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ABSTRACT

We analyze financial market data in order to produce an ex-ante assessment of the economic consequences of war with Iraq. The novel feature of our analysis derives from the existence of a market for "Saddam Securities," a new future traded on an online betting exchange that pays only if Saddam Hussein is ousted. A variety of tests suggest that this future's price provides a plausible estimate of the probability of war. The spot oil price has moved closely with the Saddam Security, suggesting that war raises oil prices by around $10 per barrel. Futures prices imply that markets expect these large immediate disruptions to dissipate quickly, with prices returning to pre-war levels within about a year and a half. Evidence on the long-run effects is fragile, and while prices are probably expected to fall a little as a result of war, any " oil dividend" will be minimal. We find large effects in equity markets: and war lowers the value of U.S. equities by around 15 percent. This effect is concentrated in the consumer discretionary sector, airlines and IT; the prospect of war bolsters the gold and energy sectors. Analyzing option prices, we find that the large estimated average effects of war reflect the market pricing in a range of different scenarios - a 70 percent probability that it will lead to market declines of 0 to 15 percent, a 20 percent chance of 15 to 30 percent declines, and a 10 percent risk of a fall in excess of 30 percent. Across countries, the most extreme effects are on the stock markets of Turkey, Israel, and several European nations. Countries that are highly enmeshed in the world economy, or net oil importers, are most likely to experience adverse effects from war.

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1. Introduction

War presents profound ethical questions. It also presents important economic questions, and the likely consequences of a U.S.-led invasion of Iraq merit substantial scrutiny. To date we have heard much speculation, but there have been few detailed studies. Economists have gone strangely silent when confronted with the ambiguity of war.

Yet even if economists have been largely quiet on the economic consequences of war (with notable exceptions including William Nordhaus and Larry Lindsey), financial markets have continued to operate relatively smoothly, incorporating new information, assessing risks, and aggregating public and expert opinion. This paper analyzes what the financial markets are telling us about the consequences of war. Of course, how informative one believes these assessments to be depends on one's view of the efficiency of these financial markets.

Our ability to make inferences about the consequences of war derives from a novel financial instrument that trades directly in this risk—a contingent contract we refer to as the "Saddam Security"—an asset whose payoffs depend on the ousting of the Iraqi leader. These securities are traded on an online betting exchange similar to the better-known Iowa Electronic Markets. The Saddam Security is traded a little more widely and liquidly than the typical contract on the Iowa market, and Wall Street is over-represented among market participants. Evidence from a variety of sources suggests that these data do in fact reflect underlying war probabilities.

We track high frequency movements in the Saddam Security and compare it with movements in oil futures markets in order to assess how war will affect the future path of oil prices. In the short run, a ten percent rise in the probability of war with Iraq raises oil prices by about $1 per barrel (or 3-4 percent), suggesting that war leads oil prices to rise around $10 per barrel higher, relative to a no-war counterfactual. We find suggestive evidence that oil prices may fall in the longer run, although these effects are both small and fragile. Thus we expect the oil price impacts of war to cause short-run economic disruption, but find little evidence that there will be a meaningful long-run oil dividend.

Turning to aggregate stock market indices, we find that the U.S. stock market is extremely sensitive to changes in the probability of war. A 10 percentage point rise in the probability of ousting Saddam lowers the S&P 500 by about 1½ percent, suggesting that war lowers U.S. equity valuations by around 15 percent. Option prices imply that this large average effect reflects a negatively skewed distribution of possible outcomes. We estimate that option prices imply a 70 percent chance that war will have a moderately negative effect on the market of 0 to -15 percent, a 20 percent chance of a -15 to -30 percent effect, and a 10 percent chance of a -30 percent effect or worse. The economic impacts of war are not confined to the U.S., and analysis of 44 other stock markets around the world suggests that they too tend to be pricing in a risk of substantial disruptions.

The analysis in this paper makes three main contributions. First, we use financial market data to better understand the consequences of a prospective policy decision—a U.S. led invasion of Iraq—in real time. A financial-market-based analysis complements expert opinion in several ways. Expert opinions tend to vary widely (from expectations of a walk-over victory to dire predictions of terrorism and regional instability) and vary fairly directly with the ideological predisposition of the predictor. Markets aggregate opinions, and by requiring a trader to put "your money where your mouth is," they lessen the cheap-talk problem and create incentives for individuals to reveal their true beliefs. In addition, whereas careful experts tend to focus on the mostly easily analyzed costs of war (e.g., the budgetary impact), financial markets are forced to price the harder-to-assess but potentially much larger general equilibrium and political economy effects of war on the national economy. Financial markets do not simply evaluate the cost of war today, but also incorporate the effect of this war on the number and intensity of future conflicts. Moreover, whereas previous studies of the effect of political events on financial markets are necessarily retrospective, our analysis is prospective.[1] Analyses like ours could conceivably be used to inform decision-making in real time.[2]

Second, our analysis may provoke a reassessment of the extent to which stock market movements can be explained by news. The conventional wisdom is that identifiable news events explain only a small portion of market movements, suggesting a role for behavioral theories of stock price movements. The wisdom is based in part on studies like Cutler, Poterba, and Summers (1989), who find that first-order news events (including political and military developments) explain only a small portion of market movements. In contrast, we find that over 30 percent of the variation in the S&P and 75 percent of the variation in spot oil prices over the last 5 months can be explained econometrically by changes in the probability of war (and, for oil, the Venezuelan crisis).[3]

A possible reconciliation of our results with previous narrative studies of financial markets is that many political events are not surprises by the time they happen. This is likely to be the case for the current war: by the time it starts, the market's assessment of its probability is likely to be close to 100 percent, and its expected stock market effects should already be priced in. This was even partly the case for a "surprise" like Pearl Harbor, since the likelihood of war with Japan and Germany was surely somewhat foreseeable even on December 6, 1941. Without securities that quantify the news content of the political narrative, the true impact of these events on the markets are almost impossible to assess.

The third contribution is simply to highlight the likely utility of political securities in improving the efficiency of markets. If some of the uncertainty about the value of the S&P over the past 5 months reflected uncertainty about war and its impact, aggregating information about the likelihood of war in a publicly observable market price should enhance the efficiency with which information about the non-war component of value is incorporated into prices. For analogous reasons, Yuan (2002) finds that the introduction of sovereign debt markets increases the liquidity of emerging market corporate bonds. If this study upwardly revises our beliefs about the extent to which political uncertainty contributes to uncertainty about asset values, then it should also revise our beliefs about the utility of political risk securities.

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1 Examples of retrospective analyses include studies of Swiss and Swedish government bonds during World War II by Frey and Kucher (2000) and Waldenström and Frey (2002), and an analysis of major events since the 1940s by Cutler, Poterba, and Summers (1989).

2 Of course, if policy makers did start basing decisions on analyses of market expectations about outcomes, this could create an endogeneity issue, complicating the analysis. We should be so lucky.

3 The figures referred to are the R-squared from long difference regressions reported in Tables 2 and 3A.

The remainder of the paper is divided into five sections. The next section reviews expert opinion on the effects of war. The third section describes the Saddam Security and presents tests of the efficiency of its pricing. The fourth section examines the co-movement of spot and future oil prices with the probability of a war in Iraq, while the fifth section does the same for U.S. and foreign equity markets. A concluding discussion follows.

2. Background

Existing studies of the economic consequences of a war with Iraq have focused on three issues affecting the U.S.: direct military expenditure, the cost of rebuilding Iraq, and changes in oil prices and their macroeconomic repercussions.

(a) Budgetary expenditures – military and peacekeeping

Current expert estimates of the direct cost of waging a war in Iraq range from $22-140 billion. The most modest estimate was an analysis conducted by the Congressional Budget Office (2002), which priced the military removal of Saddam at $22-29 billion. The Democratic Staff of the House Budget Committee (2002) have estimated $31-60 billion, while the Center for Strategic and International Studies (CSIS) (2002) has suggested that it might range up to $44 billion. At the top end, William Nordhaus (2002) has estimated the cost at $50-140 billion.

These disparities flow from disagreements over both the duration and intensity of a possible conflict. As Cordesman (2002) has pointed out, a variety of scenarios could affect this. Among the factors that would dramatically increase the military cost of the war are the possible use by Iraq of chemical or biological weapons against U.S. troops operating in an urban environment; an Iraqi missile attack on Israel; the rise of regional Iraqi warlords; domestic turmoil in countries that are now broadly supportive (particularly Turkey and Saudi Arabia); and terrorist attacks on U.S. or allied interests in the region.

Because assessing the cost of rebuilding Iraq involves estimating the willingness of the United States to invest in the reconstruction effort, the Congressional Budget Office and the House Budget Committee estimates do not deal with these costs. Nordhaus (2002) suggests that this is a major portion of total expenditure, estimating the cost of peacekeeping, reconstruction, and humanitarian assistance over the decade 2003-12 at somewhere between $106 and $615 billion. While contributions from other developed nations towards reconstruction are likely to be larger than their contributions towards direct military costs, rebuilding Iraq could still have a greater impact on the U.S. budget over the next decade than the military cost of removing Saddam.

Since financial markets do not provide us with a direct estimate of future deficits, our analysis is largely silent on budgetary impacts, except to the extent that government borrowing affects the cost of capital or the environment for business.

(b) Oil price effects

While current and future oil prices are directly observable in markets, expert opinion has focused on likely production levels. Although Iraq currently supplies only 3 percent of the world's oil, both the short-term demand for oil by the U.S. and the supply of oil by OPEC members are highly inelastic (Ghouri, 2001; Ramcharran, 2002). Additionally, conflict in the Persian Gulf region could potentially cause other oil-producing nations to change production levels for political or strategic regions.

These supply forecasts are then exploited to assess the impact of a war with Iraq on the oil price, which averaged $24 per barrel in 2002, and at the time of writing is trading around $35 per barrel. A CSIS report (Ebel, Franssen, Goldstein, and Sieminski, 2002) presents four scenarios:

- **No War:** Saddam disarms or is replaced in an internal coup. Oil prices average $24 in 2003, and $18 in 2004.
- **Benign Case:** The invasion succeeds quickly, and with no serious damage to Iraqi oilfields. Oil prices average $26 in 2003, $22 in 2004.
- **Intermediate Case:** A relatively quick war, but with high casualties. Ongoing attacks against U.S. forces, and acts of sabotage, keep Iraqi oil off the market for at least six months – a supply shock that is only partially alleviated by the release of reserves held by members of the International Energy Agency. Oil prices average price $37 in 2003, $30 in 2004.
- **Worse Case:** Iraq attacks Israel with chemical weapons, and Israel responds, heightening tensions in the Arab world. Iraq's oil fields are set on fire, and wells in other Arab countries are also sabotaged. Oil prices average $60 in 2003, $40 in 2004.[4]

It has also been suggested that the removal of Saddam would help lower long-term oil prices. Iraq is estimated to have 11 percent of the world's oil reserves – a significantly higher fraction than its share of current world oil production. This has led some analysts to speculate that its current production levels – around 2.5 million barrels per day over the past few years – could be doubled within a few years in the post-Saddam era (Marcel, 2002; Larry Lindsey, cited in Davis, 2002). Others, such as Daniel Yergin (2002), argue that even increasing Iraq's output to 3.5 million barrels per day would take three years, and expanding it to 5.5 million barrels per day would not occur until after 2010. An even lower estimate is that of Nordhaus (2002), who argues that expansion beyond the threshold of 3.5 million barrels per day is unlikely to occur so long as Iraq remains a member of OPEC (on this point, see also Council on Foreign Relations & Baker Institute 2003).

As discussed in the introduction, we find that a 10 percent increase in the probability of war has increased spot oil prices by about $1. Given that the probability of war was 75 percent at the end of our sample and that the oil price was $35, projecting our estimates out of sample would imply a price of $27.50 without war and $37.50 with. This in turn suggests that the market's expectations are roughly in line with the CSIS's intermediate case, discussed above. Oil futures suggest that the market expects the price effects to dissipate by the end of 2004, also roughly in line with the CSIS projections. Longer-term oil futures suggest that the market expects only a small long-run improvement in the oil outlook subsequent to war; these market expectations appear more in line with the less optimistic Yergin and Nordhaus scenarios.

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4 Perry (2001) also presents a "Worst Case", in which oil rise to $161 per barrel.

(c) Macroeconomic effects

Macroeconomic effects of the war could arise from short-term oil price shocks, from the effects of deficit-financed military spending, or from effects on consumer confidence in and investor expectations about the future. The IMF has estimated that a $5 per barrel rise in the short-term oil price cuts U.S. growth by 0.3 percent in the first year (Leach, 2003, 26). Using a full-employment model, which might understate short-run macro effects, Nordhaus concludes that the effect of the oil price rising to $75 per barrel (a more extreme scenario than the CSIS's "Worse Case" above) would be to lower real U.S. national income by $175 billion (1.7 percent) in the first year. Assuming that the oil price closed one-fifth of the gap each year when reverting back to its long-run level, he estimates a total cost of $778 billion over decade 2003-12. Nordhaus estimates that one-seventh of this would be the direct terms of trade effect, and six-sevenths would flow from lower profits reducing capital accumulation, and hence potential output.

Traditionally, the defense spending associated with war has been thought to have a short-run stimulus effect. Nordhaus argues that unlike World War II, Korea, and Vietnam, the rise in defense spending for the 1991 Persian Gulf War was not accompanied by an increase in GDP, casting doubt on the "iron law" of wartime booms. This likely reflected the size of the expenditure (the first Persian Gulf war resulted in a boost in defense spending of only 0.3 percent GDP; compared with 1.9 percent for Vietnam, 8.0 percent for Korea, and 41.4 percent for WWII).

Combining the effects of oil and defense spending shocks, Nordhaus estimates that a war with a very bad outcome for oil prices would lower U.S. GDP by an average of about 0.8 percent per year over the next decade, with all of the effect coming from oil. Using a multi-country model, McKibbin and Stoeckel (2003) estimate that war cost the world economy up to 2 percent of GDP by 2005. They predict milder effects in Europe and Japan than in the U.S. or Australia. In contrast, we find that U.S. and European markets are the most severely affected by war.

Our analysis suggests that financial markets are significantly more pessimistic about the effects of war. Projecting our estimates out of sample imply that moving from a 0 to a 100 percent probability of war reduces firms' values by 15 percent in the U.S. and slightly more internationally. These effects are almost an order of magnitude too large to simply reflect a temporary 1 or 2 percent decline in GDP. We now turn to presenting our results in detail, but will return to this question in the final section of the paper.

3. Assessing the Probability of War: The Saddam Security

The innovation of this paper is to exploit financial market data to reduce our reliance on expert opinion, which as the review above suggests, tends to differ widely across authors in a manner that is somewhat predictable given their ideological leanings. If financial markets are efficient, then asset prices should reflect all available information. In exploiting them, our paper follows in a long tradition in financial economics of event studies. As the probability of war has waxed and waned, so too financial and commodity markets have valued and revalued future and contingent commodities, including oil prices, stock market indices, and options and futures in these markets. These data allow us to infer the market's expectations of the economic consequences of war both through time, and under different scenarios.

