

UC Berkeley

Working Papers

Title

Secrecy and War: The Origins of Private Information

Permalink

<https://escholarship.org/uc/item/519761bq>

Author

Meirowitz, Adam

Publication Date

2007-01-29

Secrecy and War: The Origins of Private Information*

Adam Meirowitz and Anne E. Sartori

Princeton University

January 26, 2007

Abstract

This paper shows why states, acting in their own self-interest, may create informational asymmetries that lead to war. In our model, two actors with no private information invest in military capacity before engaging in crisis bargaining. If bargaining fails, the states go to war, and the payoffs of a war depend on the two states' military capacities. We show that in a large class of settings the states have incentives to keep each other guessing about their exact levels of capacity – even though doing so creates the risk of war. Thus, self interest and strategy are to blame for war. Our paper explains two stylized facts: States devote considerable resources to secrecy in the national-security realm, and often disagree about the balance of capabilities.

*An earlier version was presented at the American Political Science Association Annual Meeting, Washington, DC, September 2005. We thank Ken Schultz, Kris Ramsay, Joanne Gowa, Mark Fey, Scott Ashworth, Ahmer Tarar, Will Moore, and participants in the William Riker Seminar at the University of Rochester for useful comments.

1. Introduction

Many rationalist explanations of war hinge on private information. While the standard argument stems from a simplified description of the international environment, its logic is quite compelling. By most accounts, war is costly both in terms of weapons and lives; it uses up resources and is, thus, inefficient. As a consequence, we may think of international disputes as centering around the division of a pie that shrinks in the event of a war. So, at least in principle, there is a peaceful settlement that all states prefer to a war – a settlement in which each state gets at least the share of the pie it would have gotten in war, and at least one gets more. If the states knew each other’s values for war precisely, they would be able to reach such a peaceful settlement. Thus, a hypothetical world in which states possess all relevant information is completely peaceful.

This peaceful description is inaccurate, since states hide information about their militaries, not only about specific programs but also about their overall military budgets and the strength of their armed forces. For example, the United States Department of State publishes a book containing estimates of the foreign military expenditures of most foreign countries, and it does so with this qualification:

A primary aim [of the document being quoted] is to inform the reader of the main qualifications to the data, much of which is not as accurate as uniform presentation in statistical tables may imply. *This is particularly true of the data on military expenditures, armed forces, and arms transfers, which in many countries are subject to severe limitations of incompleteness, ambiguity, or total absence due to governmental secrecy* (emphasis added).¹

If the United States, with its large budget and extensive intelligence network, has trouble obtaining reliable information on other states’ military expenditures and armed forces, imagine the trouble faced by other countries.²

¹“Statistical Notes,” downloaded from Department of State web site: http://www.state.gov/t/vci/rls/rpt/wmeat/1999_2000/.

²In some cases the State Department also may have better estimates than it acknowledges, or other branches may have better estimates than they share with the State Department.

The well known argument of Fearon (1995) shows that extant private information can have pernicious consequences. When private information is present, states have incentives to misrepresent their values for war, bargaining failures are possible, and inefficient wars (wars that reduce the size of the pie) can occur.³

But why do states have private information in the first place? Fearon's argument is not wholly satisfying, since it does not explain the emergence of private information itself. Instead, it takes as given the premise that states begin their interaction with private information and explains why asymmetries of information are maintained throughout negotiations. This assumption is unproblematic if the private or asymmetric information is truly exogenous; however, for asymmetric information about attributes that are under the control of states, and in particular about military capacity, Fearon's explanation is incomplete. In order to truly understand the origins of military conflict, we must understand not only what leads states to keep existing information private, but also how asymmetric information emerges in the first place. This is also true if we wish to design institutions that alleviate the consequences of private information. If the factors that lead to the emergence of private information are not identical to those that lead them to hold on to existing private information, then efforts to reduce the chance of war based on only the latter will be at best incomplete. We return to this subject briefly later.

The present paper explains the origins of private information about military capacity.⁴

³Private information plays an important role in many theories of war. For example, Powell (1999) [97] shows that states never go to war with complete information. They may, however, go to war when one has private information, because a satisfied state does not know precisely what it must offer to satisfy a dissatisfied state and prevent war. Blainey (1973) [246] writes about mutual optimism as a cause of war; such disagreement can only occur when states possess private information. For an argument against mutual optimism as a cause of war when either side can unilaterally avoid conflict, see Fey and Ramsay (2005). On the difficulty in making credible commitments as an alternative cause of war, see Fearon (1995) and Powell (2004a).

⁴The literature on international conflict identifies several factors that influence a state's resolve, including its and its adversary's military capabilities, its willingness to take risks, the extent of its satisfaction with the status quo, and the extent to which it values the disputed issues (Morrow 1989a; Fearon 1992) We follow Morrow (1989a) in focussing on the first of these factors; Morrow explains the effects of such uncertainty, while we focus on its origins.

More specifically, we show why states (i) arm themselves, (ii) do so in a manner that is not predictable and (iii) keep their capacity secret, when this type of behavior places them in a setting in which wars become likely. Moreover, our explanation offers guidance into the conditions that make the genesis of private information and the ensuing risk of conflict more or less likely. To be clear, Fearon's and other work speaks to point (iii) – keeping the capacity a secret, given that (i) and (ii) are descriptively accurate. In this paper, we take a step back and also investigate why states arm themselves and their armament decisions remain unpredictable, as in the above excerpts, when it is known that if private information emerges it will make inefficient war likely. Moreover, we seek to understand why this type of behavior does not always occur.

Before proceeding, the puzzle is worth elaborating. Recall that most models about information and war begin with a nonstrategic player, Nature, randomly drawing the types of the states and letting a state observe only its own type. The states then bargain and bargaining failure results in war. But, in reality, states take actions that determine their military strength and influence their resolve. So there are actually two intertwined puzzles: Why does the international order move from a setting with no (or low) military capacity and complete information to one with both higher capacity and uncertainty, when this movement makes inefficient war possible? That is why do states not somehow remain in the happy and efficient state of known disarmament? International-relations theory tells us that states have incentives to arm when their adversaries are disarmed, but if all states in this situation arm, why do their adversaries not know that they have done so (Jervis 1978)? If we think of states as playing a prisoner's dilemma in which defection represents a decision to acquire a specified level of armament, Nash equilibrium analysis tells us that both states will arm, but also that each can figure out that the other is acquiring the specified level of armaments because each expects the other to play its equilibrium strategy. In this prisoner's dilemma, armament is explained but the emergence of real uncertainty about the capacity of the nations is not.

In our model, two actors possessing no private information are given the opportunity to acquire military capacity before engaging in crisis bargaining. If bargaining fails, they go

to war.⁵ We show that in equilibrium the actors have strong incentives to keep each other guessing about their investments in military capacity – and that they go to war, despite the absence of *ex ante* private information. This is true unless it is better to be a weak power negotiating with another weak power than a Superpower at war with a completely unarmed adversary. Our explanation for war has an important normative implication: self-interest and strategy can lead parties to undertake actions that make war possible even when they start in a world of full information, which one might think would be a world of peace.

Why do states acquire private information about military capacity, even though doing so creates the risk of war? States have two competing incentives when it comes to acquiring military capacity. First, a state with greater military capacity is likely to do better in negotiations; if a war occurs the capacity will also be beneficial (Banks 1990). In other words, each state benefits from the acquisition of military capacity. But military capacity is costly, so states do not wish to acquire too much; this incentive is especially strong if negotiation is likely to lead to a peaceful settlement. In fact, when peaceful settlement is anticipated, there is a very clear incentive to minimize the actual investment in capacity but pretend that one has made a large investment.

In a strategic or competitive setting, these individual preferences translate into a conundrum. If both states arm lightly and this is known, then either state can gain from a unilateral increase in capacity and aggressive bargaining – a unilateral increase in strength makes victory much more likely and this offsets the cost of acquiring additional capacity. If both states arm heavily and this is known, they can reach a bargain that is mutually preferred to war; however, as long as the states expect to reach a bargain, either benefits from secretly investing in a lower level of capacity. As a consequence of these competing incentives, states often purchase arms and bargain in such a way that they keep each other guessing about how much capacity they have acquired. Even though participants have the opportunity to reveal their capacity, this information cannot be credibly conveyed. In other words, decisions about how much military capacity to accumulate are unpredictable and states do not reveal how much military capacity they have purchased – even though hiding

⁵Our arguments also apply to civil wars, but we refer to states in this paper for the sake of brevity.

this information creates the risk of war.

