk premiums to the consumer. Relatedly, Scharfstein and Sunderam (2013) find that imperfect competition in mortgage lending decreases the pass-through of lower mortgage-backed security yields to mortgage rates, vitiating government policies aimed at home buyers.

Highway paving firms are heterogeneous, and many are privately owned or family owned firms. Private firms make up 99.9% of the 5.7 million firms in the U.S. (Asker et al. 2014). Yet to my knowledge, there has been no comparison of public and private firm risk management decisions, and there is only a small literature on private firm financial constraints (e.g. Saunders and Steffen 2011). Family firms raise interesting corporate governance

[2] See Section 2.3, as well as Bajari and Ye (2003) and Porter (2005).

questions and are also economically important (Schulze et al. 2001). The theoretical literature provides diverse but largely untested theories about how family firms should manage risk (Schmid et al. 2008, Shleifer and Vishny 1986).

To assess heterogeneity, I build a simple model of the firm's bidding decision that includes a risk premium in the markup on the bitumen item bid. I present a novel reduced form strategy for estimating the impact of risk - measured as the interaction between oil price volatility and time to work start - on firm bids. Using Iowa data matched to firm characteristic data, I show that firms that are publicly listed, diversified across industries, not family-owned, and larger are less responsive to oil price risk than their respective counterpart firms. The strongest results are for the public-private and diverse-concentrated relationships. For example, with 11 months between auction and work start, at the 90th percentile of oil price volatility, a firm whose only business is asphalt paving charges a markup that is roughly \$25 per ton higher than a diversified firm, equivalent to half the average markup. This finding is consistent with evidence from oil refiners in Mackay and Moeller (2007). While the increased risk premium of private firms vis-à-vis public firms is driven by the time to work start, the increased premium of non-diversified firms and family firms is driven by oil price volatility.

The firms that are most constrained and have the most insider ownership appear to place the highest value on hedging, consistent with the theoretical literature and with a number of empirical studies, including Tufano (1996), Panousi and Papanikolaou (2012), and Geczy et al. (1997). A limitation is that I do not observe hedging directly (though I do observe 100 physical forward hedging contracts for one large firm). I cannot determine whether underlying risk aversion or hedging efficiency drives my results. For example, if public and private firms have the same risk preferences but only public firms hedge in financial markets, then private firms might appear more risk averse when they are simply less sophisticated or do not have adequate scale. While I provide evidence of heterogeneous risk management, further research is needed to identify underlying risk preferences and to establish external validity beyond this context.

I explore the real outcomes of Kansas' risk removal policy in two ways. First, I examine whether different types of firms in Kansas experienced different auction results after the policy. The policy benefited private firms at the expense of public firms, but had no measurable effect on family owned vis-a-vis non-family owned firms. Second, I show that the risk removal policy reduced the price that Kansas paid per ton of bitumen by \$37, or 12% of the average. This is relevant for procurement policy. Unfortunately, I do not have access to variables like profitability and employment to fully assess how the risk removal policy affected firms' real outcomes.

My findings contribute not only to the risk management literature, but also to work on the relationship of oil prices to real outcomes, a literature that includes Bond and Cummins (2004), Henrique and Sadorsky (2011), and Bulan (2005). Finally, this paper is related to the industrial organization literature on auctions (Hendricks and Porter 1988, Athey and Levin 2001) and the highway procurement application (Bajari and Ye 2003, Krasnokutskaya 2011, Jofre-Bonet and Pesendorfer 2003).

Section 2 explains the setting and firm risk management practices, including the implications of the conventional CAPM model. It also discusses monopoly power in the industry and describes the risk removal policy. Section 3 presents the triple-difference estimation strategy and data on Iowa and Kansas highway auctions, and Section 4 presents the risk removal policy triple-difference results. In Section 5, I assess the real effects of the policy. Section 6 evaluates risk premium heterogeneity across firms, and includes a bidding model to motivate the empirical approach.

2 Context: Risk Management and the Risk Removal Policy

In Iowa and Kansas, as in most states, the state Department of Transportation (DOT) procures highway construction projects via simultaneous sealed-bid first-price auctions. First, DOT prepares a public proposal for the project detailing the location and type of work, which includes estimated quantities of materials needed and the expected date of work start. DOT also estimates the cost of each item, but these estimates are not public either before or after the auction.[3] Bidders submit itemized bids with a price specified for each item, including a per ton bid for bitumen (also called asphalt binder). The bidder with the lowest vector sum of unit item bids wins the auction. By submitting a lower bid, a paver ensures a higher chance of winning, but takes the risk that high cost realizations could make the project unprofitable.[4] Once a winner is announced and the contract signed, time passes (5

[3] The "engineer's estimate" is calculated in both states by computer programs that use recent bid history for similar projects. Materials with volatile prices, like oil products, are updated manually. There is no reserve price; the secret estimate serves as a guide for what is reasonable.

[4] The unit item bids are analytically meaningful. Contracts are contingent rather than fixed price, so the paver is paid for the miles of guardrail actually installed, or the cubic meters of earth actually excavated, rather than the estimated quantity in the proposal. It has been widely noted in the auction literature that scoring rules, or unit-price contracts, generate incentives to skew; to overbid on items that DOT has

months on average) before work begins.

2.1 Firm Risk Management

Highway pavers face cost uncertainty at the time they place their bid. Primary risks are weather and oil prices, and secondary risks are labor shortages and equipment failure. For asphalt paving, the largest risk is that an oil price spike between the time of the auction and the time of work will lead to unexpectedly high bitumen costs. An oil product, bitumen is the black, sticky material mixed with rock pieces to make asphalt. My analysis includes only paving (also called resurfacing) projects that are very asphalt-intensive.[5] Although its price is highly correlated with crude oil, there is no liquid market or futures contracts for bitumen in the US. Instead, firms purchase bitumen in one-off, non-public transactions with local suppliers, who store bitumen purchased from refineries.

Firms can manage risk via hedges, insurance, or diversification (Merton 1995). I conducted a phone survey of the twelve largest bidders in Iowa and three large bidders in Kansas, and spoke either with a President, a Vice President, or an Estimator (who writes up the bids for DOT auctions). The firms - which range from family-owned firms with a dozen full-time employees to some of the world's largest construction conglomerates - describe themselves as very risk-averse toward input costs. They usually hedge bitumen risk with physical forward contracts signed at the time of auction with local third party suppliers. Firms sometimes wait to sign later, or buy spot at the time of work and either don't hedge at all or occasionally hedge in financial markets.[6] Storing bitumen is costly, so most paving

underestimated and to underbid on items that DOT has overestimated. DOT pays the winning contractor based on quantities actually used, so it is in the contractor's interest to put his profit margin on items that are likely to overrun. Skewing is sufficiently pervasive that IDOT explicitly forbids it, reserving the right to reject bids it deems "unbalanced." In practice, this is achieved through rules of thumb; when bid items appear to be weighted in a manner that causes them to differ appreciably from the engineer's estimate, the bid is rejected (about 3% of bids are rejected for this reason). Skewing incentives do not bias my risk management findings.

[5] I do not study diesel, another oil product used in highway paving, because it is much smaller as a percentage of the total bid, and is not a bid line item but rather goes into a line item for general overhead.

[6] The physical forward contracts are based on quotes that pavers request from bitumen suppliers before the auction. The paver often signs a contract with one supplier committing to purchase the bitumen at the quoted price at the time of work start should he win the project. The price is good only for the DOT project specified in the contract, and the bitumen can be taken typically any time during the construction season (roughly mid-April to the end of October, because paving requires a road temperature no less than 55º F). The supplier must have sufficient bitumen stored to cover all contracted supply. Although end-use demand for bitumen in Iowa only exists for 1/2 the year, oil refineries produce bitumen year-round as a byproduct. The refineries typically don't store bitumen, so they sell it to third parties who own terminals (storage capacity). These third parties, my "suppliers," start storing binder in early winter, but sign contracts with

firms do not own storage facilities. Since the suppliers do store bitumen, at the time of the auction they are partially physically hedged against the short positions they are taking in their contracts with paving firms. Thus in the supplier-paver relationship, the supplier has downside risk while the paver hedges against upside risk. If the supplier has total bargaining power, the price could include *both* firms' risk premiums.

I have 100 forward physical contracts from one firm (who I call Firm Z to protect its identity) with all three local suppliers. Firm Z is among the top three firms in number of total bids submitted, and has about the mean percentage of contracts won among regular bidders. An example (fictional) contract might be for 1,200 tons of bitumen at $510 per ton, dated January 23, 2009 for IDOT project STP-038-3(46)–2C-53, effective from April 15, 2009 to November 15, 2009. Figure 1 shows the actual per ton price specified in the contract alongside the 1-month futures contract price. Figure 2 shows the markup (the bid in the auction less the forward contract price). The markup is fairly stable at about $22 per ton regardless of oil price levels and volatility. Any risk premium is apparently included in the forward contract. In the pre-2005 period, when prices were relatively low and stable, the markup averaged 13.7 percent of the bitumen bid. Post-2005, when prices were higher and more volatile, it was 5.4 percent.

A rich literature, beginning with is Mayers and Smith (1982) and Smith and Stulz (1985), is devoted to identifying market imperfections that might lead firms to hedge. Froot, Scharfstein and Stein (1993) show that hedging can mitigate an underinvestment problem that emerges when firm cash flows are not strongly correlated with investment opportunities and firms face financial distress costs. Hedging allows firms to take advantage of profitable investment opportunities even in bad cash flow states. Rampini and Viswanathan's (2013) dynamic model of collateralized financing has a more complex relationship between hedging and financial constraints; constrained firms must weigh the benefits of current investment against those of hedging.

Firms might not hedge in financial markets because of a lack of sophistication, basis risk, economies of scale in hedging, information costs, and the opportunity cost of capital dedicated to hedging. First, the paving firms are mostly small, local, and typically do not have in-house financial sophistication. In interviews, firm executives consistently expressed distrust in Wall Street, and viewed hedging in financial markets as gambling. Second, pavers face two kinds of basis risk that separate the spot price change from the futures contract: different assets (oil vs. bitumen); and different contract time horizons. Although in theory

pavers during the winter that go far beyond their storage capacity.

pavers can choose a hedge ratio to minimize the variance of the hedge, basis risk nonetheless lowers the value of hedging.[7] Haushalter (2000) finds a strong negative correlation between basis risk in hedging instruments and the fraction of production hedged, as well as a strong positive correlation between firm assets and the likelihood of hedging. Third, small firms may not hedge because of economies of scale in hedging in financial markets (Mian 1996, Geczy et al. 1997).

Hedging ties up firm capital, a fourth reason that firms might not hedge in financial markets. While the transaction costs are low, hedging requires the firm to maintain a margin if via futures contracts or to buy calls if via options on futures. In a hypothetical calculation based on information from OptionsXpress, a brokerage firm, fully hedging against oil price increases for a typical project using oil futures might require a margin in the account of $40,000.[8] If prices fall, the broker will likely issue a margin call, requiring the immediate wiring of funds - and thus a dedicated employee - into the account to prevent the contracts from being closed. Alternatively, purchasing call options on the same number of contracts might cost around $10,000.[9] However, the firm must purchase more options than the underlying oil quantity being hedged to achieve a 1-to-1 hedge, navigating the declining delta of the option as it moves out of the money. Firms are cash flow constrained during the winter, when they participate in most auctions and establish their hedging positions. The cost of hedging all their expected bitumen consumption for the following construction season may be prohibitively high, preventing investment in equipment or labor. This is the argument in Rampini, Sufi and Viswanathan (2014), who show that constrained firms may not hedge because of inadequate resources.

Last, there is evidence in the literature that financial intermediaries may reduce the benefits to hedging. For example, Etula (2013) demonstrates a link between broker-dealer effective risk aversion (broker-dealers take the other side in OTC hedging contracts) and commodity price risk premiums, a link empirically particularly strong for energy returns. Investing in a fund may not be ideal either. Bhardwaj, Gorton and Rouwenhorst (2014) show

[7]The ideal hedge is to have any change in the spot price equal to the change in the futures contract with which you are hedging.

[8]The typical project would need uses the bitumen equivalent of roughly 4,400 barrels of oil (see http://www.eia.gov/dnav/pet/tbldefs/pet_pnp_pct_tbldef2.asp). If a firm bought five six-month futures contracts at $80 per barrel with a 10% margin requirement, it would need $40,000 in the account. More importantly, if prices fall, the broker will likely issue a margin call, requiring the immediate wiring of funds - and thus a dedicated employee - into the account to prevent the contracts from being closed. To bring the amount in the account up to the initial margin requirement, the firm may have to add roughly an extra $500 for each dollar the price of oil drops.

[9]The firm could purchase a call expiring in six months. If the call costs $2, the cost of options on 5,000 barrels is $10,000.

that commodity trading advisors on average provide excess returns (after fees) to investors of roughly zero, while gross excess returns (before fees) are 6.1%. They conclude that the best rationale for investors' continued use of these vehicles is information asymmetry. In practice, studies of oil producers and airlines have found that hedging occurs in a minority of time periods (Haushalter 2000, Carter et al. 2006, Jin and Jorion 2006).

In the conventional CAPM, the expected future oil price's relationship to the futures contract price depends on the risk-adjusted discount rate, the risk-free rate, and the spot price of oil. Abstracting from storage and transport costs, if oil covaries with the market return, the risk premium should in general be positive. That is, the discount rate should exceed the risk-free rate, equivalent to a positive CAPM beta. Investors are compensated for systematic risk by a futures price that is lower than the expected future price. Thus with perfectly functioning capital markets, firms bidding in highway auctions should charge the government the CAPM-implied beta.

The crude oil beta appears to be near zero.[10] Figure 3 shows rolling betas for a conventional strict CAPM regression.[11] The sign of the oil beta is sensitive to the period chosen, because oil's correlation with the market depends on whether the oil price movement is driven by demand or supply. With a beta of 0.5 (roughly the level post-2009), and assuming annual stock market returns of 6%, the return on bearing the oil risk (in theory the difference between the 6 month futures price and the expected spot price in 6 months) should be at most 1.5%. Similarly, Ahn and Kogan (2011) find oil equity beta from a standard CAPM procedure between 1971 and 2010 to be 0.01. Thus risk-neutral firms should charge little if any premium for holding oil price risk.

Much of the theoretical literature relies in non-linearities or asymmetries in firm cost structure or information sets to explain the value of hedging (e.g. FSS and Demarzo and Duffie 1991 and 1995). Most closely related to the input cost risk studied here, the intuition in Mackay and Moeller (2007) is that convex costs can make hedging valuable (as can concave revenues). In their model, the second derivative of the cost function with respect to the input price exists because the quantity used is a function of the input price. In contrast, in

[10] A beta of zero indicates the asset has no relationship with the market portfolio, a beta of 1 indicates that the asset has the same risk (moves with) the market. Negative beta indicates that the asset tends to move in the opposite direction of the market. In this latter case, the negative risk premium indicates that the return on the asset should be less than the risk-free rate.

[11] The expected return on the asset is $E(R_i) = R_f + \beta_i(E(R_m) - R_f)$, where returns for asset i are calculated monthly using the price time series as $R_{i,t} = \frac{p_{i,t} - p_{i,t-1}}{p_{i,t-1}}$ and $\beta_i = \frac{\text{cov}(R_i, R_m)}{\text{var}(R_m)}$. Denoting the market premium $\rho_{m,t} = R_{m,t} - R_{f,t}$, and the oil premium $\rho_{o,t} = R_{o,t} - R_{f,t}$, the regression equation is $\rho_{o,t} = \beta_o \rho_{m,t} + \varepsilon_{o,t}$. I use the front-month WTI oil futures, the S&P 500 index price for the market portfolio, and 3 month Treasury Bill interest rates for the risk free rate.

my setting the quantity of the input is exogenously fixed at the required project amount. Therefore, their line of reasoning does not rationalize hedging among paving contractors. Instead, my results suggest that financial constraints best explain

I do not address the risk of losing the auction. Anecdotal evidence from interviews suggests that paving firms are risk-averse towards input costs but risk-neutral towards an individual auction for a particular project. Firms participate in many auctions and seem to treat them as a portfolio. While the risk of losing any given auction is idiosyncratic, oil price risk for the coming construction season is highly correlated across projects.

2.2 An Imperfectly Competitive Environment

In a competitive environment firms would bid down the price of bitumen risk to the cost for the least risk averse agent. Instead, paving firms and bitumen suppliers are in oligopolistic, territorial equilibria. Highway procurement is characterized by inelastic demand, high barriers to entry, information asymmetry, easy defection detection, auction setups where phony bids are possible, and a static market environment, which are all conducive to collusion (Porter 2005). Porter and Zona (1993), Ishii (2008) and Pesendorfer (2000) demonstrate collusive bidding in highway procurement contracts, and Bajari and Ye (2003) note the widespread incidence of cartels in procurement auctions. Gupta (2002) finds collusion in Florida highway procurement and estimates that this type of auction is not competitive until there are 8 bidders participating. In my data, the average number of bidders is 3.4.