Our analysis is made possible by a new dataset containing trade-by-trade records of a unique financial instrument. Participants trade in "Saddam Securities" by buying and selling an asset that pays $10 if "Saddam Hussein is not President/Leader of Iraq by [Date]," and nothing otherwise. These securities are traded over different horizons, with the key contract dates being December 2002, March 2003 and June 2003. We interpret the prices of these all-or-nothing futures (as cited in 10 cent "ticks") as the probability of war prior to each date.[5]

The source of these data is www.tradesports.com.[6] Tradesports, a dotcom based out of Ireland, describes their business as a "betting exchange". Their website provides an electronic exchange that shares many of the features of the Iowa Electronic Markets, running a continuous double auction on well-defined futures. As such, it also shadows the structure of most of the major financial exchanges around the world, (albeit at a simplified level), and Tradesports provides the electronic infrastructure for a range of futures markets. There is free entry to the market, and participants can take either side of a transaction. Like the Iowa markets, limit orders are possible, and in neither market is trading on margin accounts allowed.

However, there are important differences between Tradesports and the more familiar Iowa Electronic Markets. First, Tradesports is a for-profit company, charging a 0.4% commission. Second, Tradesports more closely approximates free entry, and becoming an active trader merely requires a credit card, and an internet connection; setting up an account is fast and free. Third, while the Iowa Electronic Markets started largely as a teaching and research tool focusing on political events, much of the business done by Tradesports is done on sporting events, although they also provide markets for futures in financial, economic, political, entertainment, and even weather-related events. Fourth, the Iowa markets restrict individual investments to $500; Tradesports has no such restrictions. And fifth, perhaps the most important difference is the clientele. Tradesports has marketed itself heavily as a trading exchange in a new set of contingent commodities rather than as a sportsbook. Their most aggressive promotion has been in the New York financial district, and many of the most active Tradesports traders are based in Wall Street or the City of London.

Thus, there are important parallels between our Tradesports data, and those data analyzed in the existing literature on political futures. A fundamental issue in these markets is whether the market is sufficiently thick to yield meaningful insights. Table 1 reports some basic turnover statistics for three Tradesports markets, and compares them with recent data from the Iowa Electronic Markets and the Chicago Mercantile Exchange.

[5] Trading in these markets opened on September 24, 2002, and our dataset ends on February 6, 2003. In late January and early February 2003, markets dated for April and May 2003 were also opened, as were markets on a UN resolution authorizing the use of force in Iraq.

[6] Many thanks to the CEO of TradeSports, John Delaney, for generously sharing these data and his expertise throughout this project.

Table 1: Comparing the Depth of Futures Markets

	Active Traders	Monthly Volume		Total Volume since Market Opened
		#Trades[b]	$ Traded	
Tradesports.com: "Saddam Security"				
Ousted by Dec '02	About 9,000 active traders of which 2,500-3,000 participated in the "Saddam Security" market[a]	17,658	$3,020	$14,084
Ousted by Mar '03		20,013	$12,722	$70,388
Ousted by June '03		31,407	$11,429	$78,351
Iowa Electronic Markets: U.S. Presidential Elections[c]				
1988 Vote Share	155	7,475	$1,535	$8,123
1992 Vote Share	592	7,883	$2,167	$21,445
1992 Winner-takes-all	471	55,104	$13,115	$51,316
1996 Vote Share	264	2,573	$404	$3,628
1996 Winner-takes-all	1,151	27,513	$5,796	$137,386
2000 Vote Share	802	4,521	$1,697	$17,576
2000 Winner-takes-all	965	42,259	$20,931	$130,058
Chicago Mercantile Exchange: S&P 500 Futures				
S&P Futures traded in January 2003	2,725 individual members + 60 clearing firms	15 million	$900 billion	n.a. (Opened 4/21/83)

(a) Estimates of TradeSports traders by John Delaney, CEO of Tradesports.
(b) #Trades adjusted to $1 units. (1988 Iowa markets were claims for $2.50; Tradesports contracts are claims for $10.)
(c) Estimates of the Iowa market derived from Berg, Nelson and Rietz (2001).

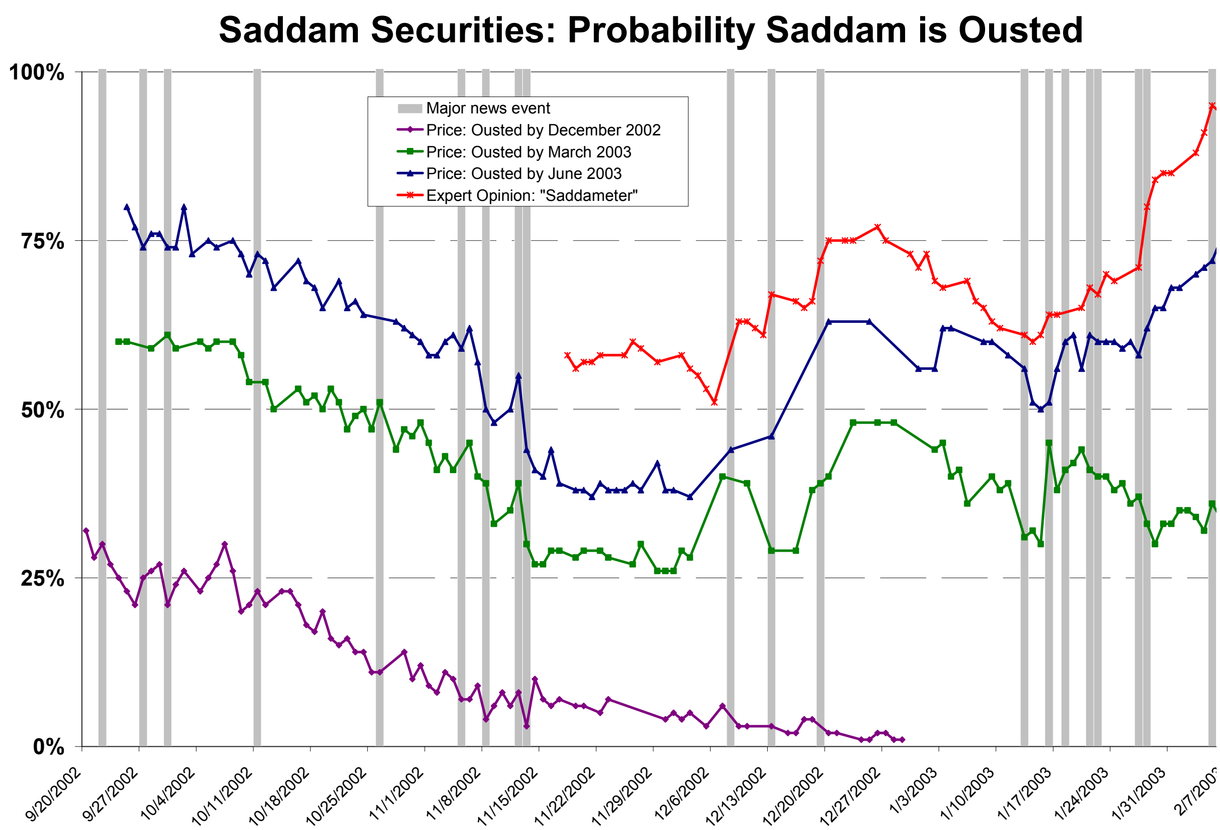
By comparison with major financial markets, trading in the Saddam Security is clearly very limited. This is a fledgling market, and the stakes are relatively small. But the comparisons with the Iowa markets are revealing, and the monthly volume of trade in the Saddam Security is comparable to that in past Iowa presidential winner-take-all markets, and considerably larger than past vote-share markets

It is worth noting that a host of studies exploiting the Iowa data have tended to find those political markets to be relatively efficient.[7] A sampling of these studies suggests that prices follow a random walk, there is no evidence that exploiting polling or other sources of information would yield profitable trading strategies, and the final predictions from even the less liquid vote-share markets have tended to outperform public polls as predictive tools. Related work by Wolfers and Leigh (2002), analyzing political betting data from a large Australian sports bookmaker, confirms these findings in another political market. The turnover in Saddam Securities is large enough that a trader could earn a tidy profit were the market to fail to reflect available information.

[7] Berg, Forsythe, Nelson and Rietz (2001) and Berg, Nelson and Rietz (2001) provide useful reviews of the findings from the Iowa Electronic markets.

Figure 1 shows the closing price for the Saddam Securities through to February 6.[8]

Figure 1: Daily Closing Prices on the Saddam Security



The first thing to note is the very close movement in prices across securities, and divergence only occurs as individual securities approach their expiration dates.

The market-based indicators can also be compared with expert opinion, and the figure also shows the one quantitative indicator of expert opinion that we could find. Slate.com's William Saletan writes a regular weekday column, "The Odds of War", concluding each article with his quantitative assessment of the likelihood of invasion.[9] He terms these assessments the "Saddameter".

[8] The market is actually open 24 hours. Here we show the closing price, at 4pm Eastern Standard Time, which corresponds to the closing of the main New York markets.

[9] In private correspondence (2/11/03), Saletan expanded on the information set underlying the Saddameter: "I read 4 papers a day (NYT, WP, WSJ, LAT), but for the Saddameter, I soon began to rely on the AP and Reuters wires, because I wanted the facts unfiltered. I never looked at op-ed pages. I never looked at stock markets or oil markets. The only stories I gave weight to, other than stuff directly related to Iraq, were stories about North Korea. Also, I did give weight to polls early on, since a serious rise in domestic antiwar sentiment might have derailed Bush's plans. But that sentiment never reached critical levels." Beyond this, Saletan also noted that he was not even aware that there was betting on the likelihood of war.

Regressing the closing price of the June 2003 Saddam Security on the most recent reading of the Saddameter yields a coefficient of 0.9, and a t-statistic of 11 (and a statistically insignificant constant of –8.3 percent); the correlation coefficient is 0.88. While the series closely co-move, there are also important differences. The Saddameter professes to be an assessment of the "chance of invasion", or "odds of war", while the Saddam Security reflects the probability that Saddam is no longer leader by a certain date. The possibility of a peaceful solution, such as the Iraqi leader being internally deposed, or seeking exile in another country should surely lead the Saddam Security to yield a higher probability than the Saddameter. That this is not the case suggests that the likelihood of ousting Saddam without conflict is probably quite low (as other expert opinion suggests). The fact that the Saddameter is consistently higher than the Saddam Securities could reflect the chance of conflict being delayed until after June 30 or suggest that Slate estimates a higher probability of war than the market. Alternatively, the U.S. might start the war and not win quickly, although most experts dismiss this possibility.

A related check on the reliability of the Saddam Security is to see whether it responds to important news events. To investigate this possibility we scanned the New York Times for each day in our data, recording our judgments of the most important news events. This narrative evidence is presented in Appendix A, and the corresponding dates are shaded in grey in Figure 1. Broadly speaking these markets responded as one might expect to news, and moreover actual news explains most of the large price movements.

Finally, we can perform some very simple tests of the efficiency with which the Saddam Security is priced. We perform Augmented Dickey Fuller tests of whether the time series of the prices of each of the Saddam Securities follows a random walk, and find that in no case can we reject the random walk hypothesis. KPSS tests yield complementary findings, rejecting the null that the prices are trend stationary. None of this is surprising given that this is financial data.

To test the speed with which information is incorporated into the price of the Saddam Security, we regress its price changes on leads and lags of changes in the Saddameter. In doing so, we match the last daily trade of each contract with the most recent Saddameter figure (the Saddameter is updated five days a week). Beyond a clearly significant contemporaneous effect, we find large magnitudes for the coefficients on a first lead and second lagged change in the Saddameter. At the same time, the sum of the four coefficients is close to the coefficient in the levels regression mentioned above, suggesting that information is incorporated after only short lags.

Table 2: Tests of Pricing Efficiency of the "Saddam Security"

Dependent Variable: ΔSaddam Security (Daily)	March Security	June Security	Combined Sample
Panel A: Dickey Fuller Tests ΔSaddam Security=β*Saddam Security(t-1)			
Saddam Security(t-1)	-0.106	-0.059	-0.081
	(.047)	(.037)	(.030)
Test statistic (t-stat)	-2.276	-1.591	8.063[(a)]
(10% critical value)	(-2.590)	(-2.591)	(18.693)
Reject Random Walk?	No	No	No
[p-value]	[p=.180]	[p=.488]	
Panel B: KPSS Tests (6 lags)			
Test statistic	0.216***	0.261***	
(1% critical value)	(.216)	(.216)	
Reject Trend Stationarity?	Yes	Yes	
Panel C: Speed with which information is incorporated			
ΔSaddameter(t+1)	0.080	0.315	0.208
	(.281)	(.197)	(.171)
ΔSaddameter(t)	0.226	0.628***	0.435***
	(.284)	(.202)	(.174)
ΔSaddameter(t-1)	-0.133	-0.065	-0.086
	(2.88)	(.205)	(.176)
ΔSaddameter(t-2)	0.252	0.262	0.246
	(.286)	(.200)	(.174)
	39	35	74
Panel D: Bid-Ask Bounce and Short-Run Pricing Errors			
ΔSaddam Security(t-1)	-0.257**	-0.030	-0.151*
	(.123)	(.126)	(.086)
ΔSaddam Security(t-2)	-0.080	-0.052	-0.044
	(.127)	(.126)	(.088)
ΔSaddam Security(t-3)	-0.090	0.046	-0.027
	(.122)	(.125)	(.087)
ΔSaddam Security(t-4)	0.129	0.019	0.094
	(.124)	(.125)	(.086)
	70	69	

Notes: ***, ** and * denote significant at 1%, 5% and 10% levels, respectively (Standard errors in parentheses)
Sample reflects the 75 days for which we match equity data to the previous trade of the Saddam Security.
Closing prices are 4pm EST.
(a) Sarno-Taylor test based on seemingly unrelated regression estimates; critical value shown is at 5% level.

We also test for whether price changes are forecastable based on recent market movements, regressing the change in the Saddam Security on its own lags. The first lag is significant and negative, albeit small, a result that likely reflects bid-ask bounce. Further lags are individually and jointly insignificant, suggesting the absence of simple profitable trading strategies.

In sum, each of the tests performed above suggest that the price of the Saddam Security is a reasonable assessment of the likelihood of war. The time series movement in the series seems sensible as measured against both expert opinion and a narrative approach. The market is deep enough that it should have value as a forecasting tool, and market data meets simple tests of efficiency. At the same time, our analysis will need to be cognizant of short lags in the incorporation of information in the Saddam Security and of the possibility of high-frequency bid-ask bounce. In addition, the high correlation of the Saddameter with the Saddam Security and the probable lack of correlation with any pricing errors suggests that the Saddameter may be valuable as an instrumental variable.