Under what circumstances do states hide information about their military capacity? One might think that they do so when the costs of investing in military capacity are high. We show instead that they are *less* likely to hide information when military capacity is costly, because they are more likely to remain disarmed when military capacity is very costly. For a very large class of bargaining models, all equilibria involve (i) arms accumulation, (ii) endogenous private information, and (iii) the risk of inefficient war (war that uses up a piece of the pie), unless a rather unlikely condition is satisfied. Specifically, these "bad properties" surface unless each state prefers the expected settlement associated with the world in which it is known that neither state has armed to every possible war – including one in which it is clearly dominant. In other words, we should expect states to develop military capacity and keep this secret unless war is so terrible that it is better to be a weak state negotiating with another weak state than a superpower at war with a completely unarmed state.

In explaining the origins of private information, our paper explains the high degree of secrecy surrounding overall military budgets and programs, and the corresponding fact that states often lack information about each other's military forces. In a rational world, two states with the same information cannot disagree about the balance of military forces. Thus, our work also provides a rational explanation for why states often disagree about the military balance, as was the case at the start of the Russo-Japanese War (Fearon 1995, 398-400)

In addition to providing a foundation for the many explanations of war that assume that states have private information, our paper also speaks to the literature on international institutions. This literature argues that international institutions function to reduce the scope of private information (e.g., Keohane (1984) [93-95]). Again, this presumes that states have private information in the first place. Moreover, as Robert Keohane remarks, "institution-building may be more difficult where security issues are concerned" (Keohane 1984, 94, 247). Our analysis explains why it is difficult to build institutions that reduce the scope of states' private information about security. If institutions were to do away with informational asymmetries, states would still have incentives to increase their capacity and to do so privately (that is, to create new private information). Put differently, any theory of how international

institutions alleviate the pernicious consequences of asymmetric information must explain how particular institutions can overcome the incentives that prevent states from revealing information about their values for war.

Our model differs from most previous formal models of crisis bargaining in that it begins with complete information and has a rich bargaining space with no commitment problems, and yet in equilibrium states sometimes go to war. The players begin with complete information; some actions are hidden, but, as we explain later, any private information is endogenous. As we have noted, private information plays a central role in the formal literature on war. Most previous models of bargaining in international crises have either been complete-information models in which states never go to war (e.g., Fearon (1995), Kydd (2000), Powell (1999)), or incomplete-information models in which states begin the game possessing private information and go to war in equilibrium (e.g., Fearon (1995), Morrow (1989a), Powell (1999), Slantchev (2005), Schultz (1998)). Powell (1993) and Morrow (1989b) contain complete-information models in which states go to war, in these models states do not have the opportunity to reach a bargain short of war.⁶

In the sense that it predicts that wars occur with rich bargaining protocols and no ex ante asymmetric information, our paper is similar to Slantchev (2003). Our explanation of war, however, is substantively quite different. We explain how and why states create private information that leads to war. Slantchev, on the other hand, shows that in the presence of multiple, stage-game equilibria and an infinite horizon, war can be supported in the short run by threats of playing inefficient equilibria in subsequent periods.

1.1. Modeling Issues

Before turning to the model and analysis, we make a few clarifications about the modeling strategy and terminology. While states begin with complete information in the models that we consider, it is possible for them to acquire a form of private information because invest-

⁶There do exist incomplete-information models in which states do not go to war. For example, in (Kydd 2000, 240), the underlying uncertainty is resolved through an arms race, so that the states do not go to war in equilibrium. Levontoglu and Tarar (2005) show that under some circumstances private information results in delay in reaching a settlement rather than in war.

ments in military capacity are not directly observed.⁷ In allowing states to take hidden actions to acquire capacity, however, we are not simply assuming that states have private information. In an equilibrium in which the states' capacity investments are in pure strategies, each state can figure out the capacity of its opponent and the ensuing equilibrium bargaining corresponds to equilibrium behavior in a bargaining model with complete information.⁸ For example, consider a hypothetical world in which the only kind of military capacity is tanks. If one state's equilibrium strategy were to purchase 500 tanks and the other's equilibrium strategy were to purchase 1000 tanks, when bargaining each state would know that the first had 500 tanks and the second had 1000 tanks. This is a natural and standard feature of Nash equilibria. However, equilibria of our game typically involve mixed strategies at the capacity-accumulation stage – that is, each state has a probability distribution over the levels of capacity that it buys.⁹ As long as this is the case, after the states acquire military capacity, each state has beliefs about the other's chosen capacity, but knows only its own level precisely. Thus, states' levels of military capacity become private knowledge. In other words, states begin the interaction without private information, but we show that for most settings they generate private information in every equilibrium of the game. (The exceptional games, in which equilibria with pure strategy accumulations exist, are ones in which it is better to be a weak state negotiating with another weak state than a superpower at war with an unarmed state).

Is the private knowledge that we describe really a form of “private information?” From the description in the previous paragraph, it should be clear that the endogenous private information about military capacity that typically surfaces in the equilibria of our large set of games looks very much like the exogenous private information that is central to standard

⁷Slantchev (2005) contains a model with endogenous military capacity, but assumes incomplete information at the start of the interaction. Kydd (2000) also contains a model in which states buy capacity, but states in his model cannot choose strategically to make their choice private information since they act sequentially and their purchases are directly observed.

⁸States also have the option of revealing the hidden information they acquire through bargaining or cheap talk, but they do not do so in equilibrium.

⁹Recall that a strategy specifies play for the whole game. For the moment we are focusing on the portion of the strategy that specifies how much capacity to invest in.

models of crisis bargaining. These models capture uncertainty by assuming that a state's type – often its military capacity – is private information. By taking a step back and starting in a complete information setting, we offer an explanation for the origins of this private information. In our analysis, the private information that each state acquires in equilibrium is information about its payoffs that it knows and the other state does not. At the time of bargaining, each state knows only its own capacity with certainty. In their study of renegotiation and contracting, Fudenberg and Tirole (1990) use the term private information in the way we use it in this paper. Bendor and Hammond (1992) use the term "endogenous uncertainty" while Palfrey and Rosenthal (1985) use the term strategic uncertainty.

We also allow for cheap-talk communication after the capacity decisions but before the bargaining stage, finding that, in equilibrium, states do not fully reveal their private information once they have acquired it. Moreover, we show that a version of our results holds for any bargaining protocol satisfying two very reasonable conditions: (1) under the protocol, if the parties were to know each other's capacities, they would reach a bargain short of war in equilibrium, and (2) under the protocol, it is possible for either party to initiate a war without the consent of the other state (although this need not occur in equilibrium). That is, we show that despite the fact that states would reach a settlement if they maintained the complete information they have at the start of the game, under many bargaining protocols they choose to create private information and to generate the risk of war.

Finally, we consider the possibility that states' private information does not remain hidden, either because they can demonstrate their capacity levels perfectly (or choose to give a perfectly verified signal), or because each state's opponent receives a noisy signal about its capabilities. We show that perfect signals can take away the problems we identify, but even slightly imprecise signals do not. If states value the future sufficiently or reach any settlement without delay, they choose to create private information and to generate the risk of war in a version of our model in which states receive a noisy signal about each other's military acquisitions under conditions that the same as those in the model without signaling.

From a modeling perspective, our analysis differs from that of many game-theoretic

models of conflict in two ways. First, instead of considering a stylized model of negotiation, we ultimately consider a large class of bargaining protocols. Second, we develop results about all equilibria instead of characterizing the fine details of a particular equilibrium.¹⁰

Specifically, the paper develops as follows. In section 3, we present the model of arms accumulation in the setting of a stylized assumption about the bargaining protocol. In section 4, we characterize necessary and sufficient conditions for equilibria in which states always avoid war. In section 5, we extend the model to allow the states to communicate after deciding about arming but prior to bargaining. Section 6 generalizes the results to a very large class of bargaining protocols. Section 7 generalizes the results to a situation in which states can demonstrate their capacities perfectly. Section 8 generalizes them to a situation in which states' choices of levels of military capacity are observed, but imperfectly so, and Section 9 concludes. In the appendix, we characterize a particular equilibrium in which states create private information.

2. The Model

In the model, two states begin by investing in military capacity. Each state's investment is unobserved by the other player, and each pays a per unit cost for acquiring capacity.¹¹ After investing in capacity, the states bargain; if bargaining fails, they go to war.

For simplicity's sake, we assume that the states bargain over a good of size one that does not begin as the property of either state. Either the states agree on a division of the pie that totals one, or they go to war. Our analyses would not be affected by changing the size of the good or by assuming that one or the other state began by owning the good.