Many of the regular bidders in my dataset have well-defined territories; Figure 4 shows the location of auction wins and losses for a large bidder, Norris. Wins are obviously concentrated around its headquarters. Appendix C contains similar maps for all the top bidders, revealing that each has a distinct territory. This may be due to tacit collusion or transportation costs (with perfect competition the rents are zero on territory boundaries and positive within). In my phone survey, one CEO suggested of his own accord that the imperfectly competitive nature of the business permitted even very risk averse pavers to stay in business.

Only a handful of bitumen suppliers serve a given local market; in Iowa there are just three. The high cost of transporting bitumen permits a spatial oligopolistic equilibrium. Like the paving firms, they enjoy markups within their territories at least as large as the differential transportation cost for the next-closest supplier. In Firm Z's 100 forward physical contracts, I find distinct territories for the suppliers, shown in Appendix C Figure 1. The three suppliers provide quotes to paving firms for on average 153 Iowa DOT auctions per year. Bids (including bitumen items) are published immediately after the auction. In interviews, the suppliers suggested that recent auctions may provide a signaling mechanism, which aligns with Friedman's (1971) seminal discussion.[12] The suppliers charge the pavers if not their full cost of risk, at least a significant portion. Imperfect competition in two layers of product markets permits firms with higher effective risk aversion to remain in the market.

2.3 A Natural Experiment: Bitumen Price Adjustment Policies

In the mid-2000s, states began to adopt oil price "adjustment" policies to transfer the risk of volatile oil prices from the private sector to the government. The Kansas DOT implemented its bitumen risk removal policy in August, 2006, at which time its director of operations announced that "The volatile price of the asphalt oil has led contractors to make bids that are more costly than necessary" (Shaad 2006). Kansas adjusts its payment to the paving firm by the amount that an oil-based price index has increased or decreased since the auction. When prices go up, the firm is paid his bid plus the index's increase, and when prices go down, the firm receives less than his bid.[13] The introduction of the policy means that Kansas firms are automatically fully hedged by the government. Thus private hedging contracts with local suppliers are unnecessary; put another way, the supply contracts that formerly may have included a risk premium no longer do.

Iowa has not yet removed oil price risk from its private contractors, apparently at least partly due to official inertia. It seems that certain members of the Kansas DOT leadership became interested in oil price volatility, which ultimately led to the policy, while

[12]

"...It seems unsatisfactory for firms to achieve only the profits of the Cournot point when each firm must realize more can be simultaneously obtained by each. This line of argument often leads to something called 'tacit collusion' under which firms are presumed to act as if they colluded. How they do this is not entirely clear, though one explanation is that their market moves are interpretable as messages" (Friedman 1971).

[13]Specifically, each month KDOT publishes an Asphalt Material Index (AMI), which they purchase from Poten & Partners. Bidders incorporate the current month's AMI into their bid for asphalt. The AMI for the month of the letting becomes the Starting Asphalt Index (SAI) for the duration of the contract. KDOT technicians take samples from the mix being placed. This serves both to monitor quality and to obtain a percent bitumen content to adjust payment based on the change in the AMI. The difference between the SAI and the AMI to the nearest dollar becomes the adjustment factor, applied to work completed during that month. The adjustment only occurs when the AMI differs from the SAI by $10 or more. The Kansas price index is almost identical to the Argus Media spot price index I use elsewhere in the paper. Both are created from surveys of recent bilateral transactions. The KDOT index is for PG 64-22 but KDOT applies it to all grades. For the index, see: http://www.ksdot.org/burconsmain/ppreq/asphaltpriceindex.asp. For the specifications, see: http://www.ksdot.org/burconsmain/specprov/pdf/90m-0295-r01.pdf.

the Iowa leadership did not develop such an interest. I have no reason to believe that a systematic difference between the states led to the different policy outcomes. Both DOTs report that some firms were in favor, and some opposed, to the policy. Kansas, located immediately to the southwest of Iowa, has similar weather patterns, road systems, and auction characteristics. There are also similar proportions of public, private and family owned firms in the two states (see Section 3.2).

The consensus in the policy community is that these price "adjustment" policies, now used by most states, reduce firms' input cost uncertainty, and the cost to the government of bearing oil price risk is offset by lower bids (Skolnik 2011). However, to my knowledge there is no public evaluation of the policies' impact on procurement cost. In the only analysis thus far, Kosmopoulou and Zhou (2014) examine only at one state, Oklahoma, so they cannot control for economic and other factors. They attribute their finding that firms bid more aggressively after the policy to the winner's curse effect, and assume firms are risk-neutral.

3 Estimation Strategy

3.1 Triple-Difference Design

Iowa and Kansas' bifurcated policies towards oil price risk offer a unique opportunity to assess firm risk preferences. I use a triple-difference design to assess whether oil price volatility affects bitumen bids in Iowa relative to Kansas since the implementation of the bitumen price adjustment policy in 2006. The triple-difference design is more robust than any differences-in-differences approach (Imbens and Wooldridge 2007). The underlying intuition, however, is the same. If two groups are ex-ante similar and one is subject to treatment in the second of two time periods, then with controls for treatment and state the estimated coefficient on the treated state should be the average difference between the treatment group and the control group, without bias from trends over time and from permanent differences between the groups. Following the suggestion in Bertrand et al. (2004), I cluster standard errors by firm in my primary specification, and demonstrate that the results are robust to alternative groupings.

I estimate the effect of oil price volatility on bids in Kansas ($\mathbf{I}_{KS_j} = 1$) after the policy was implemented ($\mathbf{I}_{Policy_t} = 1$). The regression, where i indexes bidders, j indexes auctions, and t indexes letting day, is:

$$\ln b_{ijt} = \beta_0 + \beta_1 \mathbf{I}_{KS_j} \cdot \mathbf{I}_{Policy_t} \cdot \ln V_t^{\text{oil}} + \beta_2 \ln V_t + \beta_3 \ln p_t^{\text{oil}} + \gamma' \cdot \text{Auction/Bidder Chars}$$
$$+ \beta_7 \mathbf{I}_{\text{state}_j} + \beta_8 \mathbf{I}_{\text{policy}_j} + \beta_9 \mathbf{I}_{\text{policy}_t} \cdot \ln V_t^{\text{oil}} + \beta_{10} \mathbf{I}_{\text{policy}_t} \cdot \mathbf{I}_{KS_j} + \beta_{11} \mathbf{I}_{KS_j} \cdot \ln V_t^{\text{oil}}$$
$$+ \delta \mathbf{I}_{county_j} + \delta \mathbf{I}_{month_j} + \delta \mathbf{I}_{year_j} + \epsilon_{ijt} \quad (1)$$

$$\gamma' \cdot \text{Auction/Bidder Chars} = \gamma_1 \#Bidders_j + \gamma_2 \ln AveTotalBid_j + \gamma_3 \ln ReqTons_j + \gamma_4 \ln OtherBidItems_{ij} + \gamma_5$$

where $\ln V_t^{\text{oil}}$ is oil volatility, p_t^{oil} is the 6-month futures price, $\#Bidders_j$ is the number of bidders in the auction, $AveTotalBid_j$ is the average total bid in the auction (a measure of the project scale), $ReqTons_j$ is the estimated required tons of asphalt, $\ln OtherBidItems_{ij}$ is the sum total of all other bid items that the bidder submits, and $Distance_{ij}$ is the distance in miles between the bidder and the project site. Equation 1 includes controls for the state, the time period (whether the policy was in effect), the three sets of interactions (policy-oil volatility, policy-state, and state-oil volatility), and fixed effects for the county, the month of the year, and the year. Kansas' competitive equilibrium both among pavers and between pavers and suppliers may have changed after the policy. However, changes that are unrelated to oil price risk should be controlled for by the state and state-time fixed effects.

3.2 Data on Highway Auctions and Oil Prices

My estimation of Equation 1 employs comprehensive, detailed data on auctions and payments from the Iowa and Kansas DOTs between 1998 and 2012. I focus on straightforward paving projects projects that are bitumen-intensive. In these contracts the bitumen cost comprises 11.3% of the total bid on average, but can be up to 40%.[14] Figure 5 shows Iowa and Kansas bitumen bids (bid unit items within the larger total project bid) over time, as well as the crude oil price and historical oil price volatility. Appendix A Figure 1 shows the bids and oil volatility in the years immediately around the 2006 policy.

Summary statistics are in Table 1, with bid data in the top panel and contract (auction) data in the bottom panel. There are more projects in Iowa than in Kansas; in total

[14]These projects do not include bridge work or extensive earthwork. For Kansas, the work types I include are called overlay and surfacing, codes 20,53,55,64,65,66, and 67. For Iowa, they are generally called paving and resurfacing, codes 1521, 1522, 1523, 1524, 1525, 1021 and 1022.

there are 4,618 bids in Iowa and 1,438 bids in Kansas. Iowa projects are more bitumen-intensive, but the item bids for bitumen are very similar across the two states, at $303 for Iowa and $362 for Kansas over the whole period. Kansas firms are also slightly further away from the project site than Iowa firms, at 113 miles compared to 88 miles. The auction characteristics are similar across the two states, with an average of 3.3 bidders in Iowa auctions and 3.6 bidders in Kansas auctions. Money on the table (the percent difference between the second lowest and the winning bid) is 6.3% for Iowa and 5.3% for Kansas. These figures are close to Krasnokutskaya (2011), who used data from Michigan and found that money on the table averaged 7%. The time to work start is also similar, at 4.6 months for Iowa and 5.2 months for Kansas. None of the differences are statistically significant.

I use two dependent variables. One is the unit item bid on bitumen, b^A, which is depicted in Figure 5 and is the most direct measure. However, the same percentage markup is likely not applied universally to all items, and strategizing over where to place profit across items might distort the true effect of volatility on the metric that matters to DOT, which the overall bid for the project. Therefore, I also use the total bid for the project per ton of required bitumen, b^T.[15]

In my primary specifications I use historical and implied volatility. The former is an annualized standard deviation of daily returns. Implied volatility is based on the observed prices of put and call options placed on the futures contract and derived by numerically inverting the Black-Scholes (1973) option pricing formula. The options implicitly contain information about market participants' expectations of price volatility (Chalamandaris and Tsekrekos 2009).[16] Historical volatility seems a more natural measure from the paving firms' perspectives. They are very cognizant of recent oil price trends, but do not report looking at options on oil futures, much less implied volatility. Specifically, I use historical volatility over the past 12 weeks, and Bloomberg data on at-the-money implied volatility for options expiring in 3 months. Since they are both over a 3 month period, the 12-week historical volatility and the implied volatility are considered directly comparable. I show that my results are robust to alternative measures, such as 26 week historical volatility. To control for the expected oil price, I use six-month oil futures.[17]

[15] In order to ensure that bitumen is a meaningful part of the project, I only use projects in which the portion of the total bid that is bitumen is at least $50,000. The effect of this term may also reflect the importance of diesel fuel in the total bid. Diesel price risk is highly correlated with bitumen price risk.

[16] "Model-free" option-implied volatility metrics have been developed to deal with perceived issues with Black-Scholes, but these are beyond the scope of this paper (see Bollerslev et al. 2011).

[17] There is disagreement about whether the futures price or the current spot price is the best forecast of future oil prices (Alquist and Kilian 2010, Kellogg 2010). Here I use the six month futures price, following convention in the literature on volatility and the fact that the average time to work start is five months.

4 Triple-Differences Estimation

4.1 Results

I find that the Kansas risk removal policy caused bids in Kansas to be less responsive to oil price volatility than bids in Iowa. The results from the primary specification is shown in Table 2, using both historical and implied volatility and, for the dependent variable, either the bitumen bid (b^A) or the total bid for the project per ton of bitumen (b^T). The coefficient of interest is β_1, which represents the effect of a 1% increase in volatility on bids in Kansas relative to Iowa after oil price risk shifted to the public sector.

The coefficients on the triple interactions are all negative and significant. The coefficient of -.16 in column I indicates that a 100% increase in volatility, which occurs frequently in my data, results in a 16% decrease in b^A in Kansas relative to Iowa, significant at the 5% level. Using b^T as the dependent variable gives a similar coefficient of -.15, significant at the 10% level. Both use 12-week historical volatility. The effects with implied volatility (columns III and IV) are larger, with coefficients of -.35 and -.47, both significant at the 5% level.

The CAPM exercise in Section 2.2 indicated that the crude oil beta, or volatility of oil relative to the market portfolio, has been on average zero and rarely greater than 0.5, implying a risk-adjusted return of at most 1.5% over six months. Although not directly comparable, my Iowa-Kansas analysis reveals that the magnitude of the risk premium in Iowa is at least an order of magnitude greater than CAPM would imply, keeping in mind that my statistic is relative to Kansas and relative to the pre-policy period.

The strong effect of volatility on bids suggests that at least some firms do not exploit financial markets. Imperfect competition may prevent higher cost firms from being priced out of the market. If the suppliers were competitive, the bitumen price to paving firms should reflect the supplier's cost of hedging (physically and in financial markets), not the value to the paver of reducing risk. With monopoly power, suppliers can charge the paver his full cost of risk. Both the bitumen supply market and the procurement auction market are imperfectly competitive. I cannot explore further how the policy affects the supplier-paver relationship, but evidence of a substantial risk premium - in the context of a near-zero CAPM-implied beta - suggests that with two layers of imperfect competition in product markets, the consumer does not get the benefit of the least risk averse agent.

Futures contracts not purchased for physical delivery close or roll over at the end of the month prior to the delivery month.

4.2 Robustness Tests

A number of key robustness tests are in Tables 3 and 4. For both, I use bitumen bids (b^A) and historical volatility; Appendix A Tables 1 and 2 contains these specifications using implied volatility as a covariate and total bid per ton bitumen as the dependent variable (b^T). First, Table 3 shows single differences and single interactions in columns I-IV. There is a strong positive effect of the $\mathbf{I}_{\text{policy}_t} \cdot \ln V_t^{\text{oil}}$ interaction when the triple interaction is omitted (column III). Otherwise, the single interactions are not significant. In column V, I omit the control covariates (such as the spot oil price and number of bidders in the auction). The coefficient increases somewhat in magnitude to -.21, still significant at the 5% level. Omitting month and county fixed effects, in column VI, provides a similar result as the primary specification of -18, and omitting year fixed effects in column VII yields a coefficient of -17, both significant at the 5% level.

Table 4 first conducts a series of placebo tests, in which the policy implementation year is artificially set to 2002, 2004, or 2008. In 2002 and 2008, the coefficient on the triple difference is near zero and insignificant. In 2004, it is -.22, significant at the 10% level. This placebo is close to the actual policy, and so a noisier policy effect. In column IV I demonstrate that prior to the policy, there was no measurable difference between Kansas and Iowa in their response to oil price volatility. This is shown in the interaction $\mathbf{I}_{KS_j} \cdot \ln V_t^{\text{oil}}$, which gives an insignificant coefficient of .068. Finally, column V is a falsification test with the total bid less bitumen as the dependent variable. The coefficient on the triple difference is now .058, with no significance.

Table 5 contains alternative assumptions about standard errors. Standard errors are not clustered at all in column I, and clustered by state-month, firm-month, firm-month of year, firm-state, and state-year in subsequent columns. The coefficient on the triple interaction maintains significance at the 1% level in all specifications except state-month (5% level) and state-year (10%) level. Appendix A Tables 3 and 4 show these alternative cluster assumptions using implied volatility and b^T. With implied volatility, significance is at the 1% level for all but state-month clusters (5%), and with b^T as the dependent variable significance declines to the 10% level with state-month clusters, and no significance for state-year clusters.

Many additional robustness checks are shown in Appendix A. For example, Table 5 columns I-II show that the coefficients do not change dramatically using 26 week historical volatility with the 6th month futures contract instead of 12 week volatility. Columns III and IV use the 5th month futures contract instead of the 6th month contract, and show slightly smaller effects with both b^A and b^T. Appendix A Table 6 shows specifications that exclude various covariates, and Table 7 shows that when 2008 - a year of unprecedented volatility - is excluded, the results are roughly the same, but somewhat larger with implied volatility.

5 Real Effects of the Policy in Kansas

In this section I explore the effects of the policy in Kansas in two ways. First, I examine whether auction outcomes for public and family owned firms changed after the policy, relative to private and non-family owned firms. Second, I calculate whether the Kansas government paid more for bitumen and for projects overall after the policy, given the realization of oil prices. Ideally I would also evaluate how the policy affected real variables like profitability and employment. Unfortunately I do not have access to such data, nor do I have the rich firm characteristics data that I have for Iowa.