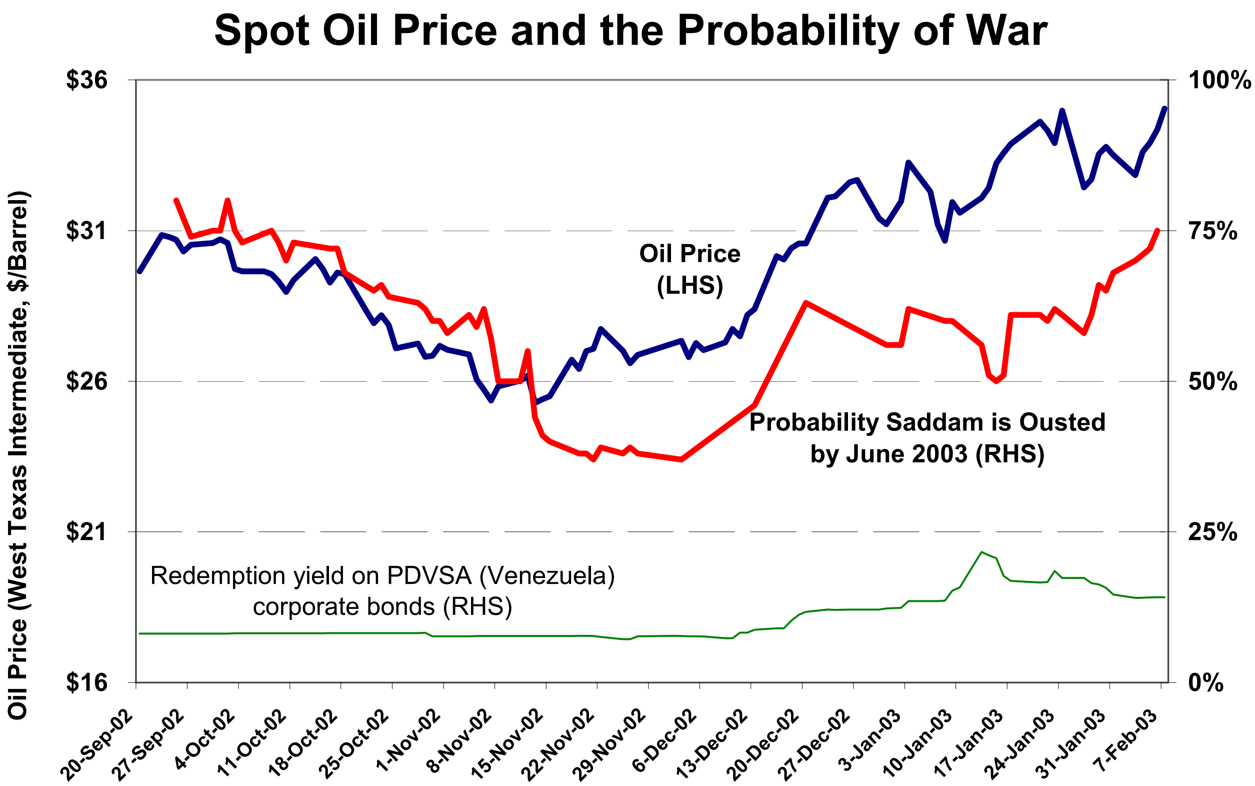
In the next two sections we turn to using these data in order to understand the market's assessment of the consequences of war, examining oil prices in section 4 and equity prices in section 5.

4. Oil Price Effects

War in Iraq clearly has major implications for oil prices, yet—particularly in the long-term—there is considerable disagreement among experts as to the magnitude and even the sign of this effect. As we have discussed in section 2, assessments of the effect of war on oil prices depend on many variables, including the length and intensity of war, how Iraq's neighbors react, and the relationship of post-Saddam Iraq with OPEC.

That oil prices have spiked as the threat of war has risen is uncontroversial. Figure 2 shows the very close correlation between the spot oil price and our indicator of the probability of war. Oil prices have risen strongly as the likelihood of war has increased.

Figure 2. Spot Oil Prices and Saddam Securities



It is also worth noting that while oil prices appear to co-move fairly closely with the Saddam Security through this period, there was another major source of volatility in these markets: escalating labor and political tensions in Venezuela, particularly in the oil sector. The prospect of reduced oil supply from Venezuela explains much of the divergence between oil prices and the Saddam Security observed in Figure 2, and hence in our regressions, we include a simple proxy to partial out this potentially confounding effect.[10]

The close correlation between high frequency movements in both oil prices and our conflict indicator provides further cause for confidence that the Saddam Security indeed reflects the likelihood of war. Moreover, the directly interpretable scaling on our independent variable allows us to make a more precise statement about the effects of conflict on oil prices.

Table 3 reports the results of various regressions of the daily closing prices in the market for West Texas Intermediate oil on the relevant closing price in the market for Saddam Securities. If there are no trades in either oil or the Saddam Security on a particular day, that day is dropped from the sample. Panel A runs the regression suggested by the chart above, regressing the spot oil price on

[10] The control variable used is the redemption yield on corporate bonds issued by PDVSA, the main Venezuelan state-run oil company. Specifically, we analyze redemption yields on 6.45% 1998 PDVSA bonds expiring on 14/2/2004 (Code 237019(RY)). We choose this variable precisely because it is a forward-looking financial instrument, likely correlated with expectations of future oil disruption.

the level of the relevant Saddam Security. We focus only on the June Saddam Security in this regression, because recent levels of the March security appear to reflect both the chance of delay and the likelihood of war.[11]

Naturally enough the effect is large: a 10 percentage point rise in the probability of Saddam being ousted raises oil prices by around $1 per barrel, which is a rise of around 3-4 percent. The second column adds future prices from the Saddam Security to the regression, which would be important if that market absorbed new information only with a lag. And finally, as a robustness check, the third column instruments for the price of the Saddam Security using Slate's Saddameter to control for measurement error.[12] Thus, the identifying variation no longer comes from two financial market securities, but rather the independent variable reflects expert assessment of global political developments. These findings largely reinforce our baseline results in column one.

[11] Making corrections to the March Saddam futures price to adjust for the looming expiry date yields qualitatively similar results.

[12] Recall from footnote 9 that, when queried, the constructor of the Saddameter claimed to never have consulted financial markets when assessing the probability of war. He was also unaware of tradesports.com or other betting markets on the Iraq war. It thus seems reasonable to assume that the Saddameter satisfies the standard IV assumptions.

Table 3. Spot Oil Prices and the Saddam Security

Dependent Variable:
Daily Spot Oil Price (West Texas Intermediate; $/Barrel; 4pm EST closing price)

	Baseline Regression	**Include leads of the Saddam Security**			**Instrumental Variables[(a)]**
		T	**T+1**	**T+2**	
		Panel A: Levels Regressions[(b)]			
June '03 Saddam Security	9.17***	0.23	2.38	7.31**	13.93***
(Effect on oil price in $)	(1.11)	(3.34)	(4.74)	(3.40)	(1.66)
Total effect			9.92***		
			(1.10)		
Adj. R^2	0.835		0.851		0.925
N	74		72		38
	Panel B: Daily First Differences (March '03 and June '03 Saddam Securities)				
Saddam Security	5.38***	5.62***	2.39	2.00	12.03*
(Effect on oil price in $)	(1.88)	(1.99)	(1.45)	(1.10)	(6.87)
Total effect			10.01***		
			(2.15)		
Adj. R^2	0.078		0.086		
N	147		143		79

Panel C: Long Differences[(b)] (March '03 and June '03 Saddam Securities)

	5 Day Diffs	**10 Day Diffs**	**20 Day Diffs**
Saddam Security	11.24***	10.49***	13.09***
(Effect on oil price in $)	(2.08)	(2.32)	(2.79)
Adj. R^2	.385	.608	.779
N	139	129	109

Notes: ***, ** and * denote significant at 1%, 5% and 10% levels, respectively (Standard errors in parentheses)
(a) Instrumental variable is Slate.com's "Saddameter"
(b) Differences are differences in number of daily observations in which both the Saddam Security and oil price traded.
(c) Newey-West standard errors used for difference regressions, controlling for autocorrelation up to twice the difference period.

The results in Panel A are based on levels regressions, and hence their precision should be read with substantial caution given the tendency of financial market prices to follow a random walk. Consequently in Panel B, we turn our attention to analyzing changes in oil prices and war probabilities. These first difference regressions raise a minor technical issue: our various Saddam Securities did not trade on every day, so day-to-day changes would risk losing much of our data. Thus we stack first differences from both the March and the June securities, analyzing changes in closing prices that sometimes extend over several days.[13] We match these changes to the

[13] For example, one week might see the March security traded only on a Tuesday and Thursday, and the June security traded only on a Monday and a Wednesday. In this instance, we would have two observations for that week: the difference in prices of the March security from Tuesday to Thursday (and the corresponding Tuesday to Thursday oil price difference), and the change in price of the June security from Monday to Wednesday (and the corresponding Monday to Wednesday change in oil price). This leads us to use Newey-West standard errors, allowing for autocorrelation up to twice the difference period. We maintain this convention throughout this paper.

corresponding changes in the closing price of the oil. This gives us a total sample of 147 observed shifts in the probability of war, which we use to predict shifts in oil prices.

The first regression in Panel B regresses the change in the oil price on the contemporaneous change in the Saddam Security. (More precisely, given that the oil prices reflect changes in closing prices while the last Saddam Security may be from earlier in the trading day, it is likely that the oil price is being regressed on a change in probabilities lagged by several hours.) This regression yields the smallest of the six estimates, presumably reflecting measurement error. The second column also includes two leads of the Saddam Security – an implicit test of whether this market is slower to respond to new information than oil market. These leads are found to be jointly significant, and the sum of the coefficients suggests an overall coefficient closer to 10. As in Panel A, the IV regression in column three yields larger but less precise estimates. (Earlier results suggest that the Saddameter reflects information shocks more rapidly, and hence these estimates reflect larger informational shocks than those in the first column.)

It seems possible that traders are reacting to news in the oil market by trading in the Saddam Security market (or vice-versa), and this is the source of the close correlation shown in Figure 2. We suspect that this is likely true, although it is worth noting that does not lead to an inference of endogeneity bias. Our regressions should not to be interpreted as causal in the sense of movements in the Saddam Security causing movements in the oil price. Rather, we suspect that movements in both markets reflect a third factor: news about geopolitical events. Our interest is not in the fact of correlation *per se*, but rather the relative scaling of the impact of geopolitical news on these two markets. Thus the causal inference we make is that political events that cause the Saddam Security to rise ten percent also cause the oil price to rise by about one dollar per barrel.

Is this a large effect? The three largest oil price shocks over the past thirty years occurred in 1973-74, 1979 and 1990. In today's dollars, the 1973-74 shock represented a price of $24 in a single month; the 1979 oil shock an increase of $31 in twelve months; and the 1990 shock an increase of $18 in two months. Our analysis suggests that the magnitude of an Iraq war oil shock is likely to be smaller than these three shocks.

More important, however, are the implications of war for oil prices in the medium to long-term. In 1990, oil prices had fallen to their pre-shock levels within a few months. But following the 1973-74 and 1979 oil shocks, prices stayed high. The likely effect of war in Iraq on long-term oil prices has been hotly debated, with estimates of Iraq's likely oil production in the post-Saddam era ranging from a doubling of output within several years, to a rise of 25 percent or less. In order to speak to these questions, we analyze oil futures from the New York Mercantile Exchange. The exchange trades in futures of Light Sweet Crude Oil, of which the oft-cited West Texas Intermediate is an example.[14] Futures contracts exist for delivery at each of the next 30 months, and long-dated futures exist for December out to seven years in the future. Throughout, we analyze closing prices in the oil

[14] The exchange claims on its website that "Over the past decade, the NYMEX Division light, sweet (low-sulfur) crude oil futures contract has become the world's most liquid forum for crude oil trading, as well as the world's largest-volume futures contract trading on a physical commodity. Because of its excellent liquidity and price transparency, the contract is used as a principal international pricing benchmark." See http://www.nymex.com/jsp/index.jsp

futures market, comparing them with the price of the last trade in the relevant Saddam Security prior to the 2:30pm close of the NYMEX market.[15]

Figure 3. Oil Futures and Saddam Security Prices

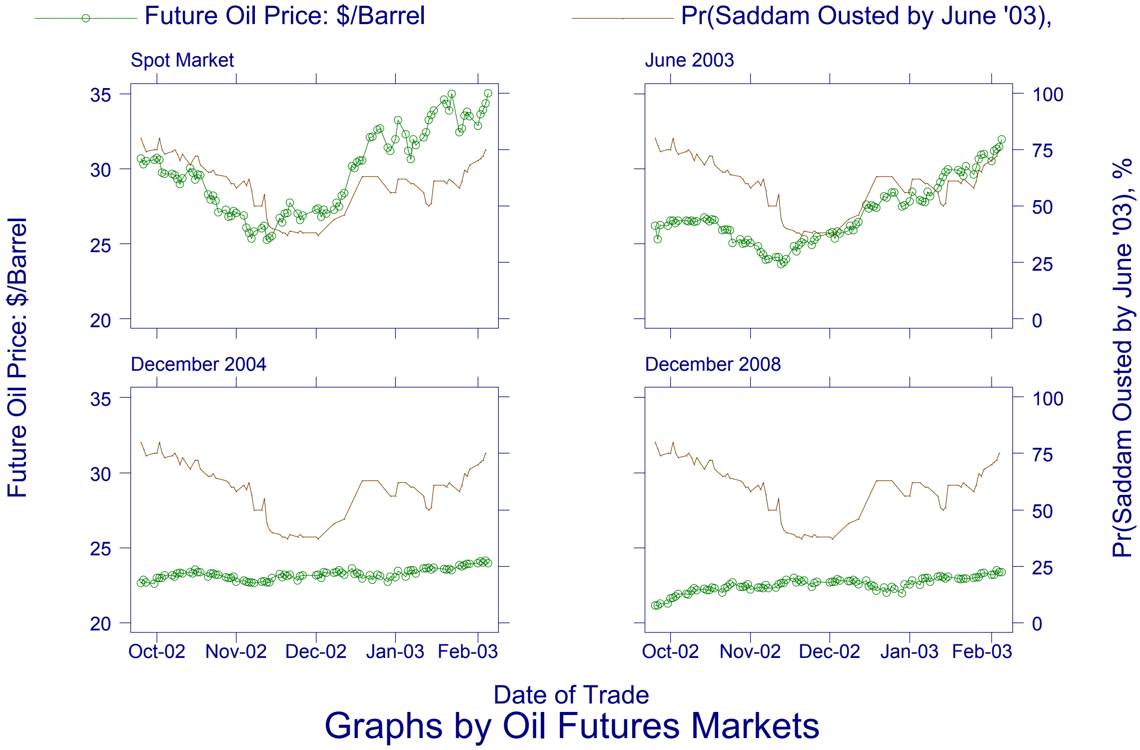


Figure 3 shows the evolution through time of both oil futures prices and the probability of war. For simplicity we show only the spot market and representative near, medium and long-term oil futures markets. The close co-movement of near-term futures and the Saddam Security is evident, while the pattern from the medium and longer-term futures is less clear.