Formally, we consider two states, 1 and 2. It is often convenient to refer to them as i and j . We first consider a simple game form without a communication stage and then extend the game to allow for communication. In period 1, each state chooses an investment $m_i \geq 0$ in

¹⁰We should note that Banks (1990) and Fey and Ramsay (2005) also study the set of equilibria to a large class of models, but both of these papers focus on crisis bargaining with fixed private information.

¹¹In the real world, some kinds of capacity are more expensive than others to acquire. In our model, one might think of an expensive type of capacity as representing two units of capacity, so that it would cost twice as much.

military capacity.¹² Only state i observes the choice of m_i . Investment by i has a marginal cost $\beta_i > 0$. In period 2, the states bargain (or begin bargaining). Either the states agree to a settlement a_i, a_j such that $a_i + a_j = 1$ and $a_i, a_j \geq 0$, or they engage in military conflict. In the event of a conflict, the payoff to state 1 is given by the function $w_1(m_1, m_2)$ and the payoff to state 2 is $w_2(m_2, m_1)$. By \mathbf{m} we denote a vector of investment levels. When it creates no ambiguity we write $w_i(\mathbf{m})$.

Two assumptions are imposed on the payoffs to war. First, military investment can only help a country in the event of war, and it can only hurt an adversary. Second, war is inefficient relative to a peaceful bargain. That is, following Fearon (1995) and others, we assume that war is costly; people die and equipment is destroyed or used up, and territory may be devastated. This means that the total pie available to be divided is decreased if the states go to war. Formally, these assumptions are:

Assumption 1: For $i \in \{1, 2\}$ the function $w_i(\mathbf{m}) : \mathbb{R}_+^2 \rightarrow [0, 1]$ is non-decreasing in m_i and non-increasing in m_j with $j \neq i$.

Assumption 2: $w_1(\mathbf{m}) + w_2(\mathbf{m}) < 1$ for all \mathbf{m} .

To begin, we focus on a very simple bargaining process, or protocol: State 1 makes an offer $a_1 \in [0, 1]$ and state 2 either accepts it (getting $1 - a_1$) or rejects it. Following a rejection war occurs. Later in the paper, we show that the main results hold for a large class of bargaining protocols. In this simple version of the model, we sometimes refer to the first state as the proposer and the second as the veto player. Throughout we focus on perfect Bayesian equilibria (PBE), which require that commitments be credible and beliefs be updated according to Bayes' Rule whenever possible.

3. When can completely peaceful equilibria exist?

We first consider the types of pure-strategy equilibria that are possible – that is, under what circumstances are there equilibria in which states' actions do not lead to private information?

¹²We use the terms capacity and arms interchangeably in this paper, but capacity in the model can include any factors that make a state more likely to win a war but are costly to accumulate – for example, a new technology or military strategy.

As we discussed earlier, states in our model begin with complete information about all features of the game. Since equilibrium strategies are common knowledge, both states will continue to know all of the relevant information as long as they acquire military capacity in pure strategies.

Since our model is one of ex ante complete information, one might expect a number of equilibria in which states arm but reach bargains short of war. We begin by showing that no such equilibrium exists: States do not arm in any pure-strategy equilibrium of this game. The reason for this is that states will reach a bargain short of war in any pure-strategy equilibrium, since, as long as states accumulate military capacity in pure strategies, the capacity levels are known (though not observed) at the time of bargaining. However, if states are reaching a bargain short of war, they each prefer to secretly remain unarmed, since acquiring arms is costly. Thus, if states are reaching a bargain and $m_i > 0$, state i has an incentive to deviate to $m_i = 0$.

Proposition 1. *There are no equilibria with pure-strategy accumulations and $\max\{m_1, m_2\} > 0$.*

Proof: Suppose that there is a pure strategy equilibrium with $m_i > 0$ for some i . In the bargaining stage of the game, sequential rationality requires that 2 accept any offer that satisfies $1 - a_1 \geq w_2(\mathbf{m})$. Thus, the maximum offer a_1 that will be accepted is $1 - w_2(\mathbf{m})$. An offer by 1 above this amount will be rejected by 2, which leads to the war payoff $w_1(\mathbf{m})$. By assumption (2), $1 - w_2(\mathbf{m}) > w_1(\mathbf{m})$, so sequential rationality requires that 1 offer $1 - w_2(\mathbf{m})$ which is accepted. Therefore, war does not occur in this equilibrium and thus an unobserved deviation to $m_i = 0$ will not change the outcome in the bargaining stage, but it will increase i 's payoff by $\beta_i m_i$. Thus, this is a profitable deviation. ■

Thus, in any equilibrium in which states do not acquire private information, neither state accumulates any military capacity. We next show that an equilibrium in which neither state arms and therefore states do not create private information is the only possible equi-

librium in which the states never go to war.¹³ Put differently, states go to war with positive probability in any equilibrium in which they generate private information. We also show that an unarmed, completely peaceful equilibrium exists only under a very limited set of circumstances.

The intuition behind this next result is again simple: Because states do not directly observe each other's military capacity, each country can arm heavily without the other knowing. Thus, a situation in which both states are unarmed and peaceful is hard to sustain, because each has an incentive to become unilaterally strong and start a war.

To get the weakest condition for an equilibrium in which neither state acquires military capacity ($\mathbf{m} = \mathbf{0}$), we first assume that such an equilibrium exists. In such an equilibrium, the offer must be $a_1 = 1 - w_2(0, 0)$ as this maximizes player 1's payoff while keeping player 2 indifferent between war and the offer. This equilibrium requires that neither party is willing to unilaterally deviate from $m_i = 0$. Since $\beta_i > 0$, such a deviation is only worthwhile if war occurs (with positive probability) following the deviation. There are two such deviations that must be ruled out: 1) The vetoer unilaterally deviates (accumulating a positive amount) and rejects a_1 . This deviation is worthwhile only if, $w_2(m_2, 0) - \beta_2 m_2 > w_2(0, 0)$. 2) The proposer deviates by accumulating capacity and offering less to the vetoer. This is only worthwhile if $w_1(m_1, 0) - \beta_1 m_1 > 1 - w_2(0, 0)$.

Proposition 2. *War occurs with probability zero in a particular equilibrium if and only if $\mathbf{m} = \mathbf{0}$ with probability one in the equilibrium. Moreover, an equilibrium of this type exists if and only if*

$$w_2(m_2, 0) - \beta_2 m_2 \leq w_2(0, 0) \text{ for all } m_2 \in (0, \infty) \quad (3.1)$$

and

$$w_1(m_1, 0) - \beta_1 m_1 \leq 1 - w_2(0, 0) \text{ for all } m_1 \in (0, \infty). \quad (3.2)$$

Proof: Step 1: We first establish the first part of the proposition. Suppose that there is an equilibrium in which war happens with probability 0. This means

¹³The following result also implies that there is no equilibrium in which only one state plays a mixed accumulation strategy (generates private information) and war occurs with probability 0.

that on the path the offer is accepted. Since $\beta_i > 0$ a deviation from any lottery putting probability on $m_i > 0$ to another strategy with $m_i = 0$ with probability one would be desirable. Thus, $\mathbf{m} = \mathbf{0}$ must occur with probability 1 in the equilibrium. Assume that $\mathbf{m} = \mathbf{0}$ with probability 1 in equilibrium. Given this and assumption 2 it is well known that in all perfect equilibria of the ultimatum game a settlement is reached.

Step 2: We now establish that such an equilibrium occurs if and only if the stated condition is satisfied. Given $\mathbf{m} = \mathbf{0}$, sequential rationality in bargaining requires that the proposer, 1, offer $a_1 = 1 - w_2(0, 0)$ as long as $1 - w_2(0, 0) \geq w_1(0, 0)$. This condition is true by assumption. There are two deviations to consider: a deviation by the proposer, 1, to increase m_1 and make an offer which is not accepted or a deviation by the vetoer, 2, to increase m_2 and to reject the offer. If 2 uses the above threshold strategy then 1's best possible deviation is desirable iff (3.2) is not satisfied. Alternatively 2's deviation is desirable iff (3.1) is not satisfied. ■

A peaceful equilibrium can exist – but only in a rare set of circumstances (parameterizations). While one might think that states will be more likely to hide information about their capacity when military capacity is more expensive, Proposition 2 states that this is not the case. All else equal, the conditions for the peaceful equilibrium are more likely to hold when the cost parameters are higher, because secretly arming becomes more costly. More generally, Proposition 2 states that the peaceful equilibrium in which states do not hide information occurs only when it is better to be a weak state negotiating with another weak state than a heavily armed state at war with an unarmed adversary, net of the costs of arming.