I find that the policy seems to have benefited privately owned firms at the expense of publicly held firms, but that the policy had no apparent effect on family owned firms vis-a-vis non-family owned firms. Table 6 compares the win percentages (number of wins divided by number of bids) before and after the policy for all firms with at least 10 total bids.[18] The top panel shows that before the policy, publicly held firms won 36% of the auctions they bid in, while privately held firms won 33%. The t-test p-value for differences in means is 0.31. After the policy, the win percentages were 18% for public firms and 27% for private firms, and the difference is significant with 99% confidence. The bottom panel conducts a similar analysis for family ownership, and shows that there was no difference in win percentages in either of the two periods.

After the policy there are fewer large bidders (firms with at least 10 bids) and they have a lower win percentage (Table 6). This is in part because the distribution of winning bids changed, shown in Figure 6. The bar heights indicate the number of firms in each category of auction win percentage. The distributions are strongly skewed left, but the skewness declines from 1.0 before the policy to 0.8 after the policy.[19] Kurtosis, or peakedness and fatness of tails, declines more dramatically from 4.9 to 3, where 3 is precisely the kurtosis

[18] I identified whether Kansas firms were publicly or privately owned by manually searching the internet.

[19] Skewness measures a distribution's symmetry, where a normal distribution has a skewness coefficient of 0. When the coefficient is positive, the median is less than the mean and the distribution is skewed right, and vice versa when it is negative. A skewness coefficient greater than 1 indicates that the distribution is highly skewed. Kurtosis measures the peakedness of the distribution, where the normal distribution has kurtosis of 3. Kurtosis greater than 3 has more observations closer to the mean and fatter tails than the normal distribution.

of the normal distribution. This means that the "winningness" of firms became more evenly distributed across firms after the policy. The reverse occurred in the total number of bids by firm, shown in the bottom graph. Skewness and kurtosis, both much more extreme than percent wins, increase after the policy. Thus after the policy a few firms were submitting more of the bids, but nonetheless wins were more evenly spread across firms.

My second test answers a public finance question: Can a state lower its asphalt paving costs by removing oil price risk from the private sector? If firms are risk neutral or charge simply the CAPM-implied price of risk, then this policy should have been quite costly for Kansas over the course of my data because between 2006 and 2012 oil prices rose between auctions and work start overwhelmingly more than they declined. State governments, with plentiful access to finance, should be risk-neutral. Only if firms charge large risk premiums will the policy be beneficial.

Using auction and payments data, I compare in Appendix B how much each state paid for bitumen after the 2006 risk-shifting policy. The mean bitumen bid was about the same in Iowa and Kansas prior to the policy intervention, at \$210 and \$205 per ton, respectively. Both states experienced cost escalation post-2006. On average Kansas paid \$489 per ton after the policy, whereas Iowa paid \$513. A simple least squares differences-in-differences design finds that the policy reduced the cost of bitumen for Kansas by \$37 per ton, or 12% of the average bid over the period. This implies that over the 166 projects post-2006, Kansas saved \$5.1 million. Although the estimated benefit is small, it bears repeating that the policy should be *least* beneficial to Kansas when prices are increasing, which they did over most of the period.

6 Heterogeneity in Firm Risk Premium

Motivated by the evidence of risk aversion towards an idiosyncratic risk, in this section I present a simple model of how risk aversion could enter a firm's bid, which motivates a reduced form estimation. The diversity of paving firms provides a unique opportunity to examine how firm ownership and other characteristics impact risk management.

6.1 A Simple Model

Consider the following simple model describing a paving firm's profit maximization problem when bidding in a highway procurement auction. The firm's estimator (often a dedicated employee) submits unit price bids for bitumen, b_B, and for everything else, b_O. He knows the actual quantities that he will use, q_B^a and q_O^a, but his total bid B is calculated based on the DOT estimated quantities, q_B^e and q_O^e.[20] Conditional on his optimal total bid B, which determines his chances of winning the project (he wins if he submits the lowest total bid), the paver solves:

$$\begin{aligned} \max_{b_B, b_O} \pi &= b_B q_B^a + b_O q_O^a - \frac{1}{2}\eta \left[(b_B - \tilde{c}_B)^2 - (b_O - c_O)^2 \right] \\ \text{s.t.} \quad & b_B q_B^e + b_O q_O^e \leq B \end{aligned} \tag{2}$$

The firm's cost for each item is c. For bitumen, this is $\tilde{c}_B = c_B + \rho$, where ρ is a non-negative risk premium, or a value to the firm of hedging. I do not microfound this parameter; it may be due to financial constraints, agency problems, or owner preferences. The last term in Equation 2 reflects a penalty for excessive skewing. To the extent that $q^e \neq q^a$ on any item, the bidder has an incentive to skew his bid toward the quantity that has been underestimated. Then he stands a higher chance of winning (a lower B) but will in expectation be paid more based on q^a . Following Bajari, Houghton and Tadelis (2010), I use a quadratic penalty η for for deviating from the engineering cost estimates.

The firm's FOC is:

$$\frac{\partial}{\partial b_B} : \; q_B^a - \lambda q_B^e = \eta \left(b_B - \tilde{c}_B \right) \tag{3}$$

where λ is a Lagrange multiplier, which I assume may be a function of everything that does not have to do with oil price risk, such as the marginal benefit of bidding a bid that scores higher, how others are skewing, etc.[21] Solving for the bid b_B gives:

$$b_B = \tilde{c}_B + \frac{1}{\eta} \left(q_B^a - \lambda q_B^e \right) = c_B + \rho + \frac{1}{\eta} \left(q_B^a - \lambda q_B^e \right) \tag{4}$$

We can think of this unit item bid as the paver's expected cost plus a markup that includes the paver's cost of risk. This markup is:

$$m_B = b_B - c_B = \rho + \frac{1}{\eta} \left(q_B^a - \lambda q_B^e \right). \tag{5}$$

Equation 5 leads to the reduced form estimation in Section 6.2.

[20] This simplifies the notion that the paving firm is more informed than the state about the quantities he will use.

[21] Specifically, $\lambda = \frac{\eta}{(q_B^e)^2 + (q_O^e)^2} \left[q_B^e \tilde{c}_B + q_O^e c_O + \frac{1}{\eta} \left(q_B^a q_B^e + q_O^a q_O^e \right) - B \right]$

6.2 Risk Premium Heterogeneity Estimation Strategy

I estimate the risk premium as the impact on bids of the forward market interacted with oil price volatility. The dependent variable is a large panel of proxy markups, $\hat{m}_B = b_B - c_B = \rho + \frac{1}{\eta}\left(q_B^a - \lambda q_B^e\right)$. I observe the bitumen bid b_B and proxy for c_B with the Argus "spot" index (B_t^{Argus}) reflecting the underlying cost of bitumen at the time of the auction.[22] The Argus "spot" index is closely correlated to the cost of oil (correlation of 0.79). The markup measure is thus: $\hat{m}_{B,j,i} = b_{B,j,i} - B_t^{Argus}$. Appendix A Figure 2 shows that as prices rose and became more volatile after, roughly, 2006, the difference between the bid unit item and the spot price transitioned from being tightly packed between \$10 and \$50 per ton to being more dispersed, with higher bids coincident with periods of high volatility.

I evaluate what portion can be attributed to oil price risk; specifically how a given level of oil price volatility affects bids at different distances in time from the work start date. A longer time between the auction and work start means that the contractor is taking on more oil price risk. Likewise, for a project that starts very soon after the auction there is no risk regardless of recent volatility. The forward market is the number of months between the auction and work start ($Wait_j$) interacted with oil price volatility $\left(V_t^{\text{oil}}\right)$. Unfortunately I do not have enough data to estimate ρ for each firm. Instead, I test whether ρ is larger for different kinds of firms, and am also able to assess whether a larger ρ for a given group of firms is driven by $Wait_j$ or V_t^{oil}.

The estimating equation for the public-private analysis, where where I_{Public_i} indicates that the firm is publicly listed, is below. The unit of observation is project j auctioned at time t.

$$\hat{m}_{B,j,i} = \alpha + \rho I_{\text{Public}_i} \cdot Wait_j \cdot \ln V_t^{\text{oil}} + \gamma' \cdot \text{Auction/Bidder Chars}$$
$$+ \beta_1 I_{\text{Public}_i} + \beta_2 \ln V_t^{\text{oil}} + \beta_3 Wait_j + \beta_4 I_{\text{Public}_i} \cdot Wait_j + \beta_5 \mathbf{I}_{Public_i} \cdot \ln V_t^{\text{oil}} + \beta_6 Wait_j \cdot \ln V_t^{\text{oil}}$$
$$+ \delta \mathbf{I}_{month_t} + \delta \mathbf{I}_{year_t} + \epsilon_{ijt} \quad (6)$$

[22]Argus is a market research firm that kindly provided their price indices for the Eastern and Western regions of Iowa to me. Since there is no liquid bitumen market, Argus surveys transactions between suppliers and contractors by phone to get prices on bitumen for-delivery in the current week. These deliveries include purchases to pave commercial projects (e.g. a Wal-Mart parking lot), state projects (e.g. a highway), and by asphalt storage firms, who act as intermediaries between the refiners and the pavers. During the winter, when no actual paving is happening this index reflects only sales to the intermediaries. These intermediaries will be suppliers in the summer, alongside the refineries, to the paving firms.

where:

$$\gamma' \cdot \text{Auction/Bidder Chars} = \gamma_1 \# Bidders_j + \gamma_2 \ln AveTotalBid_j + \gamma_3 \ln ReqTons_j + \gamma_4 \ln Distance_{ij} + \gamma_5 \text{Firm Si}$$

The specification includes double interactions and individual effects of $Wait_j$, V_t^{oil}, and I_{Public_i}. Other specifications replace I_{Public_i} with a different firm characteristic, and the regressions on firm size exclude those variables from the controls. I control for year and month of the year fixed effects (the latter is especially important because of capacity constraints that firms face as the construction season progresses). I control for firm size using both employment and revenue variables. I cluster standard errors by firm. Table 7 contains descriptive statistics for the variables used in this analysis.

The coefficient ρ on the impact of the forward market interacted with oil price volatility should reflect only differences in firm bids that relate to oil price risk. I interpret ρ as a measure of the oil price risk premium, but ρ does not provide information about underlying risk preferences, nor does it indicate how firms are hedging. If some firms hedge efficiently using oil futures, their estimated risk premium may be much lower than a firm who always hedges through a supplier. If firms manage this idiosyncratic risk by passing it to financial markets, there should be no (or a very small) premium. Differences in ρ across firms means that some firms either are more risk averse or hedge less efficiently. In either case, they pass a premium for bearing diversifiable risk to the consumer (the government).

6.3 Observable Firm Characteristics

The primary reason that most research on firm risk management has focused on publicly listed companies is because little data exists about private companies. My Iowa data provides a unique, albeit incomplete, window into the relationship of firm characteristics to risk management. I do not have firm-specific data for Kansas, so this heterogeneity analysis uses only Iowa data.

The top panel of Table 7 provides summary statistics of the characteristics. The first variable is a dummy categorical variable for a firm being publicly held ($\mathbf{I}_{\text{Public}_i}$), which changes from 0 to 1 over time for the firms that are acquired by a public company. The family firm variable, also a binary dummy ($\mathbf{I}_{\text{Famil}y_i}$), indicates that the company meets at least one of three conditions: a) the company states it is family-owned and managed on its website; b) records of executives indicate that a President or CEO has the same name as the company; or c) more than 2 top executives share the same last name.

I use the number of 8-digit SIC codes a firm does business in as a measure of diversification ($\#\text{SIC}_i$), where a higher number in the index indicates greater diversification. Firms that are less diversified may have more of the managers' wealth tied to oil prices and thus may exhibit greater risk aversion. This is obviously a crude measure of diversification, and additional SIC code industries could also be very oil-intensive. However, examination of the SIC codes suggests that additional codes are usually other types of construction, such as metalwork and sewer lines, that are less oil intensive. I also use two dummies for a firm not being diversified: $\mathbf{I}_{\text{Not Div}_i}$ takes a value of 1 if the firm operates in only one SIC code, and 0 if more; and $\mathbf{I}_{\text{Paving Primary}_i}$ takes a value of 1 if asphalt paving is the firm's primary activity, and 0 otherwise. If a firm is primarily a bridge builder, they are likely less exposed to oil price shocks than a firm that primarily paves.

My metrics for business size are the number of employees and annual revenue. Unfortunately, I only observe these for 2012 or the latest year the company was active. Thus these variables are a very rough indication of firm size. However, the stability of this industry makes these single-year measures more appropriate than they would be for other sectors (Porter and Zona 2003). I use two continuous and two binary measures. Firm Size (Emp)_i is the raw number of employees and Firm Size (Rev)_i is annual revenue. $\mathbf{I}_{\text{Small (Emp)}_i}$ is 1 for firms with less than 100 employees and 0 otherwise; $\mathbf{I}_{\text{Small (Rev)}_i}$ is 1 for firms with less than \$15 million in revenue and 0 otherwise (these are the 40th percentiles of the respective samples).

Finally, I exploit a database from the Iowa DOT describing affiliations among its contractors. The variables are a dummy variables for whether a firm's owners or officers are related by blood or marriage to another contractor $\left(\mathbf{I}_{\text{Related}_i}\right)$, whether a firm is a subsidiary company to another contractor $\left(\mathbf{I}_{\text{Subsid}_i}\right)$, and whether it has a joint venture or partnership with another contractor $\left(\mathbf{I}_{\text{JV}_i}\right)$. Unfortunately, I have no measure of leverage.

All pairwise correlations among characteristics are in Appendix A Table 9, where correlation coefficients significant at the 5% level or better are starred. The correlation between $\mathbf{I}_{\text{Family}y_i}$ and the diversification variables is quite low, as is the correlation between $\mathbf{I}_{\text{Public}_i}$ and the diversification variables. For example, the correlation between $\mathbf{I}_{\text{Family}y_i}$ and the $\mathbf{I}_{\text{Paving Primary}_i}$ (indicator for paving being the firm's primary activity) is only 0.02. Only two correlations are greater that 0.5 in either direction: Firm Size (Emp)_i with $\mathbf{I}_{\text{Public}_i}$ (0.52*), Firm Size (Emp)_i with $\#\text{SIC}_i$ (0.67*), $\mathbf{I}_{\text{Small (Rev)}_i}$ with $\mathbf{I}_{\text{Small (Emp)}_i}$ (0.88*), and Firm Size (Rev)_i with Firm Size (Emp)_i(0.68*).

For a more granular sense of the data, Appendix A Table 8 shows the top 30 bidders' number of bids, win percentage, public ownership status, family ownership status, and first and last bid date. The publicly owned firms were all originally private firms acquired by either MDU Resources, an energy and infrastructure company, or Oldcastle Materials, the US arm of CRH Plc. Nearly all 30 firms submit bids spanning the full period (1994-2012), and most were founded decades before 1994. The remaining 185 firms not included in this table collectively have 1,924 bids.

6.4 Risk Premium Heterogeneity Estimation Results

6.4.1 Public vs Private Firm Ownership

Theory suggests that privately held firms are likely to be more risk averse than publicly held firms. The rationale from FSS implies that if external finance is more costly for private firms than for public firms, managing risk will be more valuable to private firms. On the other hand, Rampini and Viswanathan (2010, 2013) and Rampini, Sufi and Viswanathan (2014) show that constrained firms may face greater costs to hedging, so regardless of their risk aversion, they may hedge less. A different line of argument is that private firms might be more risk averse if their owners are less diversified than the shareholders of public companies (Panousi and Papanikolaou 2012, Jin and Jorion 2006). However, agency problems could push the other direction. Following Stulz (1984) and Asker et al. (2012), if publicly held firms are subject to managerial agency problems and their managers are risk averse, there may be no significant difference between public and private firms.