Following the analysis in Table 3, we run regressions of each futures contract against the probability of war. We adopt the same methodology as above: running the regression in both levels and first differences, and analyzing the last trade in the June 2003 Saddam Security before the NYMEX closes at 2:30pm. Thus, for each functional form we estimate 33 separate regressions – 28 for each of the monthly futures markets for delivery each month from March 2003-June 2005, plus five for the long-dated markets for December of 2005-2009.

[15] While most futures were traded on most dates, there are some missing observations; these were imputed by applying the daily percentage change observed in the nearest shorter-term contract (and when this did not exist, the nearest longer-term contract is used.)

Figure 4. Effect of a 10 Percent Rise in War Probability on Future Oil Prices

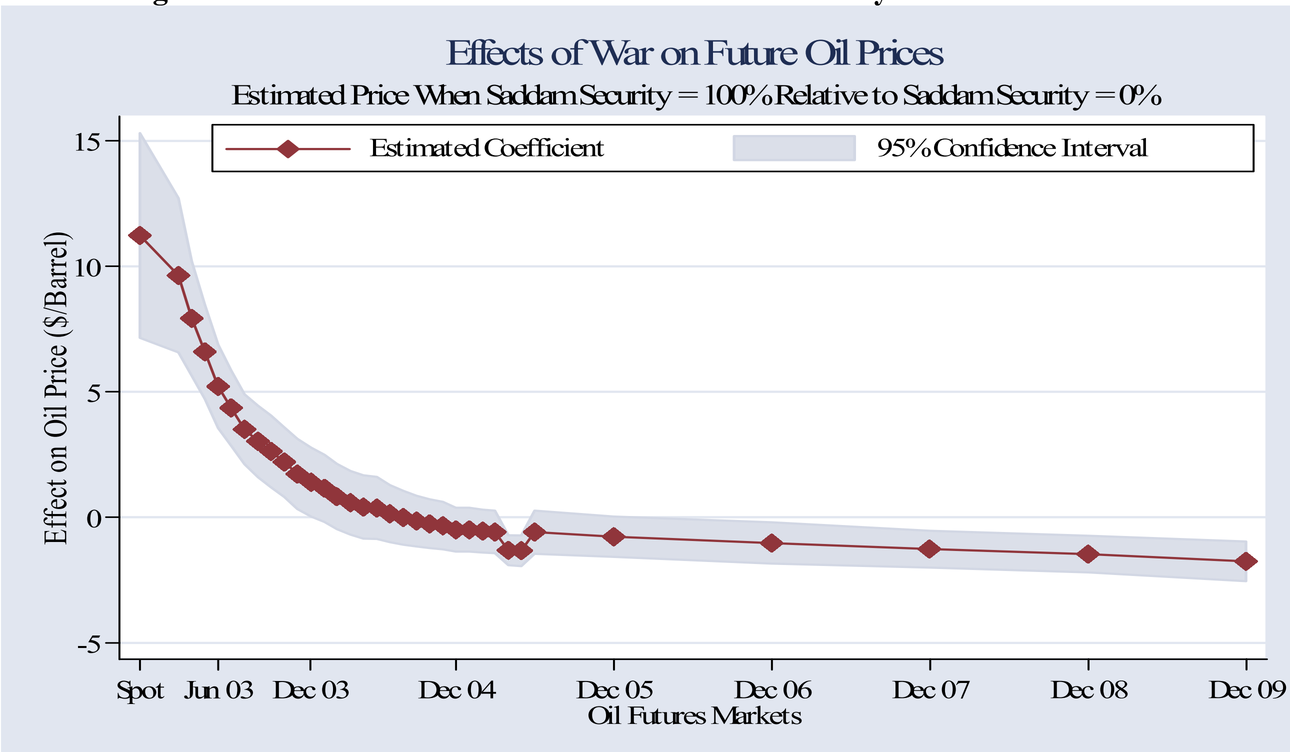


Figure 4 shows a compact representation of these results, graphing the likely impact on oil prices of war. The chart shows results from our preferred 5-day difference specification, although other specifications yield similar results. Thus, the first point on the chart shows the spot price rising by $11. The second point refers to the expected March price, which increases by around $9.50. The war premium spike then declines rather rapidly, falling to $5 by June 2003, and around $2 by the end of 2003. The effects then virtually disappears, and prices throughout 2004 and 2005 are unaffected by the probability of war. Further out there is some weak evidence that ousting Saddam may even lead prices to decline somewhat in the long-run, perhaps by around $1.50 per barrel. However, these long-run estimates are fragile, and even in this central estimate, are at best marginally statistically significant.

A natural question is whether the time profile of oil price effects depicted in Figure 4—higher prices in the short run and lower prices in the long run—is a good or a bad thing for an oil-dependent country? Consider the following simple arithmetic: after netting out exports, the U.S. imports around 9 million barrels of oil per day, or a little less than one barrel per American per month. If this oil is typically bought at around $25 per barrel, and the discount rate is ½ percent per month or 6 percent per annum, then the net present value of future oil imports is around $5000 per capita. Will the effects presented in Figure 4 raise or lower this spending estimate? Linearly interpolating the results in the chart above for months in which there is no futures market, and assuming the small decline in the December 2009 oil futures persists forever, our calculations suggest that each consumer will realize lifetime savings with a net present value of around $250 (or about 0.7 percent of one year's GDP). Beyond the usual caution about extrapolating estimates, note that this "oil dividend" depends critically on out-of-sample assumptions about oil prices. The net present value of likely spending on oil through to 2010 is about equal under any probability of war, so any "oil dividend" depends on the path of prices after 2010 – a time period about which we are unable to provide any econometric evidence. Moreover, as the standard error bands indicate, we are statistically more confident about the large short-term costs will accrue than we are about the small but persistent long-run gains.

Further, it is worth noting some important limitations of this analysis. Our estimates of the likely effects of war on the future path of oil prices provide a useful benchmark. But far greater care is required before drawing welfare implications. The calculations above are simply those macroeconomists refer to as "terms of trade" effects – the redistribution of income across countries that occurs as a result of price changes. One also needs to consider business cycle implications of these disruptions, and of potentially greater importance, the potential for lower profit rates lead to slow capital accumulation in the longer run, lowering potential output. In addition, by only analyzing the oil market, we likely miss important effects in other energy markets, broader consequences of war for the fiscal situation, consumer and business confidence, and likely damage to important political and trade relationships. That said, our partial equilibrium analysis is useful in that it suggests that if there is an "oil dividend" from war, it is likely small.[16]

General equilibrium, political, and macroeconomic consequences of war likely overwhelm the direct oil price effects. The back of our envelope does not represent an adequate forward-looking assessment of the value of future production opportunities. That said, this is precisely the role often ascribed to the stock market, and so we now turn to analyzing the relationship between U.S. equities and the Saddam Security.

5. Stock market effects

There are several reasons we might expect war in Iraq to affect on equity values. First, as discussed above, war will probably increase oil prices in the short-term, although long-term effects are likely to be small. Even if the net effects on the NPV of future oil prices is close to zero, macroeconomic reallocation may cause nonlinear or persistent costs. Second, war would involve an increase in defense procurement. This should be profit-increasing for defense contractors but will probably also increase government borrowing, driving up the cost of equity and thus reducing equity valuations. The increase in (non-diversifiable) risk associated with war should also increase the cost of equity; equity valuations are of course very sensitive to even small changes in the cost of equity. Third, this particular war seems likely to lead to worsening relations with some of the U.S.'s trading partners, potentially reducing long-term trade or foreign investment opportunities. Fourth, it is possible that an invasion of Iraq would provoke retaliation by Iraq or terrorism in general, which would have further negative consequences for equity values. Finally, the fighting of this war may affect the number and intensity of future international conflicts. With the exception of the last factor, the direction of all of these effects is rather obvious, but their magnitudes are less clear.

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[16] For a particularly colorful expression of the contrary view, note Rupert Murdoch's recent claim that: "The greatest thing to come out of this for the world economy, if you could put it that way, would be $20 a barrel for oil. That's bigger than any tax cut in any country" (Day, 2003). For more careful analysis, see Center on Foreign Relations and Baker Institute, 2003; Ebel et. al., 2002; Leach, 2003; Marcel, 2002; Nordhaus, 2002; Perry, 2001; Yergin, 2002.

This section analyzes the co-movement of the Saddam futures and equity markets to determine whether in fact recent stock market gyrations can be explained by the shifting likelihood of war. We begin by analyzing the impact of war risk on the S&P 500, using the same empirical framework as the previous section.

Figure 5. Saddam security and the S&P 500

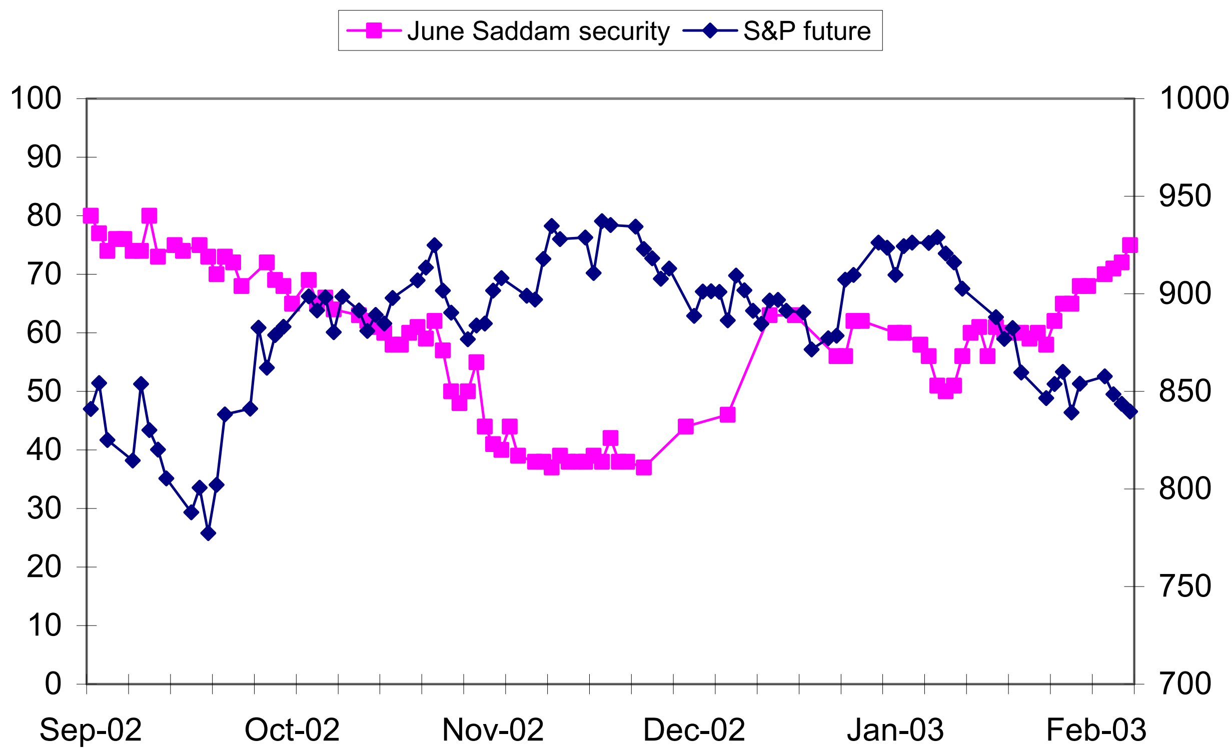

Figure 5 plots the level of the S&P 500 index and the price of the June Saddam Security over time. The graph suggests that stock prices increased as war risk declined in November and then decreased as war risk increased in December and again in late January. Table 4 presents regressions that analyze this relationship more formally. As in the previous section, we estimate both levels and difference specifications on a daily sample, in which we match the most recent transaction in each Saddam Security to the 4 pm closing value of the S&P 500. In addition, we are also able to construct a tick-by-tick sample, in which we match each trade in the Saddam securities to the next S&P future trade recorded on the CME.[17] As in the previous section, we find future changes in the Saddam Security have an economically (if not always statistically) significant relationship with current changes in the S&P, and so we include several leads in the difference specification.

[17] We use future rather than spot prices for this analysis in part because S&P futures trade 24 hours a day, as do Saddam Securities. We use the trades for the next-expiring S&P future and adjust for the change from the December to the March future in December 2002.

Table 4A. S&P 500 and the Saddam Security – Daily Data

Dependent Variable: ln(S&P Index)	Baseline Regression	Include leads of the Saddam Security			Instrumental Variables[(a)]
		T	T+1	T+2	
Panel A: Levels Regressions (June Saddam Securities)					
Saddam Security (level)	-0.262***	-0.096	0.001	-0.186**	-0.299***
	(0.028)	(0.089)	(0.124)	(0.090)	(0.042)
Total effect			-0.281***		
			(.029)		
Adj. R^2	0.54		0.56		
N	74		74		38
Panel B: Daily First Differences (March and June Saddam Securities)					
Saddam Security (diff)	-0.035	-.036	-.012	-.060*	
	(0.038)	(.040)	(.035)	(.030)	
Total effect			-.109		-0.442**
			(.069)		(.211)
Adj. R^2	0.02		0.02		
N	143		143		74
Panel C: Long Differences (March and June Saddam Securities)					
	5 Day Diffs		**10 Day Diffs**		**20 Day Diffs**
Saddam Security (long diff)	-0.145***		-0.197***		-0.185***
	(.057)		(.067)		(.055)
Adj. R^2	0.075		0.197		0.300
N	139		129		109

Notes: ***, ** and * denote significant at 1%, 5% and 10% levels, respectively
(Newey-West autocorrelation-corrected standard errors in parentheses)
(a) Instrumental variable is Slate.com's "Saddameter."

In Table 4A, level regressions on the daily sample suggest that a 10 percent increase in the probability of war is associated with a 2.6 percent decline in the S&P 500. Difference regressions suggest that a 10 percent increase is associated with a 1.1 percent decline. The analysis of the tick-by-tick data in Table 4B yields coefficients of similar magnitude.

As in the oil price analysis, the difference between the levels and difference results may reflect delays in the incorporation of public information about the war into the Saddam Security. In Panel C of each table, we examine results for longer differences, finding that these yield results between the levels and difference specifications.