To give some sense of the rarity of the peaceful equilibrium, we now turn to an example with specific payoffs for war. One might think of many wars as contests: the state that has the greater military capabilities wins, and takes the spoils of war, while the other state loses, and gets nothing. Our next example reflects this idea of war as a contest: In the event of war,

the more heavily armed state wins and gets the prize; the other state loses and gets nothing, and the states split the prize if they have acquired equal military capacity. Formally, for a number $\alpha \in (0, 1)$ we can define

$$w_j(m_j, m_i) = \begin{cases} \alpha & \text{if } m_j > m_i \\ \frac{\alpha}{2} & \text{if } m_j = m_i \\ 0 & \text{otherwise.} \end{cases} \quad (3.3)$$

In this winner-take-all example, the conditions of proposition 2 are satisfied if and only if $\alpha = 0$. Thus, in this example, the peaceful equilibrium exists only if war provides no goods to the victor. If winning a war provides some benefits, the model suggests that a world without private information and war is unsustainable when wars are winner-take-all events.

Even beyond this example, war occurs with positive probability in every equilibrium of this game unless each state derives no net benefit from a war in which it is heavily armed and faces an unarmed adversary, relative to the benefit of staying unarmed and engaging in negotiations.¹⁴ Thus, in this game of ex ante complete information, under many circumstances the only possible equilibria are ones in which states arm and go to war with positive probability. Moreover, we have shown that these equilibria must be mixed-strategy ones – that is, ones in which the states choose to create private information.

4. Communication

Now that we have established that states create private information, we turn to the question of whether or not they reveal that information, if given the chance. We modify the game to give the states the opportunity to reveal their levels of military capacity by talking. In this game, they simultaneously engage in cheap talk after the investments in military capacity and before the bargaining stage.

Loosely speaking, a PBE is fully-revealing if states reveal all of their information through

¹⁴Most formal studies treat war as a costly lottery, with each state's probability of winning and thus its expected utility reflecting the distribution of power (Powell 2004a; Wagner 2000). This approach satisfies assumptions 1 and 2, so our results apply to models with this payoff structure.

their messages in equilibrium. We show that there are no fully revealing PBE, except in the trivial case of a peaceful equilibrium, in which players already know each other's military acquisitions (or lack thereof) precisely. The logic behind this result is quite intuitive and prevalent in other studies: If there were a fully revealing PBE, then each player's message would be completely informative. But if messages were completely informative, then players would have an incentive to accumulate nothing but say that they have accumulated the maximum amount possible in order to get a better bargain. That is, consistent with Fearon (1995), states do not fully reveal their information because of incentives to get a better bargain.

Formally, each state simultaneously sends a signal $s_i \in \mathbb{R}_+^1$ after the states acquire capacity and before they bargain. An equilibrium of this modified game consists of mixed accumulation strategies, characterized by distributions $F_1(\cdot)$ and $F_2(\cdot)$, accumulation-contingent messages $\eta_i(m_i) : \mathbb{R}_+^1 \rightarrow \mathbb{R}_+^1$, an offer strategy for 1, $a(\eta_1, \eta_2, m_1) : \mathbb{R}_+^3 \rightarrow [0, 1]$, an acceptance strategy for 2, $v_2(a, \eta_1, \eta_2, m_2) : \mathbb{R}_+^3 \rightarrow \{accept, reject\}$, beliefs for player 1 about m_2 given η_1 , which we denote as $F_2(\cdot | \eta_2)$, beliefs for player 2 about m_1 conditional on η_1, η_2 , and the offer a which we denote $F_1(\cdot | a, \eta_1, \eta_2)$. These beliefs depend on η_2 because player 1's proposal strategy may depend on η_2 and thus screening is possible. In a PBE, the beliefs must be consistent with Bayes' Rule when it applies and the strategies must be sequentially rational. We say a PBE is fully-revealing if the states can infer each others' accumulations from the messages. Thus a PBE is fully-revealing if the message strategies $\eta_i(m_i)$ are invertible functions. Sequential rationality requires that given m_2 and the offer and messages (a_2, η_1, η_2) , player 2 accept any offer $a_2 = 1 - a_1$ if

$$\int w_2(m_2, m_1) dF_1(m_1 | a_2, \eta_1, \eta_2) < a_2. \quad (4.1)$$

While player 2 need not accept an offer when indifferent, in any fully-revealing equilibrium indifference must be resolved this way or else player 1 will not have an optimal offer at some histories. Thus, the above condition holds with a weak inequality in any fully revealing PBE.

For simplicity's sake, we make a stronger version of Assumption 1 in order to prove the

following proposition:

Assumption 3: For $i \in \{1, 2\}$ the function $w_i(\mathbf{m}) : \mathbb{R}_+^2 \rightarrow [0, 1]$ is strictly increasing in m_i and strictly decreasing in m_j with $j \neq i$.

Proposition 3. *Assume assumptions 2 and 3 hold. Unless accumulations are in pure strategies, and thus $\mathbf{m} = \mathbf{0}$, there are no equilibria in which states fully reveal their military accumulations in the communication stage.*

Proof: By way of contradiction, suppose that there is a fully-revealing PBE and for at least one player i the support of m_i contains (at least) two points $m'_i < m''_i$. By definition this implies that the message strategies are invertible. Let $\eta_i^{-1}(s_i) = \{z : \eta_i(z) = s_i\}$ denote the inverse of η_i at the particular message s_i . In any fully revealing PBE, on the equilibrium path the posterior beliefs $F_i(\cdot | \cdot)$ are concentrated at $\eta_i^{-1}(s_i)$. Since player 1's beliefs about m_2 are concentrated, assumption 2 (inefficiency of war) implies that the optimal offer for player 1 that will satisfy player 2's acceptance rule has $a_2(s_1, s_2) = w_2(\eta_2^{-1}(s_2), \eta_1^{-1}(s_1))$. Moreover, in equilibrium this offer is accepted (or else best responses for player 1 would not exist – a requirement of a PBE). This implies that in any fully revealing PBE, in which, given m'_2 , player 2 is supposed to send message s'_2 , if player 2 were to send a different message $s''_2 = \eta_2(m''_2)$ then $\eta_2^{-1}(s'_2) < \eta_2^{-1}(s''_2)$ and the proposal following s''_2 would be larger than the proposal following s'_2 . Thus, this deviation is desirable. Alternatively, in an equilibrium in which following m'_1 player 1 is supposed to send s'_1 a deviation by player 1 to a different message $s''_1 = \eta_1(m''_1)$ would mean that player 2 would be willing to accept a lower offer (which would be desirable to 1). Thus, we have derived a contradiction of the assumption that a fully-revealing PBE exists. ■

This result demonstrates that not only do states have strategic incentives to create private information (whenever condition (3.1) or condition (3.2) is not satisfied) but the incentive to do better in bargaining makes fully revealing the information about military capacity impossible in a setting where communication is cheap and unprovable.

5. Other Bargaining Protocols

We have seen that states create private information about military capabilities that leads to a risk of war if either condition (3.1) or condition (3.2) is not satisfied. Our analysis assumed a particular bargaining protocol. We now investigate whether this result extends to a larger class of models with accumulation of military capacity and bargaining. In particular we consider a large class of bargaining protocols and find that it remains the case that if states do not create private information and there is a zero probability of war in any equilibrium then the states must remain completely unarmed in that equilibrium. Moreover, in all of these models, rather stringent conditions (which represent natural extensions of conditions 3.1 and 3.2) must be satisfied in order for peaceful equilibria to exist.

The results in this section apply to all bargaining protocols that meet two conditions. First, as we discussed at the start of the paper, as long as war is costly, there is always some settlement that both states prefer to war. When states have complete information, they can identify settlements of this form. Thus, we consider bargaining protocols under which states reach an ex-interim efficient settlement (one that fully divides the pie) if they have complete information. This is a large class of protocols; it includes protocols with veto players and the alternating-offer Rubinstein bargaining model, which is often used to study international conflict. Second, we would argue that any state eventually has the possibility of opting out of bargaining and starting a war without the consent of its adversary, though it may never choose to do so. If instead both states have to consent to war, a state with military capacity could be forever stuck in a bargaining process it does not like, with no option of unilaterally using whatever forces it possesses. Thus, we assume that either state can end the bargaining and start a war, unilaterally in a finite amount of time (but it need never do so). The first condition is a bit more subtle as it restricts protocols based on particular aspects of their equilibrium set; the second condition is more straightforward as it speaks only to the structure of the protocol and not any description of how states will actually behave in the protocol. We give formal definitions below.