Estimates of Equation 6 are shown in Table 8. The coefficient of interest ρ is on the triple interaction in the first row, $\left(\mathbf{I}_{\text{Public}_i} = 1\right) \cdot Wait_j \cdot \ln V_t^{\text{oil}}$. The measure of risk is the interaction $Wait_j \cdot \ln V_t^{\text{oil}}$. Employing interactions (also referred to as moderating or conditioning effects) in this regression implies that coefficients should be interpreted as being relative to the base, or reference level. In the case of $\mathbf{I}_{\text{Public}_i}$, for example, the coefficient is relative to being privately held.[23]

I find a strong negative coefficient on the triple interaction, indicating that publicly held firms charge the state a lower risk premium than privately held firms. Each unit increase in the measure of risk reduces the bid markup for public firms relative to private

[23] Note that the coefficients on the controls, such as on $\left(\mathbf{I}_{\text{Public}_i} = 1\right) \cdot Wait_j$, are not general effects. For example, the coefficient on $Wait_j$ reflects the impact of $Wait_j$ when $\mathbf{I}_{\text{Public}_i}$ is zero and oil price volatility is zero. The coefficient on $\left(\mathbf{I}_{\text{Public}_i} = 1\right) \cdot Wait_j$ is the effect of the interaction between being public and months-to-start when oil price volatility is zero. That is, these are conditional effects that give the covariates' impact when other variables involved in the interaction are zero, and are different from unconditional effects.

firms by about \$5. Although the negative and significant value for ρ is informative, a more meaningful interpretation arises from graphical representation of the marginal effects of the triple interaction. I fix either $Wait_j$ or $\ln V_t^{\text{oil}}$ and allow the other to move, and then calculate the conditional marginal effect of $\mathbf{I}_{\text{Public}_i}$ on the markup. Figure 7 shows in the left panel oil volatility held at its 50th percentile level. As time-to-start moves from 1 month to 14 months, the effect of being publicly listed becomes strongly negative. At 14 months a publicly listed firm bids on average \$20 less than a privately held firm. The average markup is \$53. Figure 8 shows this latter effect more clearly. The graphs fix oil price volatility at its 10th, 40th, 60th, and 90th percentiles. The "forward curve" of the impact of months-to-start rotates counterclockwise as oil price volatility increases.

The right panel of Figure 7 fixes time-to-start at 6 months. As oil price volatility increases, the difference between public and private firms narrows, and at high levels of volatility public firms bid higher than private firms. This suggests that although the interaction coefficient is large and significant, the overall negative impact of being public is mostly driven by the time-to-start. Private firms' risk premium is more associated with the delay, suggesting they pay less attention to recent oil price volatility.

In part because I do not directly observe the paver-supplier contracts, I am unable to explain *why* different types of firms have different risk management behavior. It is possible that public firms are fully hedging on financial markets, but this is much cheaper than hedging with suppliers, and thus it appears that private firms are more risk averse, when in fact they either are less sophisticated or do not have the scale to hedge efficiently in financial markets. It is also possible that publicly held firms have greater bargaining power with suppliers than private firms, and this bargaining power varies with time-to-start. However, the total volume of bitumen used, as well as average project size, does not differ substantially across public and private firms (nor across the other dimensions, with the exception of firm size). Thus the bargaining power hypothesis seems less plausible.

6.4.2 Family vs Non-Family Firm Ownership

I conduct a similar exercise for family-owned and managed firms. On one hand, if the owners of family firms seek to maximize personal utility and smooth income, the family firms may be more risk averse (Bertrand and Schoar 2006, Shleifer and Vishny 1986, Schulze et al. 2001). On the other hand, if family firms use intense monitoring to overcome manager-shareholder agency problems, they may do less risk management (Anderson and Reeb 2003, Schmid et al. 2008).

The main specification, in Table 7 column II, reveals that family owned firms charge substantially larger risk premiums than non-family owned firms. Graphically, Figure 9 uses marginal effects to show that it is oil price volatility, not time-to-start, that drives this result. The left panel shows that the risk premium does not vary with time-to-start, while the right panel shows that at the average time-to-start the risk effect is sharply increasing in oil price volatility. This contrasts with the public vs. private analysis. However, this result is somewhat imprecise; note that the 95% confidence interval does not exclude zero in either panel. In Figure 10, I show that it does exclude zero in high oil price volatility environments. Table A5 has a waterfall series of regressions.

6.4.3 Diversified Firms vs. Concentrated Firms

Firms may manage oil price risk by diversifying to non-oil intensive sectors. Well-diversified firms in general may be less risk averse (Mackay and Moeller 2007, Faccio et al. 2011). Panel 1 of Table 9 shows that diverse firms charge consistently and robustly lower risk premiums than not diverse firms. (Here and subsequently, Table 9 shows only the coefficient ρ on the triple interaction term and graphical marginal effects. For the full tables, see Appendix A tables 10, 11, 12, and 13.) The continuous variable for diversification has a strong negative slope, and the two categorial variables for being concentrated in one industry and for paving asphalt roads being the firm's primary activity have strong positive impacts. Figures 11 and 12 show that non-diverse firms (operating in only 1 8-digit SIC code) have higher risk premiums. This result has strong statistical significance. As with family ownership, the marginal effects graphs show that this effect primarily increases not with months-to-start, but with oil price volatility.

6.4.4 Small Firms vs. Large Firms

Small firms usually have less assets than large firms to use as collateral, and therefore are often assumed to face more severe financing constraints (FSS, Hennessy and Whited 2007, Vickery 2008, Nance et al. 1993). However, some empirical literature finds that small firms do less risk management, possibly due to economies of scale in hedging (e.g. Stulz 1996). Alternatively, Rampini and Viswanathan (2010, 2013) and Rampini, Sufi and Viswanathan (2014) theorize that collateral constraints may cause hedging to be suboptimal for small firms.

The tests of firm size in Panel 2 of Table 9 suggest that larger firms are less risk averse, but the effects are smaller and much weaker than some of the other characteristics I test. The strongest result is from the continuous variable for firm size by revenue. Figures 13 and 14 reveal that this effect is both a function of time-to-start and oil price volatility; that is, the marginal effects line slopes significantly downward in both time-to-start and oil price volatility when the other variable is fixed.

6.4.5 Inter-Firm Relations

Subsidiary firms and firms whose owners and officers are related to those at other Iowa contractors may have greater access to capital and more diversified owners, leading to less risk management. Panel 3 of Table 9 examines the relationship variables. I find that firms whose owners and officers are related to those at other Iowa contractors exhibit *greater* risk premiums. This is potentially because of the large overlap between family ownership and the relationship variables.

The largest risk premiums are among firms that are both family owned and fall into one of the following categories: non-diversified, have relatives at a another firm, are a subsidiary, and are small. Coefficients on these interaction terms are shown in Panel 4 of Table 9. Figures 15 and 16 show the conditional marginal effects for being both family-owned and having owners/officers related to those at another contractor.[24]

6.4.6 Robustness

Robustness tests for the risk premium heterogeneity results are in Appendix A. For example, Tables 14 and 15 show a variety of alternative standard error assumptions for the public and family ownership estimations. Standard errors are not clustered at all in column I, and clustered by state-month, firm-month, firm-month of year, firm-state, and state-year in subsequent columns. For both public and family ownership, the coefficient on the triple interaction remains significant. For public ownership, significance drops to the 10% level with state-month, firm-month, and state-year clusters, but for family ownership significance drops to the 10% level only for state-month clusters. Similar results hold for the other firm characteristics, including the diversification variables.

[24] There are a number of additional firm characteristics that I tested, but found no significant effects. A binary variable for whether the firm's primary state is Iowa yielded a positive but not significant impact on the coefficient of interest (the triple interaction proxy for risk). Similarly, a continuous variable for the distance between the firm's primary address and the project produced a negative but insignificant result. A variable for the firm's age at bid yielded a positive but near-zero insignificant coefficient. The Dunn & Bradstreet database contains an interesting variable on whether the firm owns or rents its primary facility. In theory, a firm that owns its facility has more collateral and might be expected to be less risk averse. Unfortunately, the database only has this variable for about half of my firms. Using this subsample, the regression yielded a large positive coefficient on ownership, but without any significance.

Appendix A Table 16 shows alternative specifications for the impact of public ownership with varying covariates. Excluding month-of-year and year fixed effects increases the estimated coefficient on the triple interaction to -3.8, though it remains significant. Excluding the contract level covariates, such as the number of bidders and distance to the project, and the firm size controls, reduces the coefficient slightly to -5.3 (that is, making the estimated risk premium slightly larger for public firms relative to private firms). Omitting all the individual and single interactions increases the coefficient substantially to -0.22. Table 17 addresses alternative volatility measures for the public and family ownership regressions; with implied volatility, the difference between public and private firms widens, with a coefficient on the triple interaction of -7.7, significant at the 1% level. Similarly, implied volatility increases the difference between family and non-family owned firms, giving a coefficient of 3.7, significant at the 5% level. Using the 5th month futures contract for historical volatility instead of the 6th month contract increases the effect of public ownership slightly to -4.6, but the impact of family ownership is the same as with the 6th month contract at 2.7 (both significant at the 5% level).

7 Conclusion

In this paper I find strong evidence that firms in an imperfectly competitive setting exhibit risk averse behavior, and that different types of firms manage risk in ways broadly consistent with key theoretic hypotheses. I establish using a quasi-experiment that oil price volatility increases bitumen bids in Iowa relative to Kansas since Kansas removed oil price risk from the private sector in 2006. Given the imperfect nature of competition in this industry, firms appear to be able to be able to pass through inefficiently high costs of risk to the government without being priced out of the market.

The generality of these results is, of course, limited by my focus on public procurement and asphalt paving. However, the firms in my sample much more adequately represent the size and ownership distribution of U.S. firms than the majority of past studies on risk management, which focus on large publicly listed corporations. The industry, in which government is the consumer, also lends itself to relatively clean identification of plausibly exogenous policy changes, whereas most settings face confounding demand variables.

The risk premium heterogeneity analysis finds that firms that are publicly listed, diversified, not family-owned, and larger tend to charge economically and statistically significantly lower risk premiums relative to their counterpart firms. There is a very strong negative relationship between risk aversion and diversification away from oil-intensive construction. Greater effective risk aversion among private firms and family owned firms supports the theory that concentrated ownership generates greater demand for risk management. It is also evidence against the hypotheses that managerial agency problems may be so dire that public firms manage risk as if private, or that family firms are less risk averse because their owner-managers are smoothing personal income. I find support, albeit weaker, that small firms are more financially constrained and therefore behave in a more risk averse manner. In sum, my results support the theoretical prediction that firms more likely to be financially constrained have a higher value of hedging.

Table 1: Summary Statistics of Iowa and Kansas Auction Data, 1998-2012

Panel 1: Bids

	Iowa		Kansas		All	
	Mean (sd)	N	Mean (sd)	N	Mean (sd)	N
Total bid	\$2,254,777 (\$3,271,562)	4,618	\$2,772,247 (\$5,214,448)	1,438	\$2,377,651 (\$3,829,190)	6,056
Bitumen bid item (per ton)	\$303 (\$149)	4,618	\$362 (\$165)	1,438	\$317 (\$156)	6,056
Total bid per ton bitumen required	\$9,784 (\$28,872)	4,618	\$26,861 (\$104,318)	1,438	\$13,737 (\$56,658)	6,056
Miles to project	88 (91)	4,618	113 (227)	1,438	94 (136)	6,056
Total bid for non-bitumen items	\$1,983,852 (\$3,158,923)	4,618	\$2,513,103 (\$5,145,371)	1,438	\$2,109,523 (\$3,734,004)	6,056

Panel 2: Contracts (Auctions)

	Iowa		Kansas		All	
	Mean (sd)	N	Mean (sd)	N	Mean (sd)	N
# bidders	3.33 (2.06)	1,287	3.59 (1.73)	364	3.39 (1.99)	1,688
Money on the table	6.3% (7.6%)	1,287	5.3% (8.5%)	364	6.1% (7.8%)	1,688
Proposed tons bitumen	811 (1,099)	1,287	625 (657)	364	771 (1,023)	1,688
Months between auction and work start	4.6 (2.8)	1,287	5.2 (2.8)	364	4.7 (2.8)	1,688

Note: This table summarizes the bitumen-intensive projects (highway paving) used in the regression analysis. Money on the table is the the percent difference between the second lowest and the winning bid: $100 * \frac{(B^{Second} - B^{Win})}{B^{Win}}$. Auctions with only 1 bidder are excluded for this metric. Miles to project is Vicenty distance calculated using the latitude and longitude of the project site.

Table 2: Triple Difference Results using Risk Removal Policy

Vol Metric Used:	Historical Volatility (12 w)		Implied Volatility	
Dependent variable:	I: Log bitumen bid (b^A)	II. Log bid total per ton bitumen (b^T)	III: Log bitumen bid (b^A)	IV. Log bid total per ton bitumen (b^T)
$\mathbf{I}_{KS_j} \cdot \mathbf{I}_{Policy_t} \cdot \ln V_t^{\text{oil}}$	**-.16*** **	**-.15** **	**-.35*** **	**-.47*** **
	(.036)	(.072)	(.069)	(.14)
$\mathbf{I}_{\text{policy}_t} \cdot \ln V_t^{\text{oil}}$	.79***	.33***	.67***	.62***
	(.04)	(.089)	(.05)	(.036)
$\mathbf{I}_{\text{policy}_t} \cdot \mathbf{I}_{KS_j}$	.5***	.44*	1.2***	1.6***
	(.12)	(.24)	(.24)	(.49)
$\mathbf{I}_{KS_j} \cdot \ln V_t^{\text{oil}}$	.041	.17**	.22***	.57***
	(.029)	(.068)	(.051)	(.13)
$\ln V_t$	-.0015	.0056	-.018	.078**
	(.0089)	(.01)	(.022)	(.03)
$\mathbf{I}_{\text{state}_j}$	-.021	2.1***	-.65***	.72
	(.096)	(.23)	(.18)	(.45)
$\mathbf{I}_{\text{policy}_j}$	-2.4***	-.93***	-2.1***	-.013
	(.13)	(.25)	(.18)	(.096)
$\ln price_t^{\text{oil}}$	.27***	.14***	.29***	.074**
	(.031)	(.042)	(.026)	(.029)
$\#Bidders_j$	-.0057***	.0099***	-.0053***	.011***
	(.0011)	(.0026)	(.0012)	(.0028)
$\ln AveTotalBid_j$	-.027	.95***	-.018	.95***
	(.023)	(.015)	(.022)	(.015)
$\ln ReqTons_j$	-.006**	-.97***	-.0055*	-.97***
	(.0029)	(.0099)	(.0029)	(.01)
$\ln OtherBidItems_{ij}$	.023		.015	
	(.021)		(.02)	
$\ln Distance_{ij}$	-.0071***	.007**	-.0072***	.0062*
	(.0026)	(.0034)	(.0026)	(.0033)
County f.e.	Y	Y	Y	Y
Year f.e.	Y	Y	Y	Y
Month of year f.e.	Y	Y	Y	Y
N	6107	4542	6107	4542
R^2	.92	.97	.92	.97

Note: This table reports regression estimates of the effect of the risk removal policy on an additional unit of oil price volatility on bids in Kansas relative to Iowa after vs before the policy. This is the triple difference specification in Equation 1, where j denotes the auction, and i the firm. The sample size is smaller in regressions II and IV because only projects with bitumen bid totals $\geq$ \$50,000 are used. Standard errors clustered by firm. *** $p < .01$. $1998 \leq \text{Year} \leq 2012$.

Table 3: Robustness Tests of Triple Difference Estimation, Part I

Dependent variable: Log bitumen bid (b^A)	Interactions				Controls		
	I. None	II. Kansas-Policy	III. Policy-Vol	IV. Kansas-Vol	V. No covariates	VI. No month or county f.e.	VII. No year f.e.
$\mathbf{I}_{KS_j} \cdot \mathbf{I}_{Policy_t} \cdot \ln V_t^{\text{oil}}$					**-.21*****	**-.18*****	**-.17*****
					(.036)	(.038)	(.037)
$\mathbf{I}_{\text{policy}_t} \cdot \ln V_t^{\text{oil}}$			.74***		.61***	.85***	.81***
			(.042)		(.037)	(.04)	(.039)
$\mathbf{I}_{\text{policy}_t} \cdot \mathbf{I}_{KS_j}$		-.013			.64***	.59***	.55***
		(.016)			(.12)	(.13)	(.12)
$\mathbf{I}_{KS_j} \cdot \ln V_t^{\text{oil}}$				.0067	.072**	.047	.038
				(.02)	(.03)	(.031)	(.03)
$\ln V_t$	.053***		.0093	.04***	-.028***	.0074	.0045
	(.013)		(.0093)	(.015)	(.0087)	(.0088)	(.0095)
$\mathbf{I}_{\text{state}_j}$	.11***	.12***		.095	-.12	-.025	.0012
	(.011)	(.012)		(.065)	(.097)	(.1)	(.098)
$\mathbf{I}_{\text{policy}_j}$	.12***	.11***	-2.2***		-1.8***	-2.5***	-2.4***
	(.03)	(.032)	(.12)		(.12)	(.13)	(.13)
$\ln price_t^{\text{oil}}$	.053*	.0078	.32***	.025		.32***	.28***
	(.029)	(.029)	(.031)	(.029)		(.029)	(.033)
$\#Bidders_j$	-.0056***	-.0053***	-.0061***	-.0047***		-.0099***	-.0086***
	(.0012)	(.0012)	(.0012)	(.0012)		(.0012)	(.0013)
$\ln AveTotalBid_j$	.013	.017	-.094***	.0071		-.02	-.02
	(.024)	(.023)	(.021)	(.024)		(.024)	(.024)
$\ln ReqTons_j$	-.0086***	-.0086***	.0078***	-.0084***		-.011***	-.011***
	(.003)	(.0031)	(.0026)	(.003)		(.003)	(.003)
$\ln OtherBidItems_{ij}$	-.012	-.016	.079***	-.0073		.025	.025
	(.022)	(.021)	(.02)	(.022)		(.022)	(.022)
$\ln Distance_{ij}$	-.0088***	-.0089***	-.0046	-.0091***		-.012***	-.012***
	(.0026)	(.0027)	(.0029)	(.0027)		(.0032)	(.0032)
County f.e.	Y	Y	Y	Y	Y	N	Y
Year f.e.	Y	Y	Y	Y	Y	Y	N
Month of year f.e.	Y	Y	Y	Y	Y	N	Y
N	6107	6107	6107	6107	6107	6107	6107
R^2	.91	.91	.92	.91	.92	.92	.92

Note: This table reports estimates of the effect of the risk removal policy on an additional unit of historical oil price volatility on bids in Kansas relative to Iowa after vs before the policy. Specifications are variants on Equation 1. Standard errors clustered by firm. *** $p < .01$. $1998 \leq \text{Year} \leq 2012$.