Table 4B. S&P 500 and the Saddam Security – Tick-by-Tick Data

Dependent Variable: ln(S&P Index)					
	Baseline Regression	**Include leads of the Saddam Security**			
		T	**T+1**	**T+2**	**T+3**
Panel A: Levels Regressions (June Saddam Securities)					
Saddam Security (level)	-0.284***	-0.088	-0.061	-0.077	-0.067
	(0.013)	(0.062)	(0.075)	(0.074)	(0.074)
Total effect		-0.294***			
		(.014)			
Adj. R^2	0.56	0.57			
N	364	361			
Panel B: Daily First Differences (March and June Saddam Securities)					
Saddam Security (diff)	-0.020	-.027*	-.021	-.025*	-.017
	(0.014)	(.016)	(.016)	(.014)	(.012)
Total effect		-.090***			
		(.039)			
Adj. R^2	0.01	0.01			
N	942	936			

Panel C: Long Differences (March and June Saddam Securities)	**10 Tick Diffs**	**20 Tick Diffs**	**40 Tick Diffs**
Saddam Security (long diff)	-0.092***	-0.162***	-0.168***
	(.043)	(.057)	(.069)
Adj. R^2	0.036	0.103	0.163
N	924	904	864

Notes: See Table 4A

If the Saddam Security is reacting with lags to news about the war, then short differences may include measurement error (in this case, reaction to past rather than current news). In addition, bid-ask bounce may create an additional source of measurement error, especially in the difference specification. Measurement error would bias the estimated coefficient downward, and thus could potentially explain the difference between the levels and difference results. We find that when we instrument for Saddam Security changes with Saddameter changes from the same days, the estimated coefficient increases considerably.[18]

We conclude from the long difference and IV regressions that the daily or tick-by-tick difference specifications probably underestimate the effects of war on the S&P 500, while the levels specification results may be an overestimate. All of these estimates are large in economic terms. The 5-day difference specification represents our central estimate, and projecting these estimates out of sample suggests that a change from a zero to a 100 percent probability of war reduces the S&P 500 by around 15 percent. By comparison, the S&P 500 fell by 7.6, 6.5, and 5.5 percent in the first two trading days after the Pearl Harbor bombing, the outbreak of the Korean War, and September 11th, respectively.

[18] A Hausman (1978) test of the equivalence of the coefficients from the IV difference regression and an OLS regression on the same sample has a p-value of 0.05.

The next two subsections examine this large estimated effect of war by decomposing it in two different ways. The first decomposes it into effect on different industry sectors, and the second uses option prices to decompose the estimated mean effect of war into a probability distribution of possible effects. A third subsection repeats the analysis on foreign stock market indices.

(a) ***Effect of war on industry sectors***

Table 5 reports 5-day difference regressions for S&P sector indices. Results are reported for each of the 11 top-level sector indices and for selected sub-indices. The estimated impact of war on various sectors is largely as one would expect. War is bad for consumer discretionary industries, airlines, finance, and information technology. This is unsurprising, since one would expect these sectors to be sensitive to both adverse macroeconomic conditions and the threat of terrorism. It is likewise positive for gold mining and oil stocks, particularly the sectors of the oil industry that would benefit most from higher oil prices. The boost war provides to defense stocks is surprisingly small, albeit imprecisely estimated. This is true even if we exclude Boeing, which has a large civilian aircraft business.

Table 5. Impact of on war probability on sector index returns

Dependent variable: % Change in sector index

	Long difference regressions (5 lags)	
Sector	**Coefficient**	**S.E.**
Consumer Discretionary	-0.218***	(0.057)
Consumer Staples	0.002	(0.032)
Energy	0.028	(0.050)
Oil and Gas Drilling	0.151***	(0.052)
Oil and Gas Equipment	-0.030	(0.090)
Oil and Gas Exploration	0.142***	(0.054)
Oil and Gas Refining	0.029	(0.049)
Finance	-0.164**	(0.072)
Health Care	-0.068	(0.041)
Industrials	-0.072	(0.061)
Aerospace and Defense	0.060	(0.065)
Aerospace and Defense (excl. Boeing)	0.078	(0.067)
Information Technology	-0.402***	(0.099)
Materials	-0.072	(0.053)
Gold mining	0.481***	(0.103)
Telecom	-0.159***	(0.056)
Transportation	-0.045	(0.040)
Airlines	-0.375***	(0.113)
Utilities	0.071	(0.076)

Notes: This table repeats the 5-day difference specification in Table 4 for the 11 S&P top-level sector indices, and selected sub-indices.

(b) ***Inferring the distribution of outcomes from option prices***

The observed decline in the market as the probability of war has increased reflects the market's belief about the *average* impact of a war. However there are many possible war scenarios, and in this section, we analyze option prices to infer the market's belief about the distribution of possible effects of the war. When we do this, we find that option prices imply that the distribution of war outcomes are highly negatively skewed. We find an essentially zero probability that war will be good for the market, a 70 percent chance of a negative impact of 0 to 15 percent, and a substantial probability of extremely adverse outcomes: a 20 percent chance of a -15 to -30 percent impact and a 10 percent chance of a -30 percent impact or worse. The combination of a high probability of a relatively benign outcome (e.g., a coup against Saddam) and a small but substantial probability of a terrible outcome (e.g., chemical or biological attacks on the U.S. or its regional allies) helps explain why our estimates of the *average* effect are so large.

A direct way of observing investors' beliefs about the probability of a terrible outcome is to examine how the value of deep out-of-the-money S&P puts has varied with the probability of war. An S&P 500 put option is an option to sell the S&P 500 index at a pre-specified strike price. Buying a deep out-of-the-money put (for example, a put with a strike price of 600 when the S&P is trading at 900) would allow an investor to insure against extreme losses. Such an investor would incur losses if the S&P dropped to 600, but would not incur any beyond that point. The price of such a put option is thus an indicator of the likelihood that the S&P will drop to that level or below.

Increased war risk could increase the value of a deep out-of-the-money put for three reasons. First, any decrease in the level of the S&P 500 will raise the value of a put with a given strike price, since it brings it closer to being in-the-money. Second, if increased war risk raises uncertainty, it should increase the value of all out-of-the-money options, since uncertainty increases the likelihood that these options will prove useful. Third, if the expected impact of a war is negatively skewed, war increases the likelihood of extremely bad outcomes, and one might expect deep out-of-the-money puts to rise more than would be explained by the first two reasons alone.

Figure 6. Probability of war and the prices of out-of-the-money puts on the S&P 500

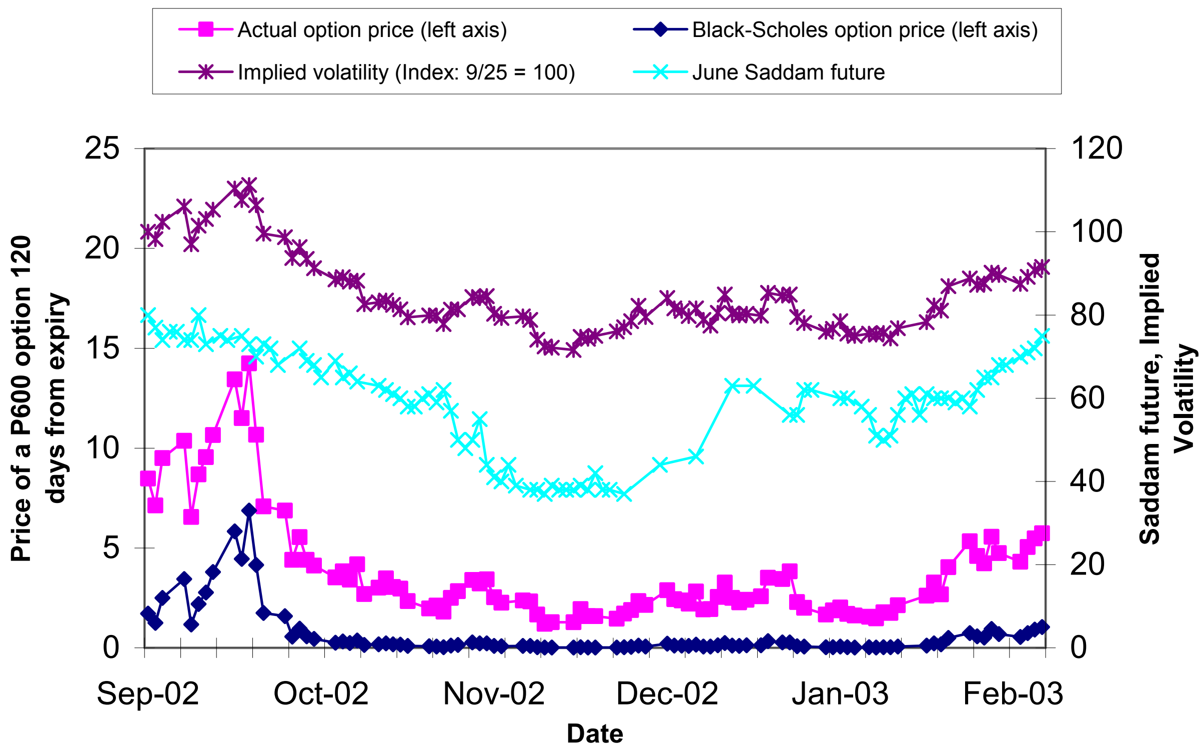

Figure 6 plots the price of the June Saddam Security and a CBOE index that measures the expected future volatility of the S&P 500 implied by at-the-money option prices. It does appear that expected future volatility increases with the probability of war. Figure 6 also plots the actual price of a 120-day-out S&P put option with a strike price of 600 and an estimate of its value constructed from the futures price and the implied volatility of at-the-money options, using the Black-Scholes (1973) formula.[19]

The prices generated from the Black-Scholes formula increase with war risk, capturing the lower level of the S&P 500 and the high expected future volatility. Black-Scholes assumes log-normally distributed returns, however, so the gap between the Black-Scholes and actual prices of a deep-out-of-the-money put option can be thought of as a measure of the extra weight put on extremely negative outcomes (that is, the negative skewness in expected future returns).

[19] On any given day, S&P options trade with expiration dates on the approximately the 21st of the next three months, plus the three quarter-ending months after that (e.g., on February 6, available options expired in February, March, April, June, September, and December). Thus only on a few days are there options that are exactly 120 days from expiry. For the purposes of Figure 6, however, it is useful to hold the days-to-expiry of the option constant over time, to control for the fact that option values decline as the expiration date approaches. We constructed our time series of prices for a 120-day-out option using the actual prices of the options with the two nearest expiration dates using the methodology described below and in Appendix B.

The existence of a gap between the Black-Scholes and actual prices of deep-out-of-the-money puts has been a feature of option prices since the 1987 crash (see e.g., Rubenstein, 1994).[20] But the fact that the gap appears to increase with war risk suggests, but obviously does not prove, that the effects of a war may be non-normally distributed.

In order to investigate this further, we use the full range of option prices to estimate what is called the state price density. A state price is the price of an imaginary security that pays $1 if a certain event happens. In this case, the state price for the state S&P = 600 is the price of a security that pays $1 if the S&P is equal to 600 when the option expires. If investors are risk neutral, then the distribution of state prices can be interpreted as investors' expectation about the probability distribution of future S&P price levels.

We use a non-parametric approach to estimate the state price density on each day, and then examine how this is affected by changes in the probability of war. The details of the method, which is based on Aït-Sahalia and Lo (1998), are given in Appendix B. But the intuition for how we estimate state prices from option prices can be gained from thinking about butterfly spreads. A butterfly involves buying a call with strike price $S - e$, selling two calls at S, and buying a call at $S+e$. This position pays nothing if the S&P at expiry is outside of the interval $(S-e, S+e)$; the profits inside this interval are given by a triangle with its peak at S. In the limit as e approaches zero, this position converges to a security that pays if and only if the S&P is equal to S.

Figure 7 presents the results of this exercise for three days: the first day of our sample, when war risk was high and the June Saddam Security traded at 80 (September 25, 2002); the day in the middle of our sample when the June Saddam Security traded at its lowest level of 37, (November 21, 2002); and the last day of our sample, when the June Saddam traded at 75 (February 6, 2003). We plot estimated state prices for options that are 120 days from expiry, since this seems like a reasonable compromise between finding a horizon over which the market expects much of the uncertainty of war to be played out, and futures contracts exist with adequate trading volume. Compared with the low-war-risk day, the state price densities on the high-war-risk days are clearly shifted to the left and spread out. In addition, the left tail of the high-war-risk distribution is fatter than that of the low-war-risk distribution.

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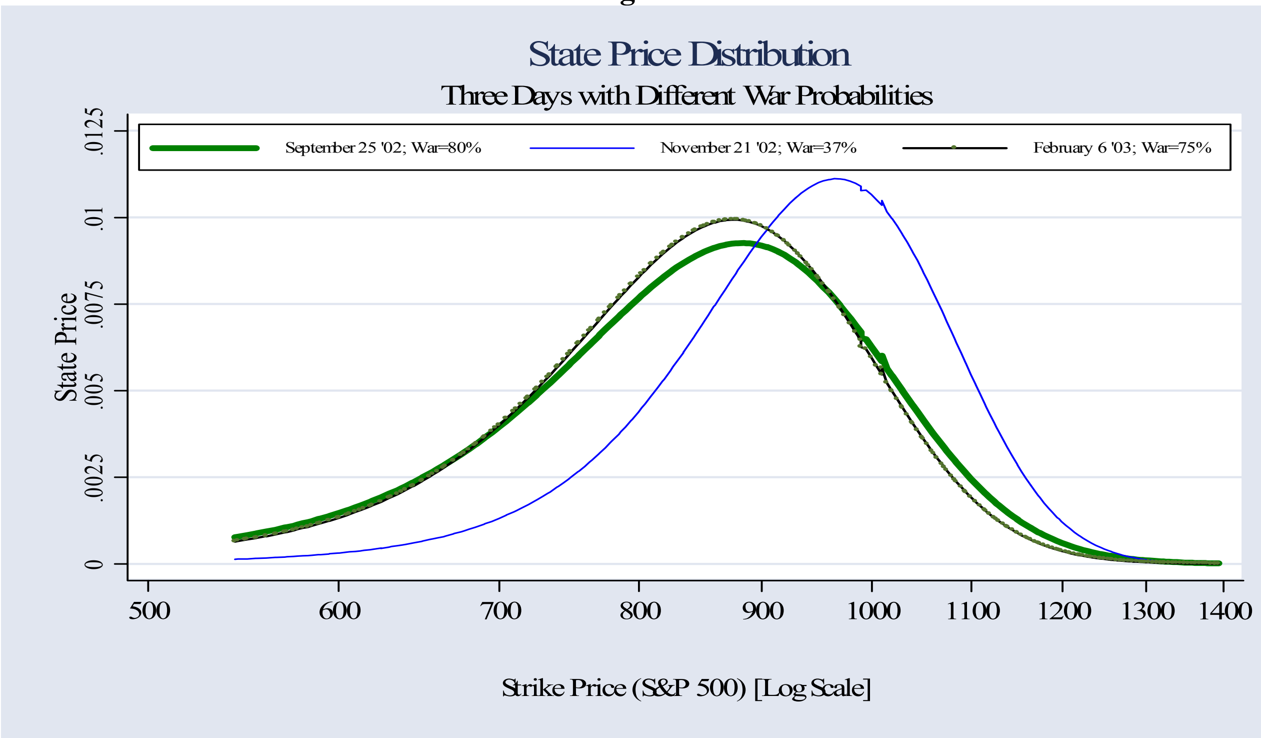
[20] Especially since the 1987 crash, the negative skewness implied by option prices has been greater than that in historical returns. Some have interpreted this as a mispricing that does not get arbitraged due to high transaction costs involved (e.g., Ederington and Guan, 2002). Others have estimated the risk aversion required at different wealth levels necessary to rationalize the relationship between option prices and historical returns and found that risk aversion would have to increase dramatically as with relatively small declines in wealth to explain the pricing of out-of-the-money options (e.g., Aït-Sahalia and Lo, 2000). Others have suggested that attempts to draw conclusions from this relationship between option prices and historical returns may suffer from a "peso problem" (Aït-Sahalia, Wang, and Yared, 2001): deep-out-of-the-money may appear over priced in most states of the world, but we are just not observing the state in which they turn out to have been a bargain.