Formally, the bargaining protocol includes a description of the available offers, sequence of speaking, and how behavior maps into payoffs. Specifically, we define a bargaining

protocol to be a pair of strategy spaces, S_1, S_2 and a mapping $b(\xi_1, \xi_2) : S_1 \times S_2 \rightarrow A \times \mathbb{N}$. The strategy spaces may be finite, countably infinite, or uncountably infinite. The set A is defined to be the union of the 2 dimensional simplex and a particular outcome that we call war. We denote this outcome by the vector $(-1, -1)$. Specifically,

$$A := \{(p_1, p_2) \in \mathbb{R}_+^2 : p_1 + p_2 = 1\} \cup \{(-1, -1)\}. \quad (5.1)$$

The mapping $b(\xi_1, \xi_2) \mapsto (p_1(\xi_1, \xi_2), p_2(\xi_1, \xi_2), t(\xi_1, \xi_2))$ assigns a vector of outcomes to the two states and a time $t \in \mathbb{N} := \{1, 2, \dots\}$ at which the decision is reached for any profile of bargaining positions. If $(-1, -1)$ is the outcome and it is reached in period t , then we say that bargaining breaks down in period t and war occurs. The payoffs from this outcome are given by $\delta^{t-1}w_i(m_i, m_j)$. If a settlement is reached in period t then state i 's payoff is $\delta^{t-1}p_i(\xi_1, \xi_2)$. The term $\delta \in (0, 1]$ serves as the common discount factor.¹⁵ Since we require that equilibria are PBE, play in the bargaining protocol will satisfy sequential rationality.

In order to state these assumption rigorously, we need to be able to talk about \mathbf{m} being known. We say the accumulation \mathbf{m} is known at the beginning of the bargaining protocol if player 1's belief about player 2's accumulation is concentrated at the correct value and player 2's belief about player 1's accumulation is concentrated at the correct value. The first assumption states that when the accumulations are known, sequentially rational play results in a peaceful settlement.

Condition 1 (war is inefficient): Whenever \mathbf{m} is known, every profile of sequentially rational play in the bargaining protocol results in some bargaining solution (p_1, p_2, t) that satisfies the conditions that $p_1 + p_2 = 1$ and t is finite.

The second assumption ensures that war is not a consensual outcome; either party can in a finite period of time initiate a conflict (the outcome $(-1, -1)$) regardless of the other player's bargaining behavior. This is an assumption about what is possible, and not about what occurs in equilibrium; neither state need ever start a war.

Condition 2 (war is not consensual): There exists a finite t' s.t. for either $i \in \{1, 2\}$

¹⁵We are assuming that any bargaining costs can be represented adequately by the discount factor – that is, if settlement is delayed by a period, each state gets a smaller payoff in present value, which is similar to paying a cost.

there exists a strategy $\xi'_i \in S_i$ s.t. for any $\xi_j \in S_j$, $b(\xi'_i, \xi_j) = (-1, -1, t)$ for some $t < t'$.

The bargaining protocol of the previous section does not satisfy condition 2 as player 1 is constrained to make an offer and in principle player 2 could accept any offer. It is easy to see that if the ultimatum game were modified so that player 1 could just start a war instead of making an offer the equilibrium set would not change. In the large class of bargaining models which satisfy these two conditions, we find, again, that in any equilibrium in which war occurs with probability zero, the states remain unarmed with probability one. For the whole class of bargaining models, peaceful equilibria exist only under a limited set of circumstances. We begin by showing that states create private information (accumulate military capacity in mixed strategies) in any equilibrium unless the states remain completely unarmed. That is, we generalize proposition 1.

Proposition 4. *There are no equilibria with pure-strategy accumulations satisfying $\max\{m_i, m_j\} > 0$.*

Proof: Assume that such an equilibrium exists with efforts \mathbf{m} . Since the equilibrium is in pure strategy accumulations, states possess all relevant information when they begin bargaining. By condition 1 a bargain will be reached with probability one. Since effort is not observed, a deviation to $m_i = 0$ (and no change in i 's bargaining actions) would not affect the outcome of the bargaining protocol. Since $\beta_i > 0$, for a state with $m_i > 0$ such a deviation would increase its utility. ■

The next result establishes that the states do not go to war if they remain completely unarmed. However, if states generate private information in equilibrium, there is always a positive probability that they go to war. This result rules out equilibria in which states generate private information (accumulate military capacity in mixed strategies), but always reach a peaceful settlement through negotiation. It generalizes the first half of proposition 2.

Proposition 5. *War occurs with probability 0 in an equilibrium if and only if $\mathbf{m} = \mathbf{0}$ with probability one in this equilibrium.*

Proof: We proceed in steps.

(\Leftarrow) If the players play pure accumulation strategies, then \mathbf{m} is known. Condition 1 then implies that war does not occur.

(\Rightarrow) Suppose that there is an equilibrium in which war happens with probability 0. This means that on the path some offer a_i is accepted. Since $\beta_i > 0$ a deviation from any non-degenerate lottery to $m_i = 0$ (and no change in i 's bargaining behavior) would be desirable. Thus, if we are in an equilibrium and no deviation is desirable it must be the case that $\mathbf{m} = \mathbf{0}$. ■

Finally, it is possible to present partial analogues to the necessary and sufficient conditions for the existence of the unarmed, peaceful equilibria – 3.1 and 3.2 in the second half of proposition 2. We have assumed that the states reach a peaceful bargain if they have complete information. We show next that – as with the particular bargaining protocol we considered earlier – a sufficient condition for the peaceful equilibrium is that neither state can benefit from unilaterally arming and starting a war when the other state is unarmed. Let Π^0 denote the set of expected payoffs pairs that are feasible given some sequentially rational profile of bargaining behavior when it is known that neither state has accumulated any military capacity ($\mathbf{m} = \mathbf{0}$).¹⁶

Proposition 6. *There is an equilibrium with $\mathbf{m} = \mathbf{0}$ if*

$$w_j(m_j, 0) - \beta_j m_j \leq \pi_j \text{ for all } m_j \in (0, \infty) \quad (5.2)$$

and

$$w_i(m_i, 0) - \beta_i m_i \leq \pi_i \text{ for all } m_i \in (0, \infty). \quad (5.3)$$

for some $(\pi_i, \pi_j) \in \Pi^0$

Proof: By assumption, following $\mathbf{m} = \mathbf{0}$ the payoffs correspond to the right-hand side of the inequalities for some equilibrium selection. We now consider a

¹⁶Recall, a payoff is the discounted value of an outcome. Thus each coordinate of a payoff vector in this set is of the form $\pi_i = \delta^{t-1} p_i(\xi_i, \xi_j)$.

unilateral deviation by i . Given that $(\pi_i, \pi_j) \in \Pi^0$ the most that i can get from a peaceful settlement is π_i . If this were not true then (π_i, π_j) would not be equilibrium payoff to bargaining when it is known that $\mathbf{m} = \mathbf{0}$. This implies that the deviation to $m_i > 0$ is profitable only if the deviation results in a lottery that puts positive probability on war, and $w_i(m_i, 0) - \beta_i m_i > \pi_i$. This is not possible if $w_i(m_i, 0) - \beta_i m_i \leq \pi_i$ for all $m_i \in (0, \infty)$. Thus, the result is established. ■

Establishing necessary conditions for the unarmed, peaceful equilibrium is a bit more challenging. In principle, the value to a state of deviating from its peaceful equilibrium strategy, arming, and starting a war can be less than its full value for war (net of the costs of arming) because of the costs of delay. We have limited our consideration to bargaining protocols that allow either state to start a war, but not necessarily immediately. Thus, with some protocols in the class we are considering, if a state deviates by arming and starting a war, it will receive only a discounted payoff from war. This implies that even when the sufficient conditions for the peaceful equilibrium are not satisfied, neither state may wish to deviate from its peaceful-equilibrium strategy of remaining unarmed. The following proposition takes discounting into account in establishing the necessary conditions for the peaceful equilibrium.