Table 4: Robustness Tests of Triple Difference Estimation, Part II

Dependent variable:	Log bitumen bid $\left(b^A\right)$			Log non-bitumen bid items
	Placebo test at year			
	I: 2002	II. 2008	III. Parallel trends (before policy)	IV. Falsification
$\mathbf{I}_{KS_j} \cdot \mathbf{I}_{Policy_t} \cdot \ln V_t^{\text{oil}}$	-.096**	-.047		.058**
	(.04)	(.044)		(.024)
$\mathbf{I}_{\text{policy}_t} \cdot \ln V_t^{\text{oil}}$	-.035	.2***		-.14***
	(.026)	(.032)		(.028)
$\mathbf{I}_{\text{policy}_t} \cdot \mathbf{I}_{KS_j}$	.33**	.13		-.12
	(.13)	(.15)		(.078)
$\mathbf{I}_{KS_j} \cdot \ln V_t^{\text{oil}}$	.087**	.023	-.013	-.11***
	(.036)	(.026)	(.032)	(.02)
$\ln V_t$	.068***	-.019**	.024***	.0013
	(.018)	(.0079)	(.0089)	(.0084)
$\mathbf{I}_{\text{state}_j}$	-.18	.048	.16	.45***
	(.12)	(.083)	(.11)	(.07)
$\mathbf{I}_{\text{policy}_j}$	1.5***	.62***		.42***
	(.096)	(.12)		(.097)
$\ln price_t^{\text{oil}}$	.021	.087***	.36***	-.093***
	(.029)	(.028)	(.011)	(.021)
$\#Bidders_j$	-.0048***	-.004***	-.0015	.0039***
	(.0012)	(.0012)	(.0014)	(.0012)
$\ln AveTotalBid_j$	.0078	.0021	.061	1.1***
	(.024)	(.023)	(.047)	(.0046)
$\ln ReqTons_j$	-.0084**	-.0078**	-.0053	-.078***
	(.0033)	(.003)	(.0042)	(.0039)
$\ln OtherBidItems_{ij}$	-.0072	-.005	-.064	
	(.022)	(.021)	(.045)	
$\ln Distance_{ij}$	-.0092***	-.0086***	-.0078**	1.0e-07
	(.0027)	(.0027)	(.0034)	(.0024)
County f.e.	Y	Y	Y	N
Year f.e.	Y	Y	Y	Y
Month of year f.e.	Y	Y	Y	N
N	6107	6107	3528	6107
R^2	.91	.91	.7	.99

Note: This table reports estimates of the effect of the risk removal policy on an additional unit of historical oil price volatility on bids in Kansas relative to Iowa after vs before the policy. Specifications are variants on Equation 1. The sample size is smaller in regressions II and IV because only projects with bitumen bid totals $\geq$ \$50,000 are used. Standard errors clustered by firm. *** $p < .01$.
$1998 \leq \text{Year} \leq 2012$.

Table 5: Robustness Tests of Triple Difference Estimation, Part III

Dependent variable: Log bitumen bid $\left(b^A\right)$						
Standard errors clustered by:	I. None (robust)	II. State-month	III. Firm-month	IV. Firm-month of year	V. Firm-state	VI. State-year
$\mathbf{I}_{KS_j} \cdot \mathbf{I}_{Policy_t} \cdot \ln V_t^{\text{oil}}$	**-.16***	**-.16**	**-.16***	**-.16***	**-.16***	**-.16*
	(.04)	(.072)	(.046)	(.044)	(.036)	(.09)
$\mathbf{I}_{\text{policy}_t} \cdot \ln V_t^{\text{oil}}$	.79***	.79***	.79***	.79***	.79***	.79***
	(.036)	(.12)	(.045)	(.05)	(.04)	(.13)
$\mathbf{I}_{\text{policy}_t} \cdot \mathbf{I}_{KS_j}$	.5***	.5**	.5***	.5***	.5***	.5
	(.13)	(.23)	(.15)	(.14)	(.12)	(.31)
$\mathbf{I}_{KS_j} \cdot \ln V_t^{\text{oil}}$	.041	.041	.041	.041	.041	.041
	(.034)	(.052)	(.039)	(.038)	(.029)	(.081)
$\ln V_t$	-.0015	-.0015	-.0015	-.0015	-.0015	-.0015
	(.0077)	(.023)	(.011)	(.01)	(.0089)	(.033)
$\mathbf{I}_{\text{state}_j}$	-.021	-.021	-.021	-.021	-.021	-.021
	(.11)	(.16)	(.13)	(.12)	(.096)	(.27)
$\mathbf{I}_{\text{policy}_j}$	-2.4***	-2.4***	-2.4***	-2.4***	-2.4***	-2.4***
	(.12)	(.38)	(.15)	(.16)	(.13)	(.41)
$\ln price_t^{\text{oil}}$	.27***	.27***	.27***	.27***	.27***	.27***
	(.021)	(.058)	(.028)	(.029)	(.031)	(.098)
$\#Bidders_j$	-.0057***	-.0057**	-.0057***	-.0057***	-.0057***	-.0057***
	(.00096)	(.0023)	(.0011)	(.0011)	(.0011)	(.002)
$\ln AveTotalBid_j$	-.027	-.027	-.027	-.027	-.027	-.027
	(.019)	(.028)	(.02)	(.02)	(.023)	(.028)
$\ln ReqTons_j$	-.006**	-.006	-.006**	-.006**	-.006**	-.006
	(.0024)	(.0047)	(.0025)	(.0024)	(.0029)	(.0054)
$\ln OtherBidItems_{ij}$	.023	.023	.023	.023	.023	.023
	(.018)	(.024)	(.019)	(.018)	(.021)	(.025)
$\ln Distance_{ij}$	-.0071***	-.0071***	-.0071***	-.0071***	-.0071***	-.0071***
	(.0021)	(.002)	(.0023)	(.0023)	(.0026)	(.0023)
County f.e.	Y	Y	Y	Y	Y	Y
Year f.e.	Y	Y	Y	Y	Y	Y
Month of year f.e.	Y	Y	Y	Y	Y	Y
N	6107	6107	6107	6107	6107	6107
R^2	.92	.92	.92	.92	.92	.92

Note: This table reports estimates of the effect of the risk removal policy on an additional unit of historical oil price volatility on bids in Kansas relative to Iowa after vs before the policy. Specifications are variants on Equation 1. Standard errors clustered as described. *** $p < .01$. $1998 \leq \text{Year} \leq 2012$.

Table 6: Kansas Firms' Win Percentages Before and After 2006 Risk Removal Policy

Public Ownership			
Firm type	Win percentage before 2006 policy	Win percentage after 2006 policy	T-test p-value
Publicly listed	.36 (.00)	.18 (0.01)	**.05**
Privately owned	.33 (.03)	.27 (.04)	**.01**
T-test p-value	**.31**	**.01**	
N	37	29	
Family Ownership			
Firm type	Win percentage before 2006 policy	Win percentage after 2006 policy	T-test p-value
Family owned	.34 (0.03)	.25 (.04)	**.16**
Not family owned	.35 (0.05)	.26 (.03)	**.21**
T-test p-value	**.78**	**.91**	
N	37	29	

Note: This table provides firm mean win percentages across all auctions in which the firm bids, as well as the p-values from t-tests for differences of means. These tests look across firm ownership types before and after the 2006 risk removal policy. I use only firms with at least 10 bids. The t-tests assume unequal variances.

Table 7: Iowa Risk Premium Heterogeneity Analysis Summary Statistics

Panel 1: Firm Characteristic Variables

Variable	Description	N	Mean	Std. Dev.	Min	Max	Source
$\mathbf{I}_{\text{Public}_i}$	Publicly Listed	8207	0.08	0.272	0	1	CIQ
$\mathbf{I}_{\text{Family}_i}$	Family-owned and managed	8125	0.71	0.46	0	1	HC
$\#\text{SIC}_i$	# 8-digit SIC codes	8207	2.1	1.5	1	8	DB
$\mathbf{I}_{\text{Not Div}_i}$	Only 1 8-digit SIC code	8207	0.55	0.50	0	1	DB
$\mathbf{I}_{\text{Paving Primary}_i}$	Paving asphalt is primary business	8207	0.74	0.44	0	1	DB, HC
$\mathbf{I}_{\text{Small (Emp)}_i}$	Small business ($\leq$ 100 employees)	8162	0.56	0.49	0	1	DB, CIQ
$\mathbf{I}_{\text{Small (Rev)}_i}$	Small business ($\leq$ \$15 mill in revenue)	8095	0.60	0.49	0	1	DB, CIQ
Firm Size $(\text{Emp})_i$	# employees	8162	304	644	1	14700	DB, CIQ
Firm Size $(\text{Rev})_i$	Annual Revenue (\$)	8095	66	370	0.02	13563	DB, CIQ
$\mathbf{I}_{\text{Related}_i}$	Owners or officers related (blood or marriage) with another firm	8207	0.09	0.29	0	1	IDOT
$\mathbf{I}_{\text{Subsid}_i}$	Subsidiary of another firm	8207	0.48	0.50	0	1	IDOT
$\mathbf{I}_{\text{JV}_i}$	Has JV or partnership with another firm	8207	0.19	0.40	0	1	IDOT

Panel 2: Bid Variables

Variable	Description	N	Mean	Std. Dev.	Min	Max	
$\hat{m}_{B,j,i}$	Markup of bid over argus "spot" price	8207	52	49	-259	575	IDOT
$Wait_j$	Months between auction and work start	8087	4.7	2.8	0	17	IDOT
$\ln V_t^{\text{oil}}$	Log of 12-week oil price volatility of CL6	8207	3.2	0.39	2.2	4.4	IDOT
$\#Bidders_j$	# bidders in auction	8207	4.4	2.3	1	12	IDOT
$\ln ReqTons_j$	Log estimated tons bitumen for project	8207	5.5	2.0	-1.9	9.3	IDOT
$\ln Distance_{ij}$	Log miles between firm primary address and project site	8207	4.0	1.1	-1.4	8.8	IDOT
$\ln AveTotalBid_j$	Log average total bid in auction	8207	14	1.1	9.2	18	IDOT

Note: This table provides summary statistics of data used in the heterogeneity analysis. Sources are CapitalIQ (CIQ), Dunn & Bradstreet Hoovers (DB), the Iowa DOT (IDOT) and hand collection via the web (HC) (primarily company websites, the Iowa Department of State, and business record websites like Manta).

Table 8: Markup Analysis - Impact of Public and Family Ownership

Dependent Variable: Estimated Markup ($\hat{m}_{B,j,i}$)

	I. Impact of public ownership		II. Impact of family ownership
$\mathbf{I}_{\text{Public}_i} = 1 \cdot Wait_j \cdot \ln V_t^{\text{oil}}$	**-5****	$\mathbf{I}_{\textbf{Family}_i} = 1 \cdot Wait_j \cdot \ln V_t^{\textbf{oil}}$	**2.7****
	(2)		(1.2)
$\mathbf{I}_{\text{Public}_i} = 1 \cdot Wait_j$	14**	$\mathbf{I}_{\text{Family}_i} = 1 \cdot Wait_j$	-8.3**
	(6.4)		(3.7)
$\mathbf{I}_{\text{Public}_i} = 1 \cdot \ln V_t^{\text{oil}}$	44***	$\mathbf{I}_{\text{Family}_i} = 1 \cdot \ln V_t^{\text{oil}}$	-7.5
	(14)		(8.6)
$Wait_j \cdot \ln V_t^{\text{oil}}$	-1.3***	$Wait_j \cdot \ln V_t^{\text{oil}}$	-3.6***
	(.44)		(1.1)
$\mathbf{I}_{\text{Public}_i} = 1$	-136***	$\mathbf{I}_{\text{Family}_i} = 1$	26
	(43)		(25)
$Wait_j$	4.6***	$Wait_j$	12***
	(1.4)		(3.5)
$\ln V_t^{\text{oil}}$	9.2***	$\ln V_t^{\text{oil}}$	18**
	(2.7)		(7.9)
$\#Bidders_j$	-.63*	$\#Bidders_j$	-.66**
	(.33)		(.33)
$\ln ReqTons_j$	-6.5***	$\ln ReqTons_j$	-6.5***
	(.58)		(.55)
$\ln Distance_{ij}$	-1.1	$\ln Distance_{ij}$	-1.3
	(1.1)		(1.2)
$\ln AveTotalBid_j$	3***	$\ln AveTotalBid_j$	3***
	(.8)		(.8)
Firm Size (Emp)$_i$	.00072	Firm Size (Emp)$_i$	.0013
	(.0029)		(.004)
Firm Size (Rev)$_i$	.0004	Firm Size (Rev)$_i$	-.000025
	(.0033)		(.0044)
Year f.e.	Y	Year f.e.	Y
Month-of-year f.e	Y	Month-of-year f.e	Y
N	7970	N	7927
R^2	.49	R^2	.48

Note: This table reports results from the markup estimation in Equation 6. The coefficient of interest on the triple interaction gives the impact of risk, measured as the interaction between the time-to-start and oil volatility, for public firms relative to private firms in Column I, and family owned relative to non-family owned firms in Column II. Standard errors clustered by firm. *** $p < .01$. $1994 \leq \text{Year} \leq 2012$.