Figure 7



We can make this analysis more formal by regressing state prices on war risk and comparing the predicted distributions for high and low war risk days. Table 6 presents the results of regressions of state prices on the Saddam Security for different strike prices. Both 5-day difference and levels specifications show war risk shifting density primarily from the 950-1150 range to the 600-800 range.

Table 6. Effect of an increase in probability of war on S&P 500 state prices

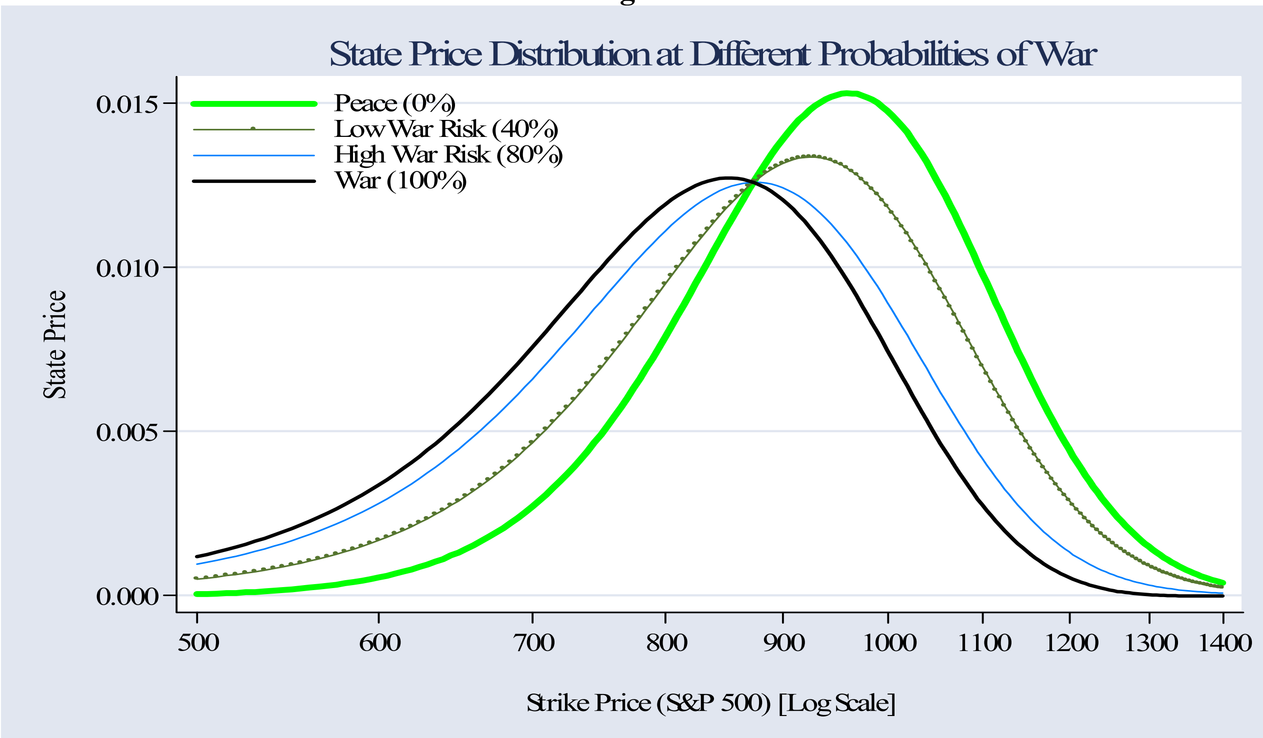
Dependent variable: State price 120 days from expiry

	5-day difference regressions		**Levels regressions**	
Strike price	**Coeff.**	**SE**	**Coeff.**	**SE**
350	0.0115	(0.0063)	0.0170	(0.0026)
400	0.0172	(0.0076)	0.0224	(0.0029)
450	0.0257	(0.0106)	0.0317	(0.0039)
500	0.0389	(0.0157)	0.0459	(0.0057)
550	0.0574	(0.0231)	0.0657	(0.0081)
600	0.0798	(0.0330)	0.0892	(0.0112)
650	0.1028	(0.0441)	0.1122	(0.0146)
700	0.1180	(0.0534)	0.1255	(0.0171)
750	0.1150	(0.0569)	0.1180	(0.0177)
800	0.0858	(0.0489)	0.0811	(0.0150)
850	0.0315	(0.0291)	0.0175	(0.0098)
900	-0.0346	(0.0170)	-0.0568	(0.0084)
950	-0.0919	(0.0421)	-0.1176	(0.0146)
1000	-0.1241	(0.0628)	-0.1466	(0.0198)
1050	-0.1270	(0.0681)	-0.1408	(0.0209)
1100	-0.1089	(0.0591)	-0.1118	(0.0181)
1150	-0.0820	(0.0425)	-0.0758	(0.0132)
1200	-0.0555	(0.0261)	-0.0449	(0.0084)
1250	-0.0341	(0.0143)	-0.0237	(0.0048)
1300	-0.0192	(0.0074)	-0.0114	(0.0026)
1350	-0.0100	(0.0038)	-0.0051	(0.0014)
1400	-0.0048	(0.0019)	-0.0021	(0.0007)
1450	-0.0022	(0.0009)	-0.0008	(0.0004)

Notes: Each coefficient is from a separate regression of the change (level) in the state price at a given level of the S&P on the change (level) in the price of the Saddam security. As in Table 4, the difference regressions include both the March and June securities, while the levels regressions include June only. State prices are multiplied by 100, they represent the cost of an interval of 100 in state space.

Figure 8 uses the long difference regressions from Table 6 to predict state price densities at different levels of war risk. The state price density for the last day of our sample (February 6, when the price of the June Saddam Security was 75) was taken as a benchmark, and the coefficients from Table 6 were applied to estimate the state price density at war probabilities of 0, 40, 80, and 100. The range of June Saddam securities in our sample is 37-80, so the predictions for war probabilities of 0 and 100 are out-of-sample predictions that should be interpreted with caution. The higher-war-risk distributions clearly have lower means, higher variance, and more negative skew, as evidenced by the fatter left-hand tails.

Figure 8



These distributions can be compared to estimate the effects of increases in the probability of war. The impact of increased probability of war appears from the figure to be to add a mean-shifting spread to the distribution without war. It is therefore possible to use these two distributions to derive the implied distribution of the incremental impact of war risk under the assumption that war risk adds a mean-altering spread to the probability distribution under low war risk.

We start by defining S_L as the value of the stock market in 120 days under low war risk; S_L is itself uncertain (reflecting non-war related sources of risk), and distributed according to the probability distribution function $f_L(S_L)$. The effects of war, W, are also unknown, and the likelihood of the different scenarios playing out are given by the probability distribution function $g(W)$. The stock-market outcome under high war risk, S_H, is simply the sum of S_L and W. We define W such that it is conditionally independent of S_L. Consequently, by Bayes Rule, the following must hold for every value of S_H:

$$f_H(S_H) = \int f_L(S_L) \cdot g(S_H - S_L) \cdot dS_L$$

Intuitively this says that the probability that we observe, say, a moderately bad value of the S&P under high war risk reflects the probabilities of the various permutations of bad stockmarket outcome with good war outcome, through to moderate outcomes on both, and even a good stockmarket outcome coupled with a bad war outcome. Since we observe $f_H(S_H)$ and $f_L(S_L)$, we can use this set of restrictions to solve for $g(W)$, the probability distribution of likely effects of war on the stock market.

The final step before we do this is to use an asset-pricing model to convert state prices into implied probabilities. If investors are risk neutral, a state price distribution can be interpreted as a probability distribution. (The intuition here is clear: a risk-neutral investor is willing to pay *f(S)* for an option that pays $1 if event *S* occurs.) If investors are risk averse, however, then state securities will be more expensive in low-wealth states. The relationship between state prices and probabilities is given by $p(S) = \lambda \cdot f(S) \cdot U'(S)$, where *p(S)* is the state price and *f(S)* is the probability that the S&P index is *S*, λ is a constant and *U'(S)* is marginal utility at a market level of *S*. When investors are risk averse, state securities are more expensive when wealth levels are low, since marginal utility is higher.

For simplicity, we assume a representative consumer with different levels of constant relative risk aversion. We assume that this representative consumer holds all her wealth in the S&P 500, an assumption that leads us to overstate the effects of risk aversion. As one extreme, we assume zero risk aversion, which would imply that state prices can be interpreted as probabilities. We also estimate *g(W)* for CRRAs of one and two, the estimates given by Arrow (1971) and Friend and Blume (1975), respectively.[21] A CRRA of 2 would imply that the state price-to-probability ratio at S&P = 500 is four times that at S&P = 1,000.

Figures 9 and 10 graph our numerical solutions for *g(W)* for the three parameterizations of risk aversion.[22] Figure 9 graphs the probability density function; Figure 10 graphs the cumulative distribution function. Regardless of the risk aversion assumed, the bulk of the probability mass is concentrated in the 0 to -20 range; the risk aversion assumption affects primarily whether the estimated probability of an outcome worse than a 20 percent drop is ten or twenty percent.

Assuming a CRRA of one, we estimate that there is 70 percent probability that changing from a 0 to a 100 percent chance of war reduces the S&P 500 by 0 to 15 percent. There is a small probability of a large negative impact: a 20 percent probability of a 15 to 30 percent decline and a 10 percent probability of a worse than 30 percent decline.

If the probability of war is 100 percent by the day it starts, the average effect of 15 percent should be priced in at that time. Figure 9 implies that there would be a 70 percent probability that the market would rally by 0-15 percent in the 3-4 months after the start of the war; while the long left hand tail implies that there is a 30 percent probability of further, possibly more substantial, market declines.

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[21] Some studies have calculated that much higher levels of risk aversion would be necessary to rationalize the equity premium (e.g., Mehra and Prescott, 1985), the purchase of very disadvantageous forms of insurance (e.g., Ciochetti and Dubin, 1994), or the high average prices of deep-out-of-the-money puts themselves (Aït-Sahalia and Lo, 2000; Jackwerth, 2000).

[22] We set *g(W)* point-by-point to minimize the mean-squared error of our resulting estimate of $f_H(S_H)$.

Figure 9

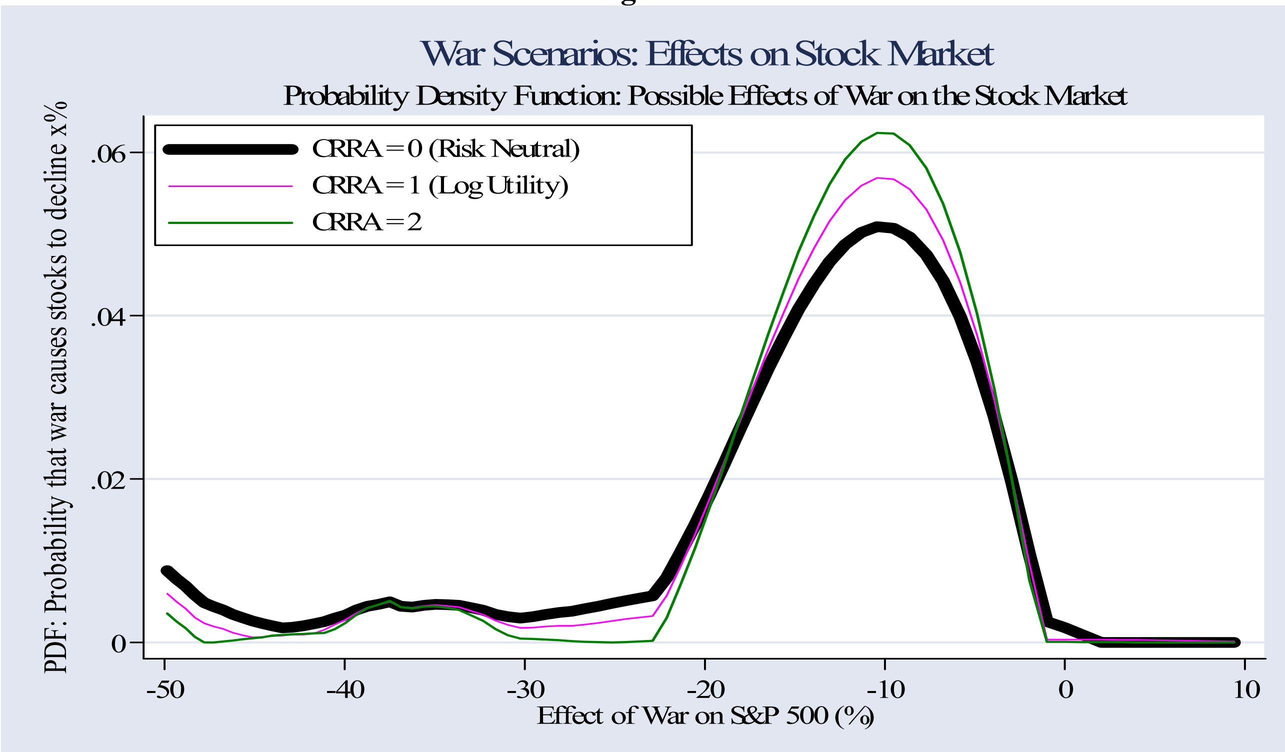
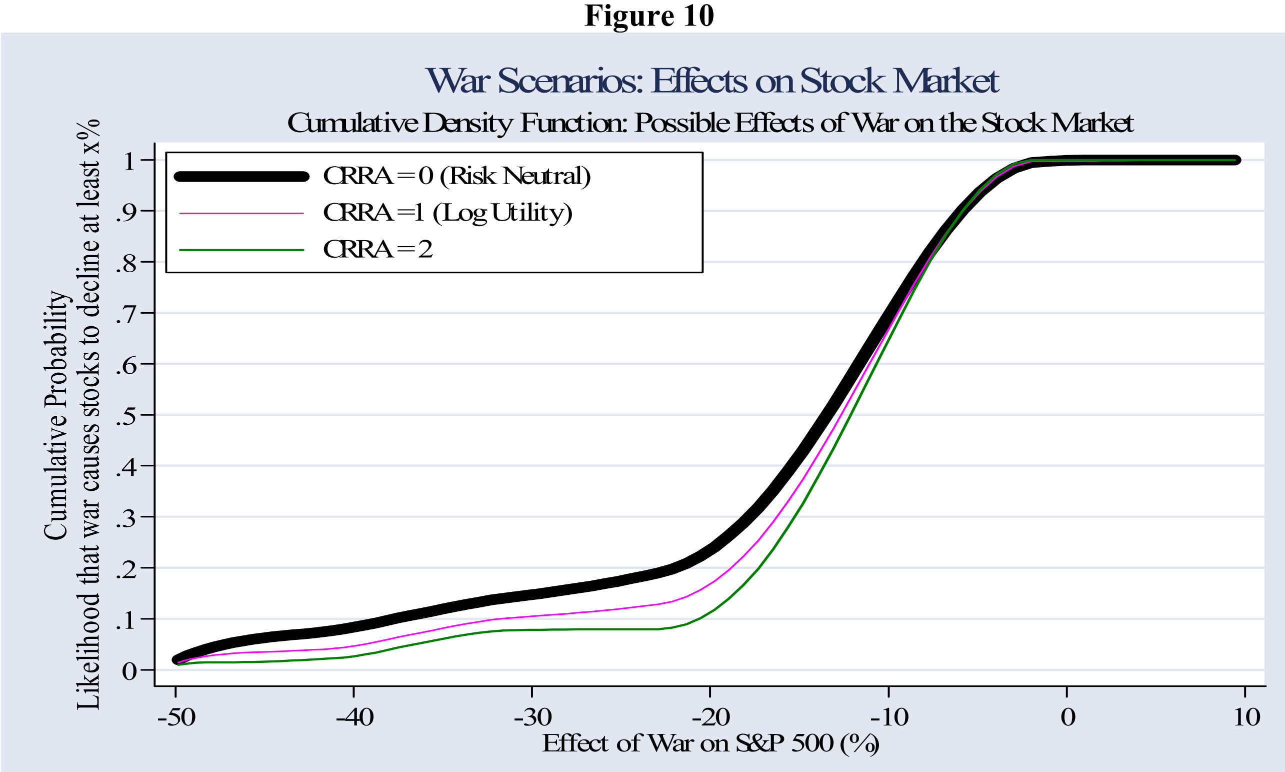