Proposition 7. *There is an equilibrium with $\mathbf{m} = \mathbf{0}$ only if*

$$w_j(m_j, 0) - \beta_j m_j \leq \frac{\pi_j}{\delta^{t'-1}} \text{ for all } m_j \in (0, \infty) \quad (5.4)$$

and

$$w_i(m_i, 0) - \beta_i m_i \leq \frac{\pi_i}{\delta^{t'-1}} \text{ for all } m_i \in (0, \infty). \quad (5.5)$$

for some $(\pi_i, \pi_j) \in \Pi^0$

Proof: Step 1: First note that for every pair $(\pi_i, \pi_j) \in \Pi^0$ and the supporting equilibrium strategy profile, given knowledge of $\mathbf{m} = \mathbf{0}$, there is no unilateral deviation by i from the conjectured equilibrium strategy that involves $m_i = 0$ and different actions in the bargaining game that results in a payoff higher than

π_i . Second, consider a unilateral deviation from a particular profile that starts with $\mathbf{m} = \mathbf{0}$ and has sequentially rational play in the bargaining protocol. Any such deviation that (i) reaches a settled outcome (not $(-1, -1)$) with probability one and (ii) involves $m_i > 0$ could be improved upon by the strategy that has $m_i = 0$ and mimics this deviation. These two points imply that in considering equilibria with $\mathbf{m} = \mathbf{0}$ it is sufficient to consider deviations that reach war with positive probability and yield war payoffs that exceed π_i .

Step 2: Assume that an equilibrium with $\mathbf{m} = \mathbf{0}$ exists. The conclusion of step 1 implies that it must be the case that for the t' defined in condition 2

$$\delta^{t'-1} w_i(m_i, 0) - \beta_i m_i \leq \pi_i \text{ for all } m_i \in (0, \infty). \quad (5.6)$$

If this were not true, then the equilibrium with $m = 0$ would not exist as i could unilaterally increase its payoff by selecting some $m_i > 0$ and selecting the bargaining action ξ'_i defined in condition 2. Since t' is finite, multiplication by $\frac{1}{\delta^{t'-1}}$ is permissible and the conclusion is established. ■

In order to contrast these results with conditions 3.1 and 3.2, consider bargaining protocols with the following property: each state's payoff from a bargain is the same in every completely peaceful equilibrium – that is, every equilibrium in which the countries do not arm and therefore always reach a bargain. (This is the set of bargaining protocols in which Π^0 is a singleton). Taken together, the last two results demonstrate that for a large class of bargaining protocols the condition

$$w_i(m_i, 0) - \beta_i m_i \leq \pi_i \text{ for all } m_i \in (0, \infty) \quad (5.7)$$

is sufficient but not necessary for peaceful equilibria. Recall that with the particular bargaining protocol considered earlier in the paper, this condition is necessary and sufficient. Within this large class of bargaining protocols, the necessary and sufficient conditions become analogous to conditions 3.1 and 3.2 if the states become sufficiently patient. (They converge to the natural analogues of conditions 3.1 and 3.2 in the limit as δ goes to 1.) Similarly, if

the states have the option of starting a war immediately, though they may choose not to exercise it (that is, if $t' = 1$), then the peaceful-equilibrium conditions are exactly analogous to conditions 3.1 and 3.2.

Like propositions 3.1 and 3.2, these results show that states are less likely to hide information when arming is costly, because they are more likely to remain disarmed when arming is costly. Looking at the left-hand side of the inequalities, one can see that the payoff to unilaterally arming and starting a war goes down as the per-unit cost of arming (β) goes up, and thus states are more content to remain peacefully disarmed.

Within this large class of bargaining models, it remains the case that if states create private information they risk war. If states are sufficiently patient or have the option of starting a war immediately, the peaceful equilibrium exists only if it is better to be a weak state negotiating with another weak state than a superpower at war with an unarmed state. Otherwise, the peaceful equilibrium exists only under a limited set of circumstances that depend upon the states' degree of patience and/or on the time that it takes them to mobilize forces and begin a war. The appendix contains an example of an equilibrium with private information and war.

6. Arming When Demonstration of Capacity is Possible

Thusfar, we have shown the extreme difficulties in avoiding the creation of private information about military capacity and an associated risk of war – even if states can engage in cheap talk after they acquire arms. We consider now a stylized model in which states can choose whether or not to demonstrate their capacity; if a state chooses to costlessly demonstrate its capacity, this fully reveals the information to the adversary. We can also think of this as a situation in which one can choose to let opponents perfectly monitor. The states simultaneously select their capacities m_i, m_j simultaneously and then prior to bargaining each state selects a message $s_i \in \{m_i, \phi\}$. The signal $s_i = m_i$ is interpreted as a verified statement about or demonstration of one's capacity, and $s_i = \phi$ is interpreted as an uninformative speech. We focus on the ultimatum bargaining protocol. In this setting, a state cannot

deviate from a conjectured profile that involves informative communication without letting its opponent know that it has deviated. The requirements for a pure strategy equilibrium $m = (m_1, m_2), s = (m_1, m_2)$ are (1) that

$$\begin{aligned} m_1 &\in \arg \max \{1 - w_2(m_2, m_1) - \beta_1 m_1\} \\ m_2 &\in \arg \max \{w_2(m_2, m_1) - \beta_2 m_2\}, \end{aligned}$$

and (2) given the strategy profile no player has an incentive to deviate to a pair m'_i, ϕ with $m'_i \neq m_i$. If the payoff from war is discontinuous (as in 3.3), then no pair m_1, m_2 can meet these requirements and states must play mixed strategies in equilibrium. If, however, the payoffs from war are continuous, pure-strategy equilibria may exist. For example, in the case of

$$w_i(m_i, m_j) = \frac{pm_i}{m_i + m_j} \tag{6.1}$$

with $p \in (0, 1)$, first order conditions from (1) yield

$$\begin{aligned} \frac{pm_2}{(m_1 + m_2)^2} &= \beta_1 \\ \frac{pm_1}{(m_1 + m_2)^2} &= \beta_2 \end{aligned}$$

and the solution is given by

$$\begin{aligned} m_1 &= \frac{p\beta_2}{(\beta_2 + \beta_1)^2} \\ m_2 &= \frac{p\beta_1}{(\beta_2 + \beta_1)^2}. \end{aligned}$$

These values satisfy the second-order conditions at any values of m_1 and m_2 . So as long as the payoffs to these accumulations exceed 0, condition (1) is satisfied. The boundary condition requires,

$$\begin{aligned} \frac{p\beta_2}{p\beta_2 + p\beta_1} &\geq \frac{p\beta_1\beta_2}{(\beta_2 + \beta_1)^2} \\ \frac{p\beta_1}{p\beta_2 + p\beta_1} &\geq \frac{p\beta_1\beta_2}{(\beta_2 + \beta_1)^2} \end{aligned}$$

Simplifying yields

$$1 \geq \max \left\{ \frac{p\beta_1}{\beta_2 + \beta_1}, \frac{p\beta_2}{\beta_2 + \beta_1} \right\}.$$

In order to check that condition (2) is satisfied, we need to specify off-the-path beliefs for bargaining games in which $s_i = \phi$. The equilibrium is supported if the beliefs assign probability 1 to $m_i = 0$ given $s_i = \phi$. To see this, note that we already have seen that the equilibrium payoff to i exceeds the payoff to bargaining as if $m_i = 0$. It remains to verify that i does not prefer to arm, announce $s_i = \phi$, and then have a conflict. For 1 the maximum payoff to this deviation solves

$$m_1 \in \arg \max \left\{ \frac{pm_1}{m_1 + m_2} - \beta_1 m_1 \right\},$$

which has the same first-order condition as above since the partial derivatives of $1 - \frac{pm_2}{m_1 + m_2}$ and $\frac{pm_1}{m_1 + m_2}$ with respect to m_1 are the same. Similarly, since the second state is solving the same problem, the optimal deviation cannot improve its payoff. It is interesting to note that in this equilibrium, secrecy is interpreted as a sign of weakness. That is, when states reveal information about their capacities in equilibrium, but have the option of choosing not to, opponents must treat failure to reveal information as a signal that i is weaker than the equilibrium level m_i . Were this not true, i would benefit from hiding its information (changing s_i from m_i to ϕ). The results of our analysis of this example are as follows.

Proposition 8. *With the smooth war technology in 6.1, and the ability to demonstrate capacity perfectly, there is an equilibrium in which the states select capacities in pure strategies, reveal their capacities, and reach a negotiated settlement; war occurs with probability 0.*

However, before we conclude that this hypothetical, effective demonstration or monitoring technology is a cure-all, we should consider the possibility that states' payoffs from war are different from (6.1). Earlier in the paper, we considered a situation in which war was like a contest that states win, lose, or tie (3.3). If these are the appropriate payoffs from war, the

pure-strategy equilibrium of the previous proposition no longer exists. Instead, as we now show, states arm and create private information, but still do not go to war.