Table 9: Markup Analysis - Diversification, Firm Size, and Relationships

Dependent Variable: Estimated Markup ($\hat{m}_{B,j,i}$)

Panel 1: Industrial Sector Diversification

Diversification Variable:	I. # SIC codes	II. **1** | Not Diversified (1 SIC code)	III. **1** | Paving Primary Activity	
Div $\text{Var}_i \cdot Wait_j \cdot \ln V_t^{\text{oil}}$	**-.77****	**2.1****	**2.7****	
	(.33)	(.97)	(1.3)	

Panel 2: Impact of Firm Size

Size Variable:	IV. **1** | Small (Emp)	V. **1** | Small (Rev)	VI. Firm Size (Emp)	VII. Firm Size (Rev)
Size $\text{Var}_i \cdot Wait_j \cdot \ln V_t^{\text{oil}}$	**1.7***	**.43**	**-.0019***	**-.0081****
	(.99)	(.98)	(.00099)	(.0035)

Panel 3: Relationship to other Iowa Contractors

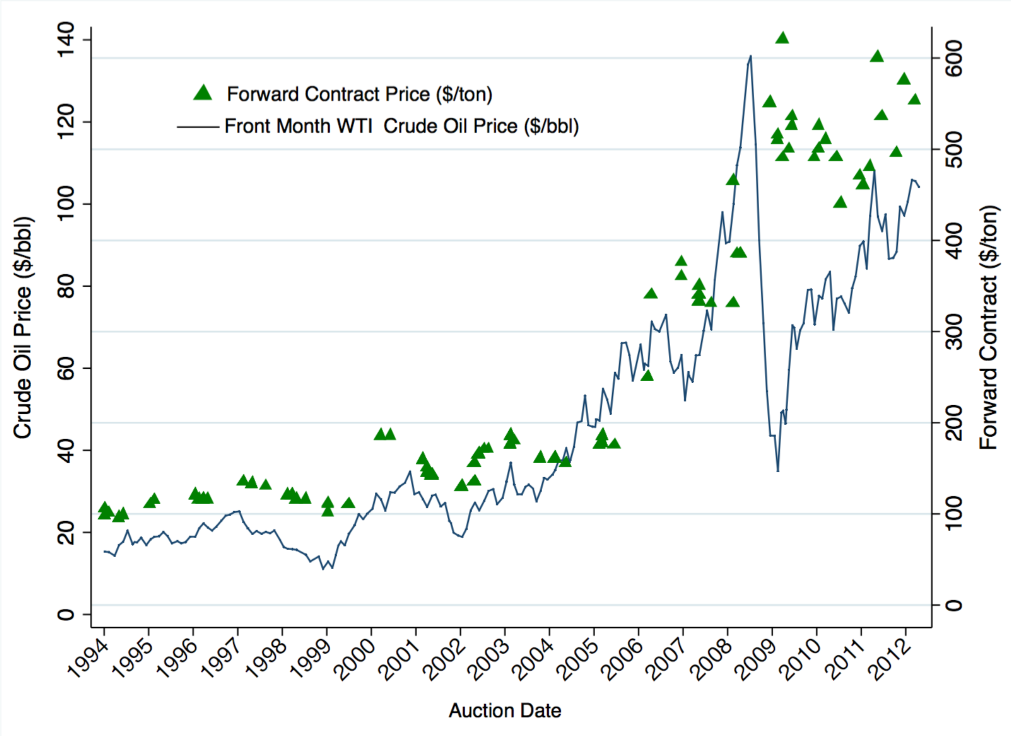
Relation Variable:	VIII. **1** | Related	IX. **1** | Subsidiary	X. **1** | JV	
Rel $\text{Var}_i \cdot Wait_j \cdot \ln V_t^{\text{oil}}$	**1.8***	**2.7****	**.32**	
	(1)	(1.1)	(.98)	

Panel 4: Interaction of Family Ownership with Diversification, Size and Relationship

Family Variable:	XI. **1** | Family·**1** | Not Diverse	XII, **1** | Family·**1** | Related	XIII. **1** | Family·**1** | Subsidiary	XIV. **1** | Family·**1** | Small (Emp)
Fam $\text{Var}_i \cdot Wait_j \cdot \ln V_t^{\text{oil}}$	**2.5*****	**2.2****	**2.7*****	**2.5*****
	(.93)	(.95)	(.92)	(.9)

Note: This table reports the coefficient of interest from the markup estimation in Equation 6. For example, in Column I the coefficient of interest on the triple interaction gives the impact of risk, measured as the interaction between the time-to-start and oil volatility, and the degree of firm diversification, measured by the number of SIC codes in which the firm is active. See Appendix A for the full specification. Standard errors clustered by firm. *** $p < .01$. $1994 \leq \text{Year} \leq 2012$.

Figure 1: Firm Z Forward Physical Bitumen Contract Prices



Note: This figure shows the bitumen prices in 100 forward physical contracts between one large paving firm and bitumen suppliers, as well as the spot oil price. The contract prices are the cost to the paving firm of bitumen.

Figure 2: Firm Z Bitumen Bid Markup Over Forward Physical Contract with Supplier

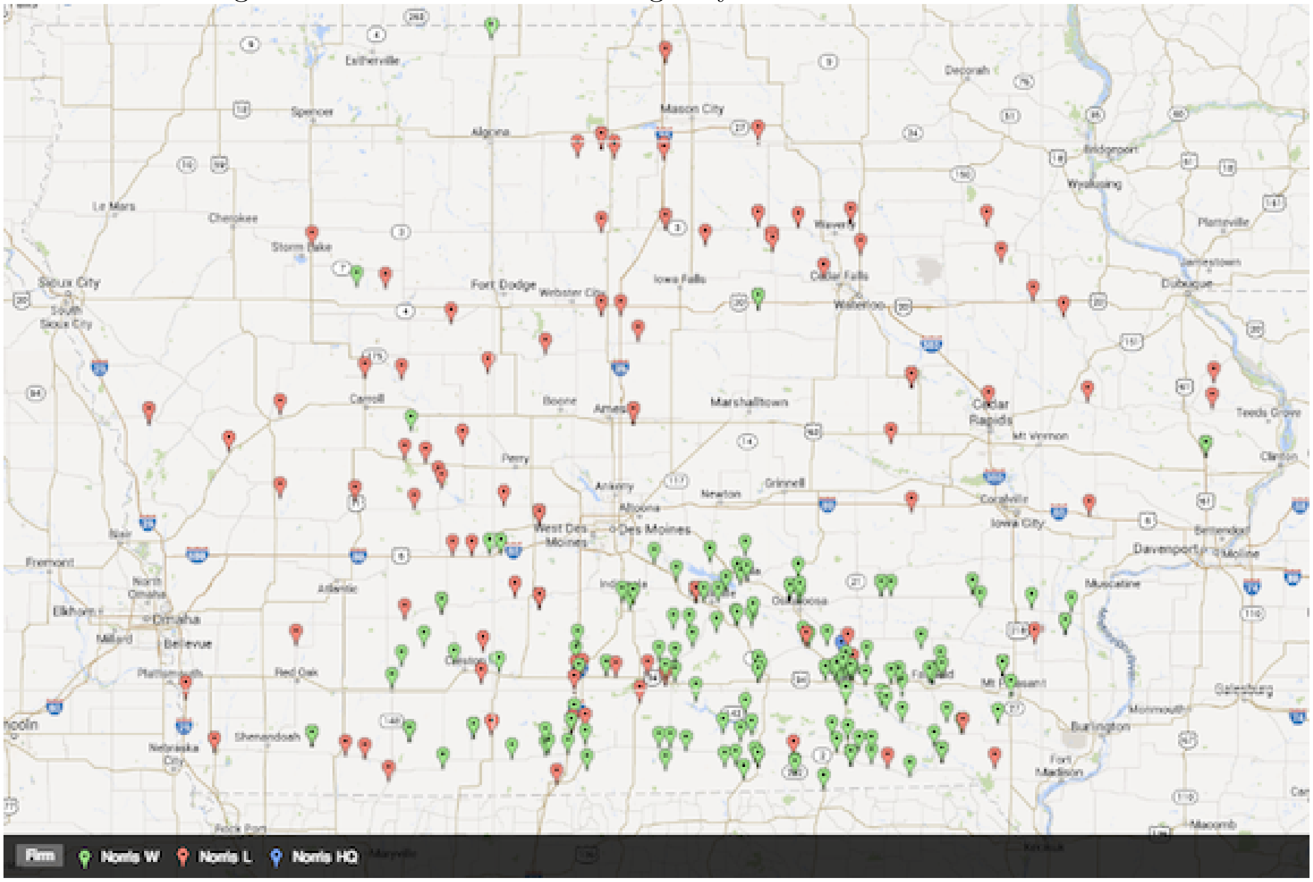
Note: This figure shows the paving firm's bitumen markup, defined as the project-specific unit bid less the project-specific forward contract price. It uses the 100 forward physical contracts between one large paving firm and bitumen suppliers, as well as the bid observed in auctions.

Figure 3: Rolling Betas for Crude Oil

Note: Front month WTI oil futures contract, S&P 500 index, and 3-month T-bills used.
Each point represents a beta estimated for the period of the previous 1, 3, 5 or 7 years.

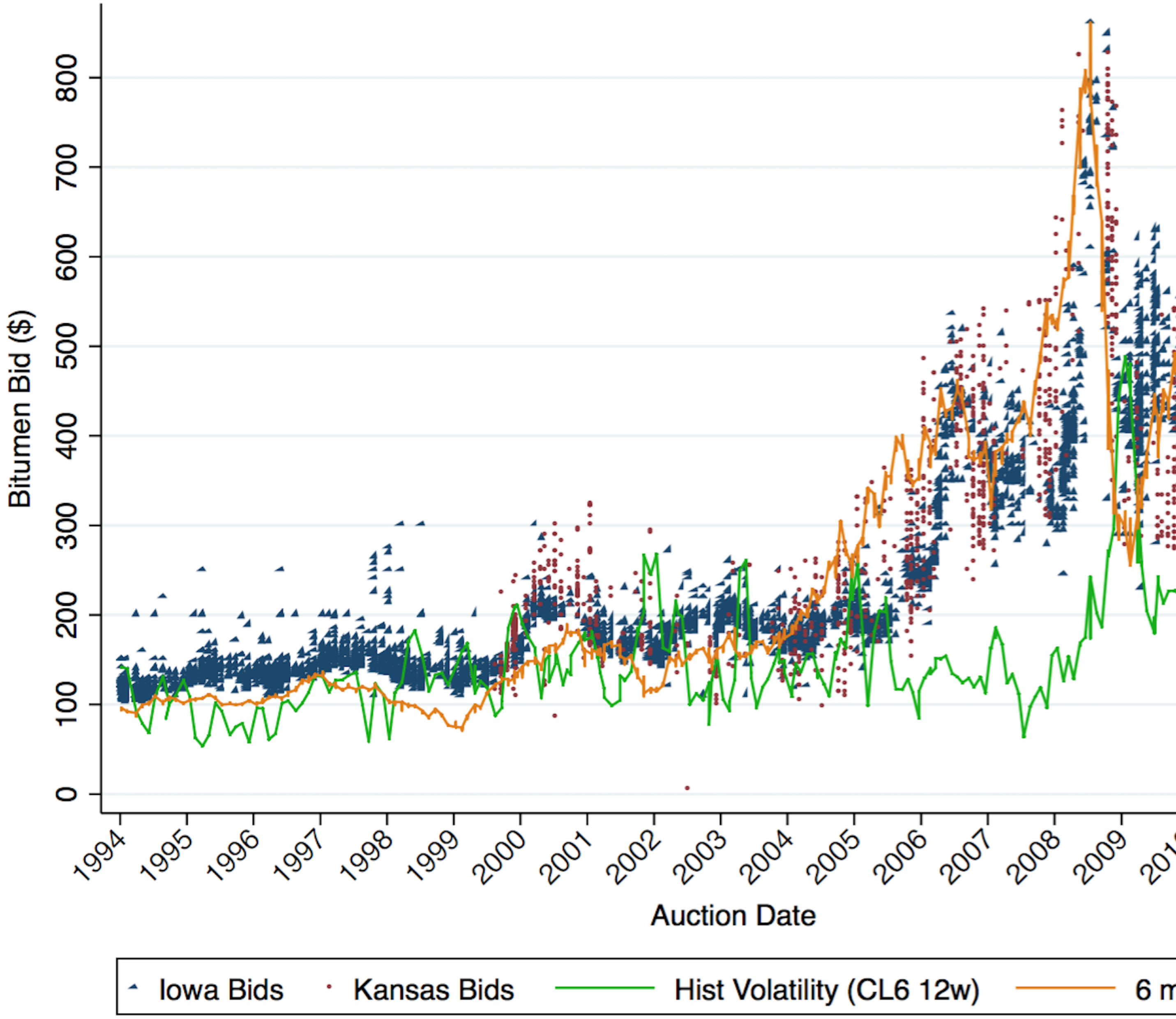
Note: This figure shows rolling crude oil betas for a conventional strict CAPM regression. I use front-month WTI oil futures, the S&P 500 index price for the market portfolio, and 3 month Treasury Bill interest rates for the risk free rate. The sign of the beta is sensitive to the period over which it is calculated, but on average is close to zero.

Figure 4: Norris Bids in Iowa Highway Procurement Auctions



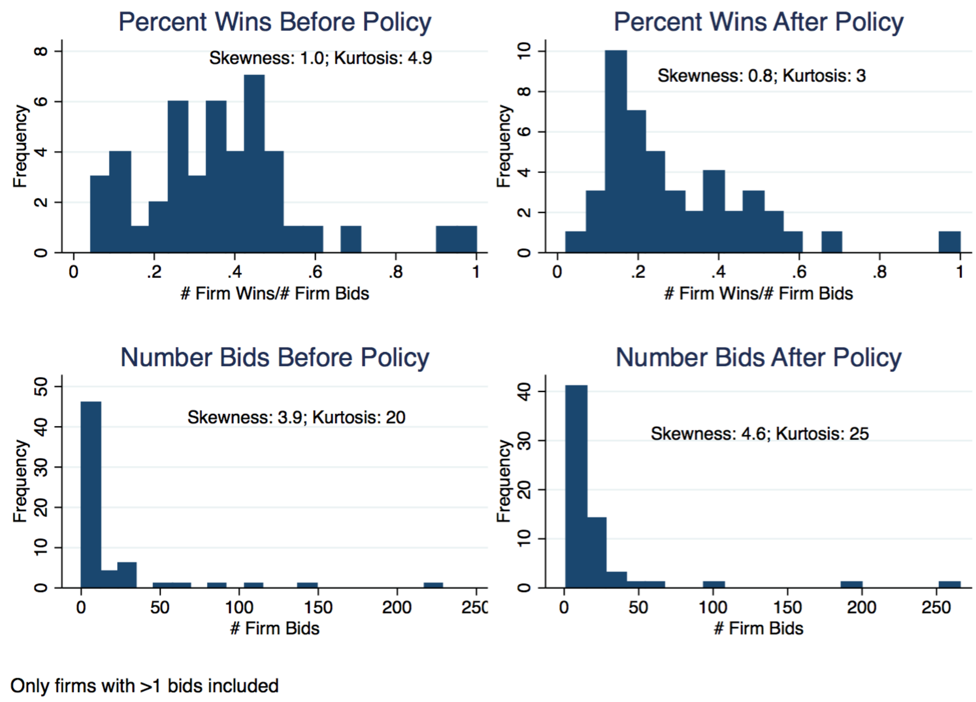
Note: This figure shows the location of auction wins (green) and losses (red) for a large bidder, Norris. The firm headquarters is blue. Wins are obviously concentrated around its headquarters. Appendix C contains similar maps for all the top bidders, suggesting that each has a distinct territory.

Figure 5: Bitumen Bids in Iowa and Kansas, Oil Price, and Oil Volatility



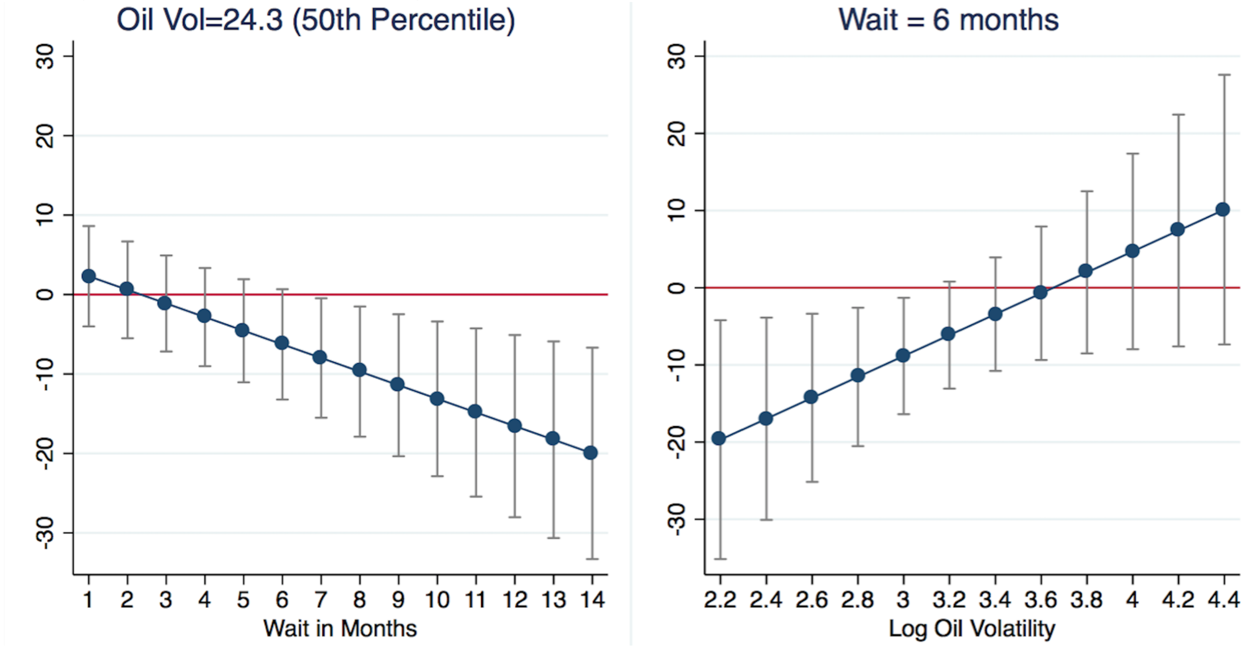
Note: This figure shows all of the highway asphalt paving procurement auction bids in my data from Iowa (blue) and Kansas (red). The Iowa data begins in 1994, and Kansas in 1998. It also shows the 6-month WTI oil futures price and the 12-week historical oil price volatility using the 6-month WTI contract.