Figure 10



c) Country effects

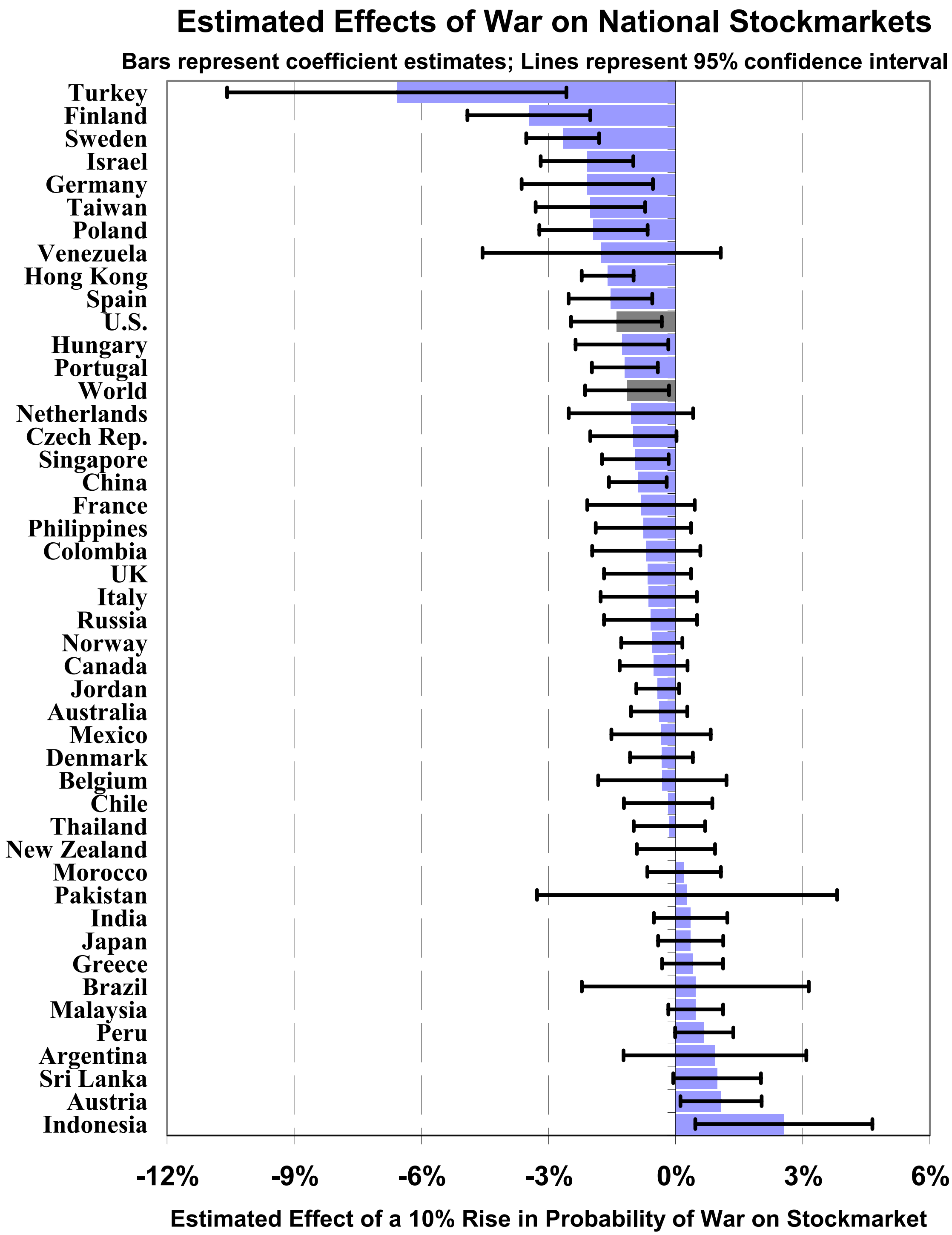
Next, we turn to the impact of war on stock markets around the world. We analyze the 44 other national stockmarkets for which the Morgan Stanley Capital International (MSCI) total return indices facilitate meaningful cross-country comparisons, plus the MSCI World Index – a market capitalization-weighted index that covers markets in 23 developed countries.[23] (For consistency with the analysis above, we continue to analyze the S&P 500 for the U.S.) In all cases, we analyze closing prices and measure returns in U.S. dollars. For each country, our independent variable is the most recent trading price of each type of Saddam Security as of the close of that country's stock exchange.[24] As above, we focus on 5-day difference regressions.

Figure 11 reports our estimates of the effect of war on different countries' stock markets. At the top of the list is Turkey, where a 10 percent increase in the probability of war is associated with a 6.6 percent fall in the value of the stock market. Moving from top to bottom on the chart, five of the next nine countries are European (Finland, Sweden, Germany, Poland, and Spain) along with two in East Asia (Taiwan and Hong Kong), one in Latin America (Venezuela), and Israel. The U.S. ranks 11th. For the World index, a 10 percent increase in the probability of war is associated with a 1.1 percent fall in the World index.

[23] For more details, see http://www.msci.com/methodology/index.html.

[24] To take a simple example, the Turkish stock market closes at 4.30pm Istanbul time, which is 2.30pm Dublin time (or Greenwich Mean Time). So each day's closing price in the Turkish stock market is regressed against the last trading prices of each type of Saddam securities prior to 2.30pm GMT. Once the Istanbul market has closed, any new information about the probability of Saddam being deposed can only be reflected in the next day's trading.

Figure 11



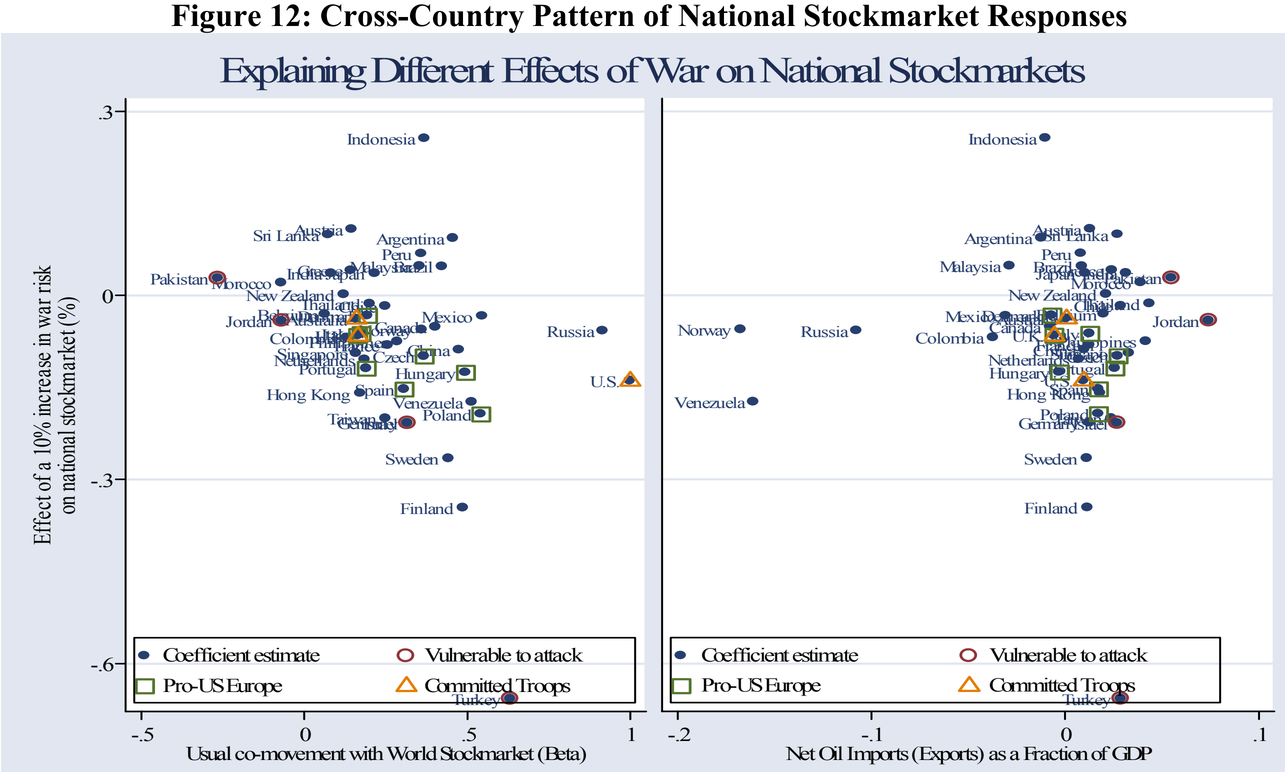
In 32 of the 45 countries, a higher probability of war is associated with a fall in the stock market, and in fourteen of these, the fall is statistically significant at the 5 percent level. In Austria and

Indonesia, a higher probability of war has a positive effect that is statistically distinguishable from zero.

What explains the differing national effects? In the case of Turkey, the explanation seems clear. Turkey is the only NATO member to border Iraq, and along with Saudi Arabia (which does not have an MSCI-indexed stock market), may be one of the main bases from which a ground attack is mounted. (Our sample ends before the Turkish parliament voted not to allow the basing of U.S. troops within Turkey.) The other country for which large effects might be expected is Israel, and a 10 percent rise in the probability of war is associated with a 2.1 percent fall in the stock market. Israel is a likely target of Iraqi missiles again (this time potentially with chemical or biological warheads). However, Iraq represents Israel's most serious military threat in the region, so the removal of Saddam could also have significant benefits for Israel's medium and long-term growth prospects.

Beyond this narrative account, we constructed several variables in order to try to describe the observed pattern of cross-country effects. We start by computing something akin to a country-level beta, taking the coefficient from a regression of five-day differences in each country's stock index against the MSCI world index. We calculate this on a sample of daily data that runs from March 1998 until August 2001 (an 18-month period prior to heightened concerns about global terrorism). The left panel of Figure 12 shows that this variable has substantial explanatory power, and several of the puzzling observations in Figure 11 (including Finland and Sweden) appear to simply reflect "high beta" stockmarkets.

Figure 12: Cross-Country Pattern of National Stockmarket Responses



The right panel of Figure 12 shows the impact of a country's oil dependency. While there clearly exist extreme observations, equity markets in oil importing countries price in a larger war penalty. In our multivariate analysis we also incorporate further country characteristics, including a dummy variable for that group of nations which are highly vulnerable to attack or severe civil unrest in the event of a war (Israel, Jordan, Pakistan, and Turkey); a dummy variable for Europe; a dummy for the eight European nations whose leaders signaled their support for the U.S. in a January 30 letter published in the Wall Street Journal (the Czech Republic, Denmark, Hungary, Italy, Poland, Portugal, Spain, and the UK); and a separate variable for those nations who had substantively agreed to commit troops to the conflict at the beginning of February (Australia, the UK, and the U.S.).

Table 7: Explaining Cross-Country Pattern of the Effects of War

Dependent Variable: Estimated Effect of War on National Stockmarket	
Usual Co-movement with MSCI World (Beta)	-.28***
	(.074)
Net Oil Imports (Fraction of GDP)	-.51**
	(.25)
Vulnerable to Attack or Unrest	-.093***
(Turkey, Israel, Jordan, Pakistan)	(.036)
Europe	-.067
	(.047)
Pro-U.S. Europe	.011
	(.046)
Troops committed	.009
(Australia, U.K., U.S.)	(.037)
Adj. R^2	.41
N	45

Notes: ***, ** and * denote significant at 1%, 5% and 10% levels, respectively (Standard errors in parentheses).
Country-level observations weighted by the inverse of the squared standard error on the dependent variable.

The results in Table 7 confirm that financial markets have priced in larger adverse effects of war in high-beta countries and oil-importing nations. Controlling for these factors, neither the variables describing a country's commitment to the removal of Saddam, nor the dummy variable for European markets, are statistically significant. [25]

6. Discussion

By studying an unusual financial instrument, the Saddam Security, we are able to track shifts in the probability of war between September 2002 and February 2003. Our data series began at the time of the negotiations within the UN Security Council that ultimately led to Resolution 1441, and ended with U.S. Secretary of State Colin Powell's address to the United Nations.

Analyzing movements in the Saddam Security, we estimate that a 10 percent rise in the probability of war raises oil prices by about $1 and lowers the S&P 500 by about 1.5 percent. Projecting these

[25] Single-stage regressions, in which a panel of country-level stock returns were regressed on an interaction of the changes in war probabilities and the country-specific explanatory variables, yielded qualitatively similar results.

effects out of sample suggests that moving from a 0 to a 100 percent probability of war raises oil prices by $10 and reduces the S&P by 15 percent.