First, note that an equilibrium of the form $m = (m_1, m_2)$, $s = (m_1, m_2)$ must result in a tie or at least one player must be selecting $m_i = 0$. In a tie, however, a player could improve by selecting a slightly higher accumulation and announcing it. Thus, there are no pure-strategy equilibria if these are the appropriate payoffs from war. In an equilibrium in which the states are randomizing at the accumulation stage, will states reveal their strength through s_i ? One possibility is that the states are supposed to randomize and then announce the amount of capacity that they actually purchased, $s_i = m_i$. Following these announcements, sequential rationality in bargaining would result in the payoffs $1 - w_2(m_2, m_1)$ and $w_2(m_2, m_1)$ respectively. An equilibrium of this form must specify off-the-path beliefs if a state were to keep its information secret. In this conjectured equilibrium, if i deviates and selects $s_i = \phi$, then j will take this as evidence that $m_i = 0$. Following such a deviation, bargaining will break down unless i receives more than $w_i(m_i, m_j)$ from the equilibrium offer. However, given the specified belief for j , the most that i can get from a sequentially rational bargaining strategy profile is $w_i(0, m_j)$ if $i = 2$ and $1 - w_j(m_j, 0)$ if $i = 1$. Clearly, if i weakly prefers such an offer to war, then i is at least as well off avoiding the deviation to $s_i = \phi$, because under the conjectured equilibrium i gets $w_i(m_i, m_j)$ if $i = 2$ and $1 - w_j(m_j, m_i)$ if $i = 1$ and, by monotonicity, in either case this is at least as good. Thus, if i has an incentive to make this deviation, it must be because it is going to reject the offer and get the war payoff $w_i(m_i, m_j)$. In order to rule out this deviation for each level of m_i , it must be the case that i prefers the settlement from bargaining over the payoff from war. More precisely, this requires that given m_i and the belief that m_j is chosen according to the equilibrium mixed strategy, the expected payoff to bargaining is at least as high as the expected payoff to war. But since this condition is satisfied by any offer (or acceptance rule) in the bargaining protocol the deviation is not desirable. This lead us to the following conclusion

Proposition 9. *With the discontinuous war technology in 3.3 and the ability to demonstrate capacity perfectly, in equilibrium states randomize at the arming stage, reveal their strength, and reach a negotiated settlement; war occurs with probability 0.*

These results are encouraging. Unlike the analyses we presented earlier, they point to the possibility of avoiding war completely without unlikely scenarios in which war is never valuable, no matter how strong a state is relative to its opponent. While these results rely upon a particular bargaining protocol, a more general version could be developed that allows for a large class of protocols. In addition, the results having to do with the continuous payoff from war can be readily extended to necessary and sufficient conditions for pure-strategy equilibria under more general differentiable payoff functions. Extensions of this form are technical. Instead, we conclude the paper with an important and surprising robustness check.

7. Noisy Signals about Military Acquisitions

The previous section showed the benefits of being able to demonstrate military capacity perfectly: states may arm and create private information about their military capacities, yet always avoid war if statements about military acquisitions are known to be correct. This result is encouraging, given our earlier results showing that without these signals, assumed to be verified, almost all equilibria involve the creation of private information and the risk of war. However, in the real world, technologies for monitoring others' military capacity and thus verifying their claims about their capabilities are imperfect. For this reason, we now consider a model in which states obtain information about their opponent's choices of military capacity, but this information is imprecise. This situation differs in two ways from the one in the previous section. First, a state does not choose whether or not to give information about its capacity to the opponent; instead, the opponent exogenously receives a signal. Second, the signal a state receives about its adversary is noisy.

We now show that many of our earlier results about the difficulties of avoiding private information and war hold in a modified version of our model in which states observe noisy signals about each other's choices of military capacity. If instead of being able to commit to demonstrating ones strength, ($s_i = m_i$) states can only commit to allowing the other state to observe a noisy signal of strength, $s_i = m_i + \varepsilon$, where ε might be thought of as white noise, the encouraging findings of the previous section do not generalize. No matter how small

the variance of ε , if the shocks have full support and players are sufficiently patient then a peaceful equilibrium exists only under strong conditions like those presented in proposition 6. Thus, there is a disjuncture between complete demonstration of capacity, which we considered in the previous section, and noisy signals, which we consider here. Even a little bit of noise in the information a player gets about its opponent's capacity is enough to make war a possibility.

We now assume that after the states have simultaneously chosen their levels m_1 and m_2 , but before they bargain, each state i receives an exogenous noisy signal $\sigma_i \in \mathbb{R}^1$ about the other's (j 's) chosen capacity. In the event that a state plays a mixed strategy, the opponent receives a noisy signal about the realization of the mixed-strategy. We assume nothing about the distribution of the signal $F(\sigma_i|m_j)$ except that it has full support for any level of capacity m_j that the state may have chosen and that conditional on m_i, m_j the signals are independent.¹⁷ The full support assumption states that for two distinct levels m'_j and m''_j the conditional distributions $F(\cdot | m'_j)$ and $F(\cdot | m''_j)$ have the same support. This assumption requires that a state cannot "rule out" any level of capacity because of the signal it has observed. This assumption can be satisfied in settings in which the conditional distributions have arbitrarily low variance. For example (though this need not be the case), it could be that the distribution of the signals that i receives is normally distributed with a mean of m_j and variance $\varepsilon > 0$, where ε is very small.

The reason why many of the results about the difficulties of avoiding private information and war hold with partial observability is that the addition of the noisy signals $\sigma = (\sigma_1, \sigma_2)$ does not change the fact that if states acquire capacity in pure strategies, they know each other's capacity precisely at the beginning of the bargaining stage. That is, if a state knows its opponent's capacity precisely before seeing the signal, it still knows it precisely after seeing the signal. More technically, if state j acquires $m_j = m_j^1$ with probability one in equilibrium, then by Bayes' Rule, state i must believe that $m_j = m_j^1$ with probability one after seeing any σ_j , since the prior belief is that $m_j = m_j^1$ and $F(\sigma_j|m_j)$ has full support

¹⁷It would be natural to assume that the distributions $F(\cdot | m'_j)$ and $F(\cdot | m''_j)$ are ordered (in terms of likelihood ratio or first order stochastic dominance) if $m'_j < m''_j$. Our analysis is, of course, consistent with this type of assumption, but this structure is not needed for the following results.

for all m_j .

We begin again by showing that states create private information (accumulate military capacity in mixed strategies) in any equilibrium unless the states remain completely unarmed.

Proposition 10. *There are no equilibria in which the accumulations are in pure strategies with $\max\{m_i, m_j\} > 0$.*

Proof: Assume that such an equilibrium exists with efforts $\{m_i^*, m_j^*\}$. Since the equilibrium accumulations are in pure strategies and $F(\sigma_i|m_j)$ has full support for all m_j , states possess all relevant information when they begin bargaining. By condition 1, a bargain will be reached with probability one. Since state j must believe that $m_i = m_i^*$ after seeing any σ_j , a deviation to $m_i = 0$ would not affect the outcome of the bargaining protocol. Since $\beta_i > 0$, for a state with $m_i^* > 0$ such a deviation would increase its utility. ■

We next show that in the model with imperfect observability, states do not go to war if they remain completely unarmed.

Proposition 11. *In any equilibrium in which the accumulations are in pure strategies, war occurs with probability 0.*

Proof: Consider an equilibrium with pure strategy accumulations. Since the equilibrium is in pure strategy accumulations and $F(\sigma_i|m_j)$ has full support for all m_j , by Bayes' Rule, i continues to believe $m_j = m_j^*$ after seeing any σ_i and j continues to believe $m_i = m_i^*$ after seeing any σ_j . Condition 1 then implies that war does not occur. ■

Finally, we show that if states generate private information in equilibrium, there is always a positive probability that they go to war.

Proposition 12. *If war occurs with probability 0 in an equilibrium that involves no delay¹⁸ or in any equilibrium to a game with $\delta = 1$, then $\mathbf{m} = \mathbf{0}$ with probability one in this equilibrium.*

¹⁸To be clear, no delay means that following any profile of accumulations m and messages that are possible in equilibrium, the resulting bargaining strategies reach a settlement before any discounting occurs.

Proof: We proceed in steps.

Step 1: We consider an equilibrium with pure-strategy accumulations. Suppose that there is an equilibrium in which both states' accumulations are in pure strategies, at least one state's accumulation is not zero ($m_i \neq 0$), and the states go to war with probability 0. This means that on the path some offer a_i is accepted with probability 1. Since the equilibrium involves pure strategy accumulations, by Bayes' Rule, i continues to believe $m_j = m_j^*$ after seeing any σ_j and j continues to believe $m_i = m_i^*$ after seeing any σ_i . Since $\beta_i > 0$, a deviation to $m_i = 0$ would be desirable. Thus, if we are in an equilibrium with pure strategy accumulations and no deviation is desirable, it must be the case that $\mathbf{m} = \mathbf{0}$.