Figure 6: Kansas Firms Win Percentage Before and After the 2006 Risk Removal Policy



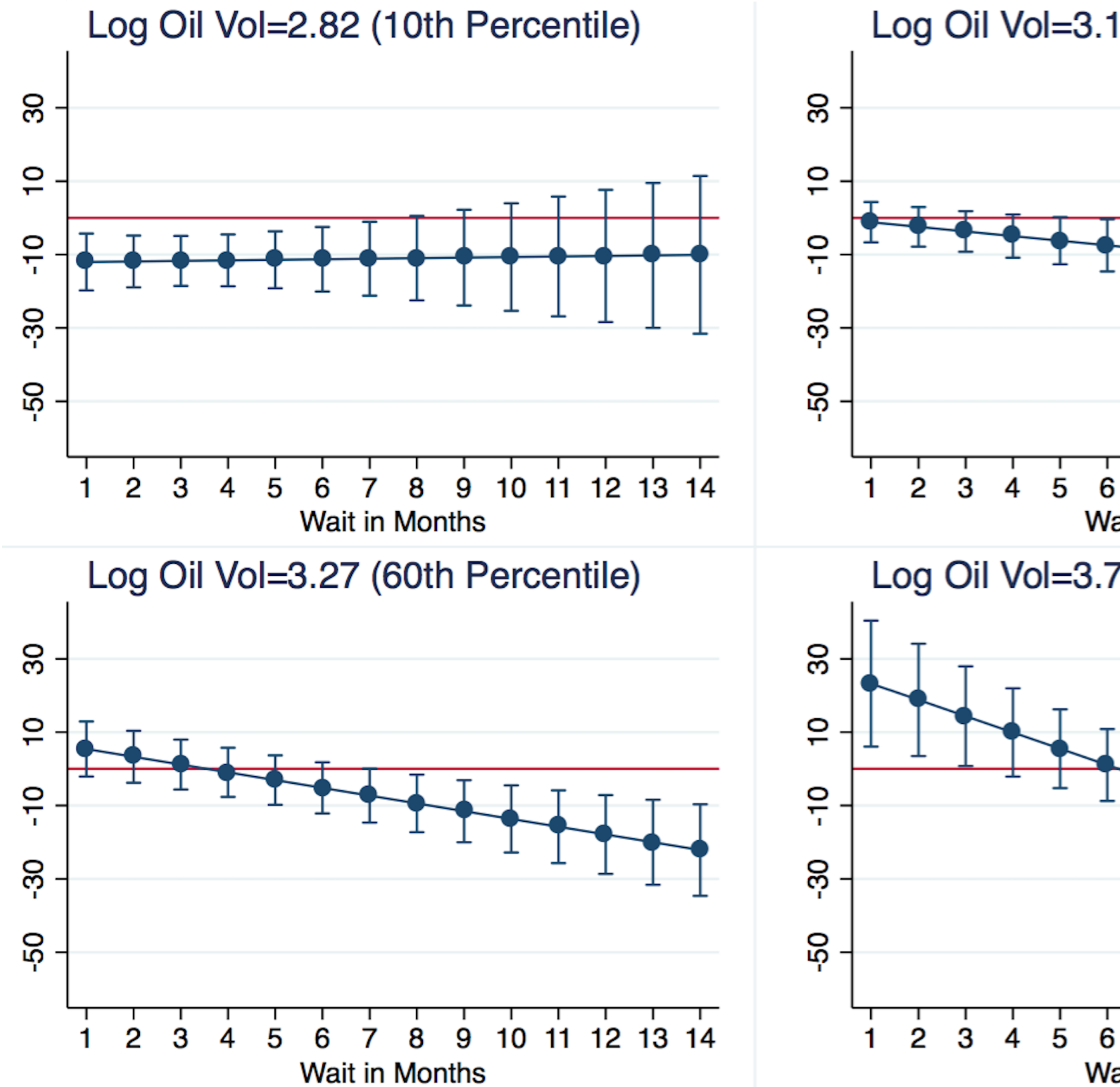
Note: The top two graphs in this figure show the frequency of of firms in various categories of win percentages. The bottom two graphs show the frequency of firms by the firms' total number of bids, with the firms sorted by their number of bids. The changing distributions indicate that after the policy a few firms were submitting more of the bids, but wins were more evenly spread across firms.

Figure 7: Conditional Marginal Effect on Bitumen Bid Markup of Public Ownership



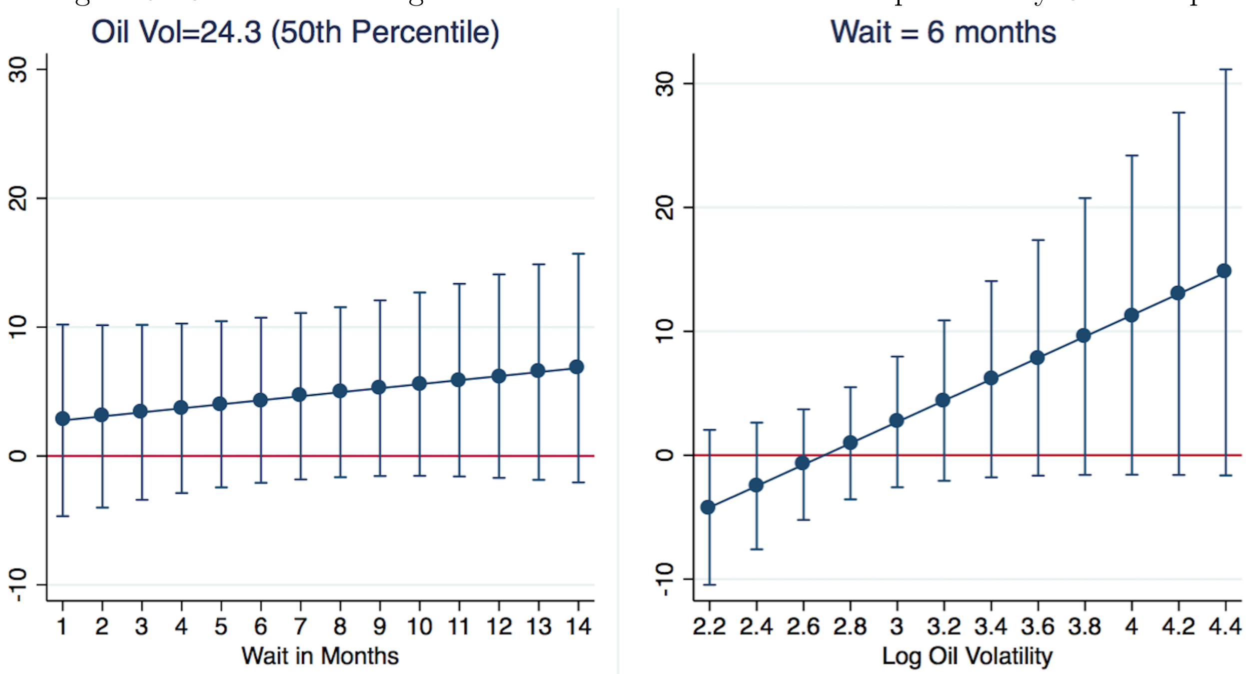
Note: This figure shows marginal effects of oil price risk on bitumen bid markup from the regression in Equation 6, whose results are in Table 8 Column I. In the left graph oil volatility is fixed at its 50th percentile, and the y-axis indicates the conditional marginal effect of a firm being publicly rather than privately owned as the time to start increases. In the right graph the time to start is fixed at its mean and the same conditional effect is calculated as log oil price volatility increases. 95% confidence intervals shown.

Figure 8: Conditional Marginal Effect on Bitumen Bid Markup of Public Ownership



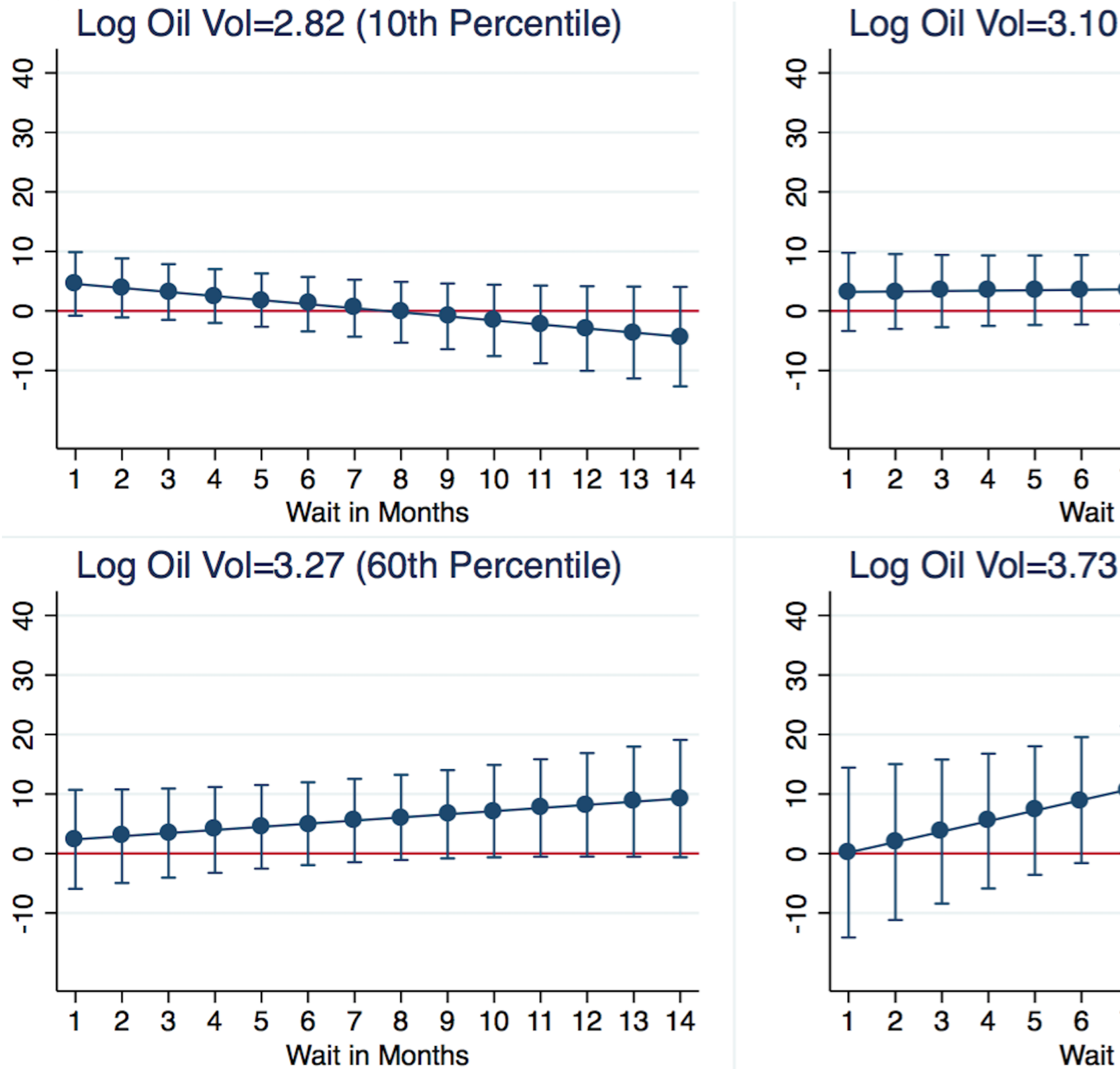
Note: This figure shows marginal effects of oil price risk on bitumen bid markup from the regression in Equation 6, whose results are in Table 8 Column I. The graphs fix oil price volatility at its 10th, 40th, 60th, and 90th percentiles. They show the conditional marginal effect of a firm being publicly rather than privately owned as the time to start increases. 95% confidence intervals shown.

Figure 9: Conditional Marginal Effect on Bitumen Bid Markup of Family Ownership



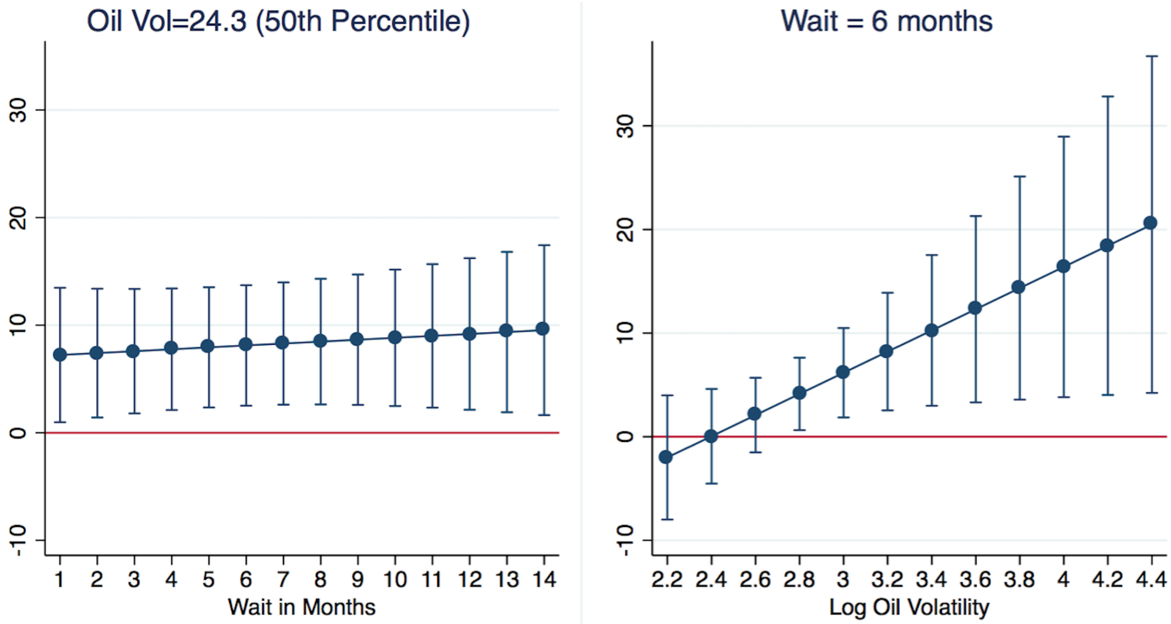
Note: This figure shows marginal effects of oil price risk on bitumen bid markup from the regression in Equation 6, whose results are in Table 8 Column II. In the left graph oil volatility is fixed at its 50th percentile, and the y-axis indicates the conditional marginal effect of a firm being family rather than non-family owned as the time to start increases. In the right graph the time to start is fixed at its mean and the same conditional effect is calculated as log oil price volatility increases. 95% confidence intervals shown.

Figure 10: Conditional Marginal Effect on Bitumen Bid Markup of Family Ownership



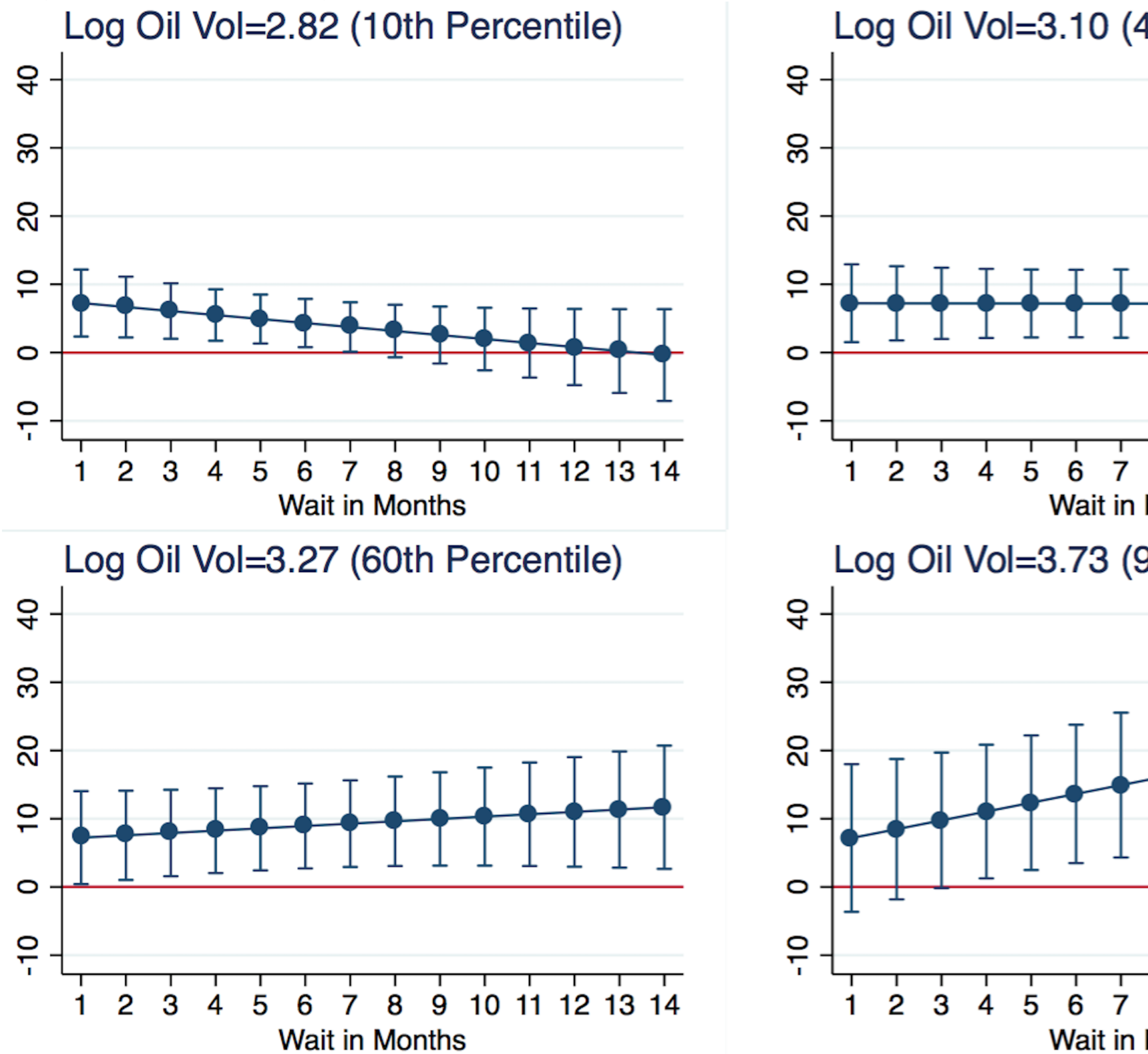
Note: This figure shows marginal effects of oil price risk on bitumen bid markup from the regression in Equation 6, whose results are in Table 8 Column II. The graphs fix oil price volatility at its 10th, 40th, 60th, and 90th percentiles. They show the conditional marginal effect of a firm being family rather than non-family owned as the time to start increases. 95% confidence intervals shown.