If we benchmark these market expectations against expert opinion about the consequences of the war, we find that expectations about oil prices appear consistent with the CSIS's "intermediate case." But the effect of war on equity valuations appears to conflict with the evidence on oil. Oil futures suggest that any adverse effect of war on oil prices will be short-term and that the NPV of the long-run terms of trade shock is zero or slightly beneficial for a net oil importer, like the U.S. Macro models of the effect of such an oil shock yield effects that are much smaller than the effect suggested by equity prices.

This suggests something of a puzzle, and we turn to a more speculative exercise in order to try to better understand the source of the large war discount built into equity markets. The starting point of this exercise is the observation that in equilibrium equity prices reflect the net present value of future earnings, discounted by a discount rate that is sum of a risk-free rate and an equity risk premium. Changes in equity prices should either come from changes in future earnings, changes in the risk-free rate, or changes in the equity premium. We can directly analyze the last two factors. Doing so suggests that war should not have a major effect on the discount rate, suggesting war has negative effects on future profits other than via oil prices.

Figure 13 shows the yield on both nominal inflation-indexed U.S. government bonds, as well as the difference between the two, which can be roughly interpreted as long-run inflation expectations.[26] As the graph suggests, the yield on nominal bonds is negatively correlated with the probability of war, and this is driven almost entirely by a decline in the real rate of return required by investors to hold these bonds. Regressions identical in structure to those in Tables 3 and 4 show that war leads the yield on 5, 10 and 30 year government bonds to fall by one, two-thirds and two-fifths percentage points, respectively. The absence of any impact on inflation expectations leads to the implication that these effects are equally evident in indexed as nominal bonds. Taking a 30-year bond yield as the risk-free rate relevant for equity valuations and the estimates imply that war should reduce the required earnings-price ratio by about 0.4 percent. Given a current S&P earnings-price ratio of 2.5 percent, this implies an earnings-price ratio of 2.8 percent without war and 2.4 percent with war.[27] This in turn implies that war should *increase* equity prices by 15 percent. So changes in the risk-free rate do not explain the negative effect of war on equity prices.

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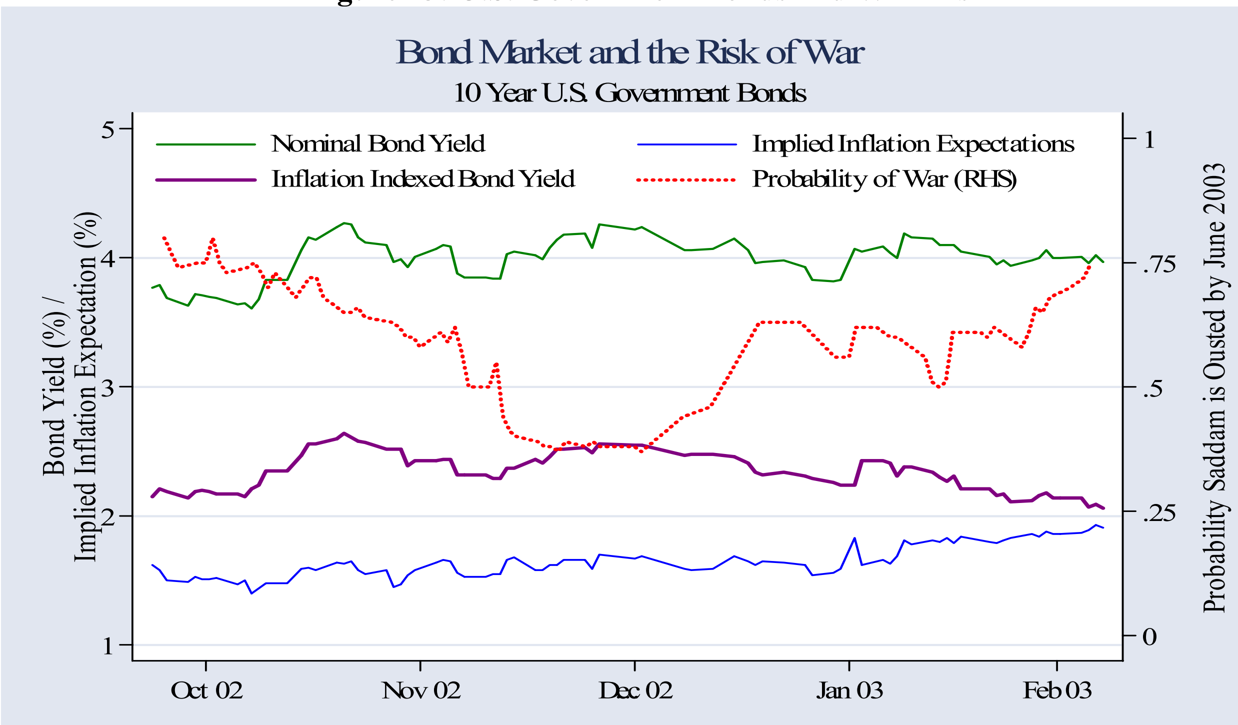
[26] This is only an approximation: the nominal rate differs from the real rate by inflation expectations, an inflation risk premium, and also due to differences in the timing and tax treatment of payouts. It seems likely that war risk may affect the inflation risk premium.

[27] As a measure of the current earnings-price ratio, we take the ratio of core earnings of the S&P 500 for the third quarter of 2002 and divide it by the then current level of the S&P. The earnings price ratio should be equal to the cost of equity less the expected constant exponential growth in earnings, so holding future earnings growth constant, a change in the cost of equity of 0.4 percentage points changes the earnings price ratio by a like amount.

Figure 13: U.S. Government Bonds and War Risk



War also raises risk, and equity investors will demand a discount to induce them to hold this risk. We can exploit the results generated in Figures 9 and 10 to estimate the discount a risk-averse investor should demand for holding the extra war-related risk. (In doing so, we implicitly assume that aggregate U.S. war risk is undiversifiable, a finding roughly consistent with our cross-country results.) Assuming investors have log utility, the probability density function in Figure 9 implies an expected effect of war of 13 percent, as compared with its impact on prices of 15 percent. This implies that if investors have log utility, the effect of war in increasing non-diversifiable risk reduces equity prices by 2 percent. With a constant of relative risk aversion of 2, the p.d.f. in Figure 9 implies an expected value of 11 percent, and thus a risk effect of 4 percent. But even if we assume investors are extremely risk averse, with a CRRA of 10, the expected effect of war implied by option prices would still be 8 percent; in other words, uncertainty coupled with risk aversion would still explain less than half of the effect of war on equity values.[28]

We are left with the conclusion that the effect of war on equity prices is probably via expectations of future earnings rather than the discount rate. The macroeconomic effects of a short-run-only oil shock seem likely to be too small to explain the implied reduction in future profits, but war might be expected to have direct macroeconomic effects in reducing consumer and investor confidence. These effects are consistent with our finding that the negative effects of war are strongest in the consumer discretionary and business equipment sectors.

Finally, a few notes on the magnitudes involved. A decline in the S&P 500 of 15 percent translates to the destruction of $1.1 trillion dollars of wealth. Beyond the S&P, broader market indices also

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[28] A CRRA of 10 implies that an investor would be indifferent between a wealth of 1.08*x* and a 50-50 gamble between *x* and 2*x*.

show a similar relationship with the Saddam Security, suggesting perhaps an even larger decline in wealth. That said, publicly-traded firms tend to be more cyclically-sensitive than others, so in percentage terms, the average effect of war on the economy-wide return to capital might be substantially smaller. Moreover, the profits-to-GDP ratio is somewhat pro-cyclical, suggesting that shifts in the functional distribution of income might also provide a partial explanation.

We are not sure whether to be troubled by the fact that our estimates suggest much larger costs of war than other analysts have suggested. Certainly one suspects that markets take account of a wider variety of costs than are factored into standard macroeconomic analyses. Our analysis of the probability distribution of likely effects of war suggests that it is reasonably likely that the outcome will be in line with the sorts of effects suggested by other economists, and perhaps our modal estimates are reasonably consistent. However the small but important likelihood of substantially worse outcomes is surely irreconcilable with the standard macroeconomic approach, and we suspect that this reflects broader political economy and geopolitical concerns.

This leads fairly naturally to a note of caution about our estimates. While we have generally interpreted our estimates as reflecting the consequences of war in Iraq, it may be that these movements reflect the market learning more about the Bush Administration's general foreign policy stance. As such, perhaps these large estimates reflect not just the likelihood of war with Iraq, but also the consequences of this foreign policy orientation for future conflicts.

A final note of caution: although we are able to use financial data to extend our understanding of the costs of war from effects on budgets to effects on oil markets and firm values, it is important to recognize that our analysis is necessarily incomplete. While we have attempted to assess some of the economic consequences of war on the United States and a variety of other countries, our study necessarily omits any consideration of the effect that military intervention might have on the Iraqi population and Iraq's economy. Just as opponents of war cite the potential loss of Iraqi lives as a major reason for not intervening, supporters claim that it is the Iraqi people who will reap the greatest benefits from Saddam's removal.[29] An analysis of the possible humanitarian costs and benefits of military intervention on the Iraqi people is beyond the scope of this paper.

[29] For an attempt to assess these claims, see International Crisis Group (2002).

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Appendix A: Major News Events

The following reflects our assessment of the major news revealed during our sample. The corresponding dates are shaded in grey in Figure 1.

Date	**Event**
9/22/2002	Having voiced strong anti-war views during the campaign, Gerhard Schroeder wins German election.
9/27/2002	The U.S. presents a UN resolution giving Iraq 30 days to comply with inspections before use of force
9/30/2002	Iraqi officials agree to give UN inspectors unfettered access
10/11/2002	U.S. Senate backs use of force
10/26/2002	Major anti-war protests
11/5/2002	Republicans hold onto House and regain control of Senate
11/8/2002	UN Security Council votes 15-0 that Iraq must disarm
11/12/2002	Reports that Iraq bought nerve gas antidote
11/13/2002	Iraq agrees to admit weapons inspectors
12/8/2002	Iraq's report to UN claims it has no weapons of mass destruction
12/13/2002	US highlights major omissions from Iraq's WMD report
12/19/2002	Powell declares Iraq in "material breach" of UN Security Council resolution
1/13/2003	Turkey lets the US survey bases for possible troop deployment
1/16/2003	UN inspectors discover warheads in Iraq capable of carrying chemical weapons
1/18/2003	Major anti-war protests
1/21/2003	Britain mobilizes 26,000 troops
1/22/2003	Rumors circulated that some Arab leaders are angling to have Saddam exiled
1/27/2003	UN inspectors issue report giving Iraq a mixed report on compliance
1/28/2003	Bush makes case for war in State of the Union address
2/5/2003	Powell addresses the UN

Source: New York Times, September 20, 2002-February 7, 2003.

Appendix B. Estimating state price densities from option prices

To estimate the state price density from option prices, we follow the method described in Aït-Sahalia and Lo (1998), hereafter AL, with certain modifications.[30] AL estimate state prices by first estimating the call-option pricing function $H(S, X, \tau, r, \delta)$, where S and X are the spot and strike prices, τ is the time to expiry, and r and δ are the interest rate and dividend yield. Rather than estimating H fully non-parametrically, which would be very data-intensive since it has five dimensions, AL estimate Black-Scholes implied volatilities non-parametrically as a function of S/X and τ, but rely on the Black-Scholes formula for equating current and future payoffs using r and δ. They estimate $\sigma(S/X, \tau)$ in the formula:

$$H(S, X, \tau, r, \delta) = H_{BS}[S, X, \tau, r, \delta; \sigma(S/X, \tau)]$$

where $H_{BS}(S, X, \tau, r, \delta, \sigma)$ is the Black-Scholes formula.

We modify this approach in several minor ways. First, our option prices are for options on futures traded on the Chicago Mercantile Exchange (CME), so we use the formula in Black (1976) for pricing options on futures, writing F for the future price.[31] Second, unlike AL, who are interested in estimating only the option pricing function, we are interesting in using our option pricing function to estimate how state price densities are changing from day-to-day. We therefore need to make assumptions to reduce the data-intensity of the method while preserving its flexibility with respect to the non-normality of future returns.

We do this by non-parametrically estimating the function $\sigma(z, \tau)$ for each day, where $z = [ln(X) - ln(F)]/[\sigma_{ATM} * \sqrt{\tau}]$ and σ_{ATM} is the average implied daily volatility for at-the-money options. The parameter z can viewed as a z-score for that option. When we express implied volatilities as a function of z, we find that the "volatility smile" (the shape of $\sigma(z)$ for a given τ), does not change significantly with τ for τ greater than 15 days. This is convenient, since it allows us to estimate $\sigma(z, \tau)$ with limited worries about its sensitivity to our estimation method. For simplicity, we follow AL and use kernel smoothing to estimate $\sigma(z)$ for each day and τ and then use linear interpolation to generate $\sigma(z)$ for τ's that we do not observe.

Having estimated $\sigma(z, \tau)$, we can then use this to calculate $H(F, X, \tau, r, \delta) = H_B[F, X, \tau, r, \delta; \sigma(z, \tau)]$, where H_B is Black's formula for options on futures. We then use this function to estimate state prices for each strike price. State prices can be derived from H by differentiating with respect to X

[30] Bliss and Panigirtzoglou (2002) compare Aït-Sahalia and Lo's method for estimating state prices by estimating implied volatilities with other methods, finding that it more robust to perturbations in option prices.

[31] Our data from the CME are settlement prices for S&P 500 futures and options on futures. Settlement prices are a less ideal data source than bid-ask midpoints, but the need to conduct a timely analysis prevented us from obtaining the more standard CBOE options quotes for our sample period. The CME calculates settlement prices using recent trade and quotes data and then performs a fair value adjustment for market movements since the option last traded. Each option price is matched a futures settlement price; if a future is not available for a given expiry month, we use the dividend yield and risk-free rate to estimate one from the future with the nearest expiry. Following the past literature, we use only the prices of out-of-the-money options, since these are less sensitive to any measurement error in the futures price. We convert the prices of put options into implied call option prices by applying put-call parity.

(Breeden and Litzenberger, 1978). The value of a call option on a future and its derivatives can be written:

$$H(F,X,\tau,r) = e^{-r\tau}\int_0^{\infty}\max(P-X,0)\cdot p(P,F,\tau)\cdot dP$$

$$\frac{\partial H}{\partial X} = -e^{-r\tau}\int_X^{\infty} p(P,F,\tau)\cdot dP$$

$$\frac{\partial^2 H}{\partial X^2} = e^{-r\tau}\cdot p(P,F,\tau)$$

The second derivative gives the state price function $p(P,F,\tau)$: the price of a security worth a dollar if the price at expiry equals P. The first derivative gives the delta of the option or, alternatively, the price of a security worth a dollar if the price at expiry is greater than X. If investors were risk-neutral, we could interpret the state price density as the p.d.f. of future returns and the delta as one minus the c.d.f.