Step 2: Now we consider an equilibrium in which player i 's accumulation is in mixed strategies with a support containing two distinct levels, m_i' and m_i'' . Supposed that there is such an equilibrium in which the states go to war with probability 0. This means that on the path an offer is accepted with probability 1 (and we can select m_i' and m_i'' such that war occurs with probability 0 following these two accumulation levels). Since both m_i' and m_i'' are in the support of i 's equilibrium strategy, we must have $v_i' - v_i'' = \beta_i(m_i' - m_i'')$ where v_i' and v_i'' denote the expected discounted payoffs to the equilibrium settlement when i selects m_i' and m_i'' respectively. This means that $v_i' \neq v_i''$.

Step 3: Now let $\xi_i(m_i, \sigma_i)$ and $\xi_j(m_j, \sigma_j)$ denote the mappings from private information from the accumulation stage into strategies in the bargaining protocol. With this notation, we can express equilibrium expected discounted payoffs from the bargaining settlement as functions of the form $v_i(\xi_i(m_i, \sigma_i), \xi_j(m_j, \sigma_j))$ and $v_j(\xi_i(m_i, \sigma_i), \xi_j(m_j, \sigma_j))$. Since war occurs with probability 0 on the path following both m_i' and m_i'' it cannot be the case that $v_i(\xi_i(m_i', \sigma_i), \xi_j(m_j, \sigma_j)) \neq v_i(\xi_i(m_i'', \sigma_i), \xi_j(m_j, \sigma_j))$. If this inequality held, say with the former larger than the latter, then player i would have an incentive to deviate (say by playing $\xi_i(m_i', \sigma_i)$ when $m_i = m_i''$). Recall that state j would not know that i had deviated (because m_i is hidden and the support of $F(\sigma_j|m_i')$ coincides with

the support of $F(\sigma_j|m_i'')$, and thus player j 's bargaining behavior could not respond to the deviation. Thus we have shown that $v_i(\xi_i(m_i', \sigma_i), \xi_j(m_j, \sigma_j)) = v_i(\xi_i(m_i'', \sigma_i), \xi_j(m_j, \sigma_j))$.

Step 4: But since $v_i' \neq v_i''$, it must be the case that $\xi_j(m_j, \sigma_j') \neq \xi_j(m_j, \sigma_j'')$ for some realizations σ_j' and σ_j'' . Now since i does not observe σ_j and since σ_i and σ_j are independent (by construction the mixtures that players use are independent and thus the signals are unconditionally independent) it cannot be the case that $v_j(\xi_i(m_i, \sigma_i), \xi_j(m_j, \sigma_j')) \neq v_j(\xi_i(m_i, \sigma_i), \xi_j(m_j, \sigma_j''))$ for any values of m_i, σ_j, m_j . This is true because if the inequality held, j would have an incentive to deviate (this can be shown by using a very similar argument). So, holding fixed m_j , the expected discounted payoff from bargaining to j cannot be different under m_i' and m_i'' . But since war happens with probability 0, the assertion that $v_i' \neq v_i''$ contradicts the assumption that equilibrium settlements sum to 1 and the assumption that $\delta = 1$ or the equilibrium involves no delay. ■

We also note that the necessary and sufficient conditions for the existence of the unarmed, peaceful equilibrium are exactly as given in Propositions 6 and 7. To see these results, remember that in an equilibrium with $\mathbf{m} = \mathbf{0}$, since $F(\cdot|m_j)$ has full support for all m_j and the equilibrium is in pure strategies, $\mathbf{m} = \mathbf{0}$ remains known after the signals are observed. The proofs then proceed exactly as given in the previous section. (For the proof of Proposition 7 with the added noisy signals, note that any deviation that reaches settlement with probability one and involves $m_i > 0$ could be improved on by a strategy that has $m_i = 0$ and mimics this deviation because j will believe $m_i = 0$ after any signal it receives.)

Without discounting, we again rule out equilibria in which states generate private information about their military capacities and never go to war. With discounting, we cannot rule out such equilibria. While the existence and precise form of any such equilibria depend on the particular bargaining protocol, we can make several observations about their features. First, if an equilibrium of this form exists, it must involve states taking some time to reach a bargain (delay). Second, a state's (i 's) payoffs cannot be affected by the signal σ_i that it observes about the adversary's capabilities; if it were, the state always would pretend to

observe the signal that gave it the best payoff. Thus, in such an equilibrium, the noisy signals are not valuable. This finding leads to an interesting conclusion. States would not be willing to devote resources to see a noisy signal of the form considered in any equilibrium in which war occurs with probability 0. Thus, while we have not extended proposition 5 to the case of noisy signals, equilibria that involve war with probability 0 but nondeterministic arming require that states can observe signals that are meaningless to them (in the sense that what a state learns about an opponent's strength does not affect its payoff). This finding leads us to conclude that a satisfactory explanation of arms accumulation and bargaining that involves private information and costly spying must also involve a risk of war.

Third, if an equilibrium in which states generate private information and never go to war exists, the payoff of any state i that generates private information must be affected by the signal that its adversary observes about its capacity, σ_j . For a state to be willing to create uncertainty about its payoffs, it must expect a better bargain, on average, when it has invested more in military capacity; thus, the adversary's actions must be tied to the signals it receives. The second and third points together imply that an equilibrium of the noisy signals game with private information and without war must take a particular form: The signal a state receives about its adversary must affect the adversary's expected payoff without affecting its own. This is only possible if the probability that a settlement occurs in a given period is affected by the signals.

Thus, without discounting, our results about the difficulties of avoiding private information and war extend to a version of the model that includes noisy signals about the states' military accumulations – even when those signals are just a little bit noisy. Even with some ability to observe each other's accumulations, states create private information in every equilibrium except the ones in which they remain disarmed. In addition, a peaceful equilibrium exists only if it is better to be a weak state negotiating with a weak state than a superpower negotiating with an unarmed state. With discounting, we do not rule out the possibility of a peaceful equilibrium in which states create private information about their military capacities. Such an equilibrium only can exist, however, when it takes time to reach a bargain, and when (in equilibrium) getting information about an adversary's military capacity is not

valuable.

8. Conclusion

We have presented a simple model in which states acquire military capacity, bargain, and go to war only if they fail to reach an agreement. The model has no ex ante private information. If states maintain a situation of full information (their investments in military capacity are in pure strategies or they choose to reveal their military capacity through communication or bargaining), there is always a bargain they prefer to war. Yet, under very weak conditions – that the value of conflict when a state is very strong and its opponent is unarmed is higher than the value of a settlement when both states are symmetrically weak – every equilibrium involves the creation of private information, and war occurs with positive probability in every equilibrium. States behave this way because of competing incentives – the incentive to prevail in war, and the incentive to minimize military expenditures. These conclusions are quite robust; they follow from a large class of bargaining models, and from an alternative version of the model in which states get noisy signals about their adversaries’ military acquisitions.

While the substantive conclusions of the analysis are negative in the sense that completely peaceful equilibria exist only in unlikely circumstances, one important positive interpretation should be noted. The model and analysis broaden the scope of rationalist studies of security. By moving beyond a taxonomy of the types of asymmetric information and explaining the emergence of this critical feature of the international landscape, the model provides a framework from which future studies may learn how bargaining procedures, consensual bilateral agreements, and consensual international institutions can limit the scope of costly asymmetric information and investment in military capacity.

In the introduction to this paper, we noted that international institutions often are thought to reduce the likelihood of war in part by providing information to states and lessening the extent of harmful private information. Our paper points to two holes in the literature on international institutions. We find that desirable equilibria in which states reveal information and do not go to war are possible when the institution allows states to demonstrate their military capabilities perfectly (with no noise or possibility of cheating).

Regrettably, this conclusion hinges on the term "perfectly;" even a minuscule amount of noise (or doubt on the part of a state receiving a signal) undermines the effectiveness of the institutions. We might think of this conclusion as saying that "close-to-perfect" signals and information are not good enough.

Finally, states in our model begin with no private information but have incentives to acquire it. The institutions literature does not explain how institutions can overcome states' incentives to acquire additional private information once international institutions (hypothetically) have revealed all existing private information. Thus, a logical next step is to investigate whether any voluntary monitoring schemes can ameliorate the incentives for arming and secrecy