Figure 11: Conditional Marginal Effect on Bitumen Bid Markup of Firm Not Diversified



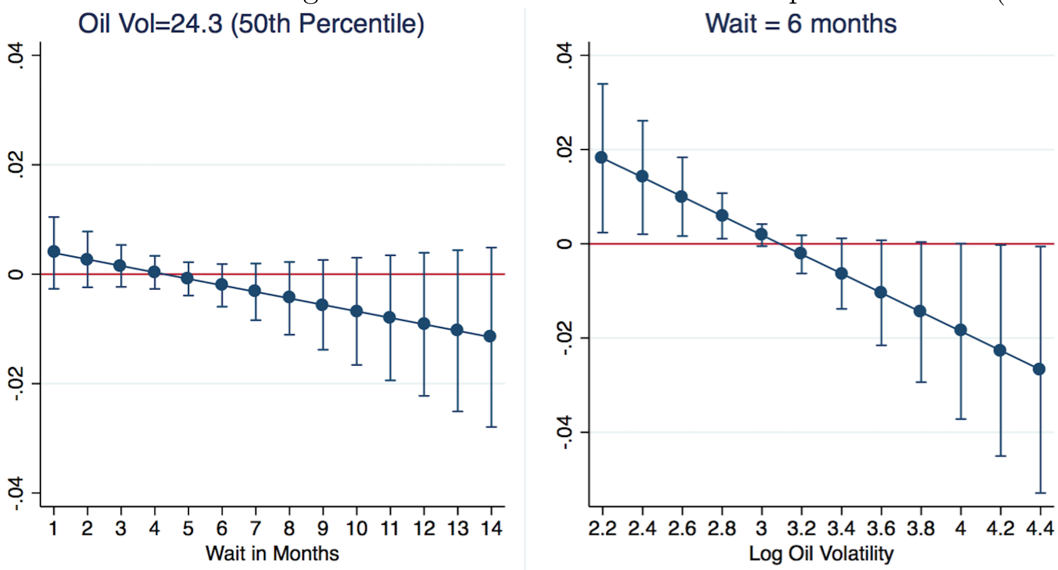
Note: This figure shows marginal effects of oil price risk on bitumen bid markup from the regression in Equation 6, whose results are in Table 9 Column II. In the left graph oil volatility is fixed at its 50th percentile, and the y-axis indicates the conditional marginal effect of a firm being not diversified (defined as being active in only one SIC code). In the right graph the time to start is fixed at its mean and the same conditional effect is calculated as log oil price volatility increases. 95% confidence intervals shown.

Figure 12: Conditional Marginal Effect on Bitumen Bid Markup of Firm Not Diversified



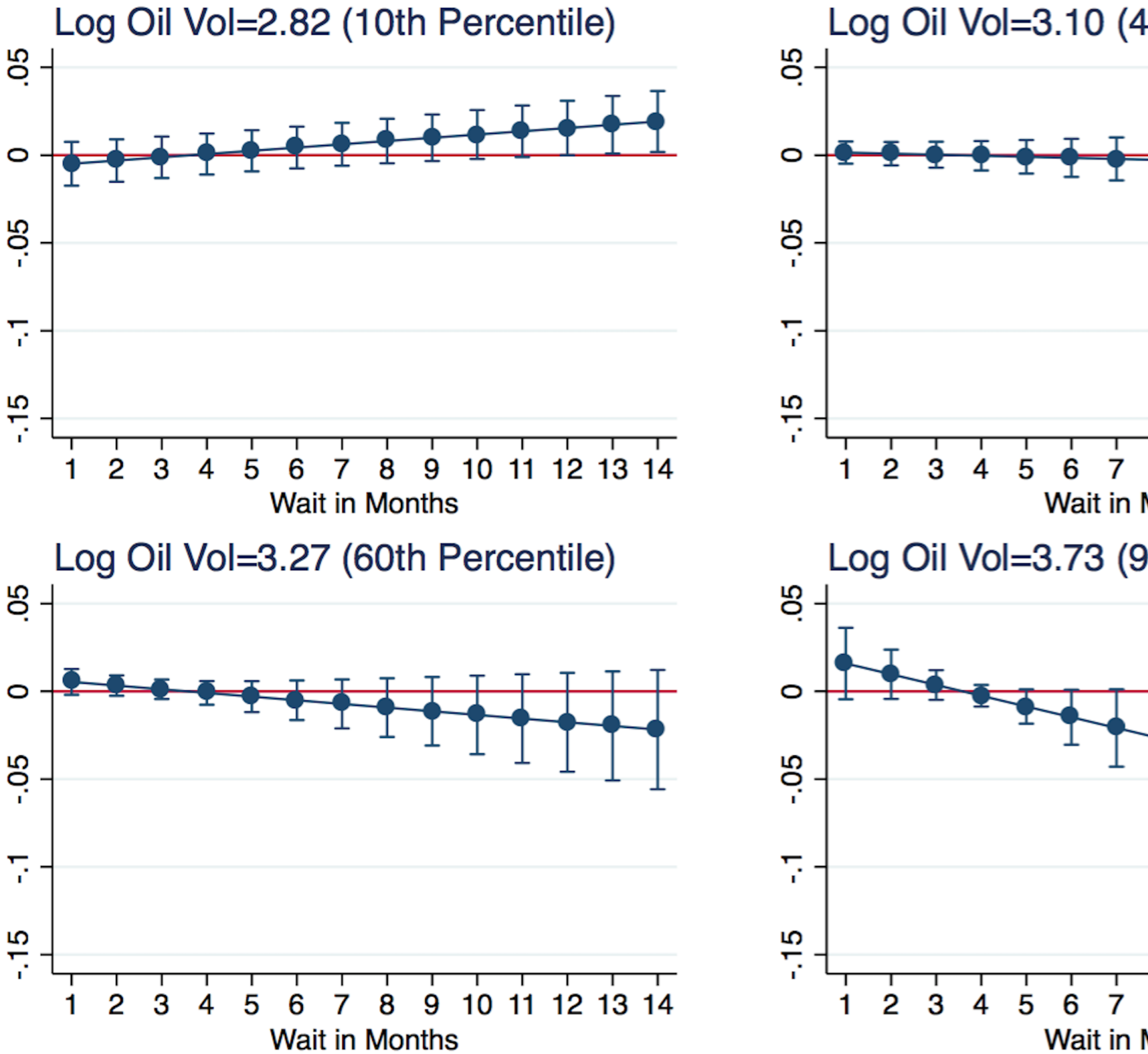
Note: This figure shows marginal effects of oil price risk on bitumen bid markup from the regression in Equation 6, whose results are in Table 9 Column II. The graphs fix oil price volatility at its 10th, 40th, 60th, and 90th percentiles. They show the conditional marginal effect of a firm being not diversified (defined as being active in only one SIC code) as the time to start increases. 95% confidence intervals shown.

Figure 13: Conditional Marginal Effect on Bitumen Bid Markup of Firm Size (Revenue)



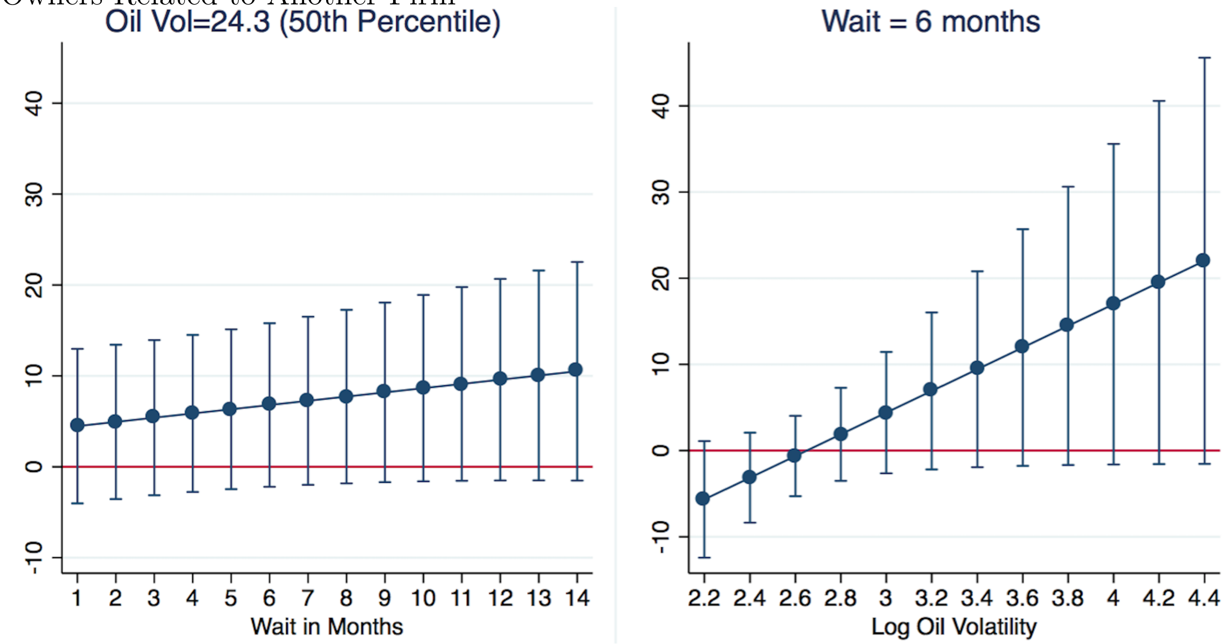
Note: This figure shows marginal effects of oil price risk on bitumen bid markup from the regression in Equation 6, whose results are in Table 9 Column VII. In the left graph oil volatility is fixed at its 50th percentile, and the y-axis indicates the conditional marginal effect of log firm revenue. In the right graph the time to start is fixed at its mean and the same conditional effect is calculated as log oil price volatility increases. 95% confidence intervals shown.

Figure 14: Conditional Marginal Effect on Bitumen Bid Markup of Firm Size (Revenue)



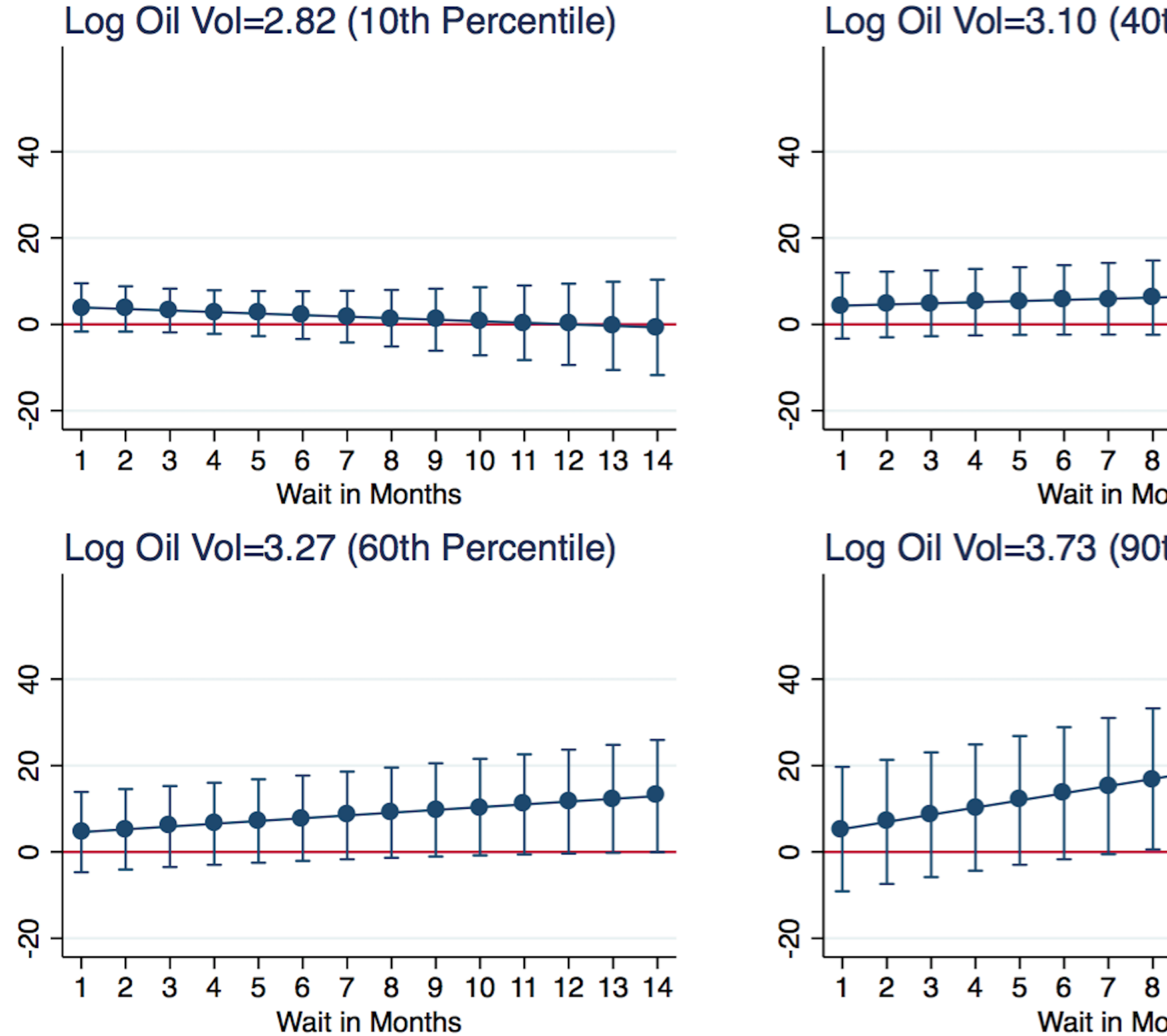
Note: This figure shows marginal effects of oil price risk on bitumen bid markup from the regression in Equation 6, whose results are in Table 9 Column VII. The graphs fix oil price volatility at its 10th, 40th, 60th, and 90th percentiles. They show the conditional marginal effect of log firm revenue as the time to start increases. 95% confidence intervals shown.

Figure 15: Conditional Marginal Effect on Bitumen Bid Markup of being Family Owned & Owners Related to Another Firm



Note: This figure shows marginal effects of oil price risk on bitumen bid markup from the regression in Equation 6, whose results are in Table 9 Column XII. In the left graph oil volatility is fixed at its 50th percentile, and the y-axis indicates the conditional marginal effect of a firm both being family owned and having its owners or officers related to another firm in the data. In the right graph the time to start is fixed at its mean and the same conditional effect is calculated as log oil price volatility increases. 95% confidence intervals shown.

Figure 16: Conditional Marginal Effect on Bitumen Bid Markup of Family Owned & Owners Related to Another Firm



Note: This figure shows marginal effects of oil price risk on bitumen bid markup from the regression in Equation 6, whose results are in Table 9 Column XII. The graphs fix oil price volatility at its 10th, 40th, 60th, and 90th percentiles. They show the conditional marginal effect of a firm both being family owned and having its owners or officers related to another firm in the data as the time to start increases. 95% confidence intervals shown.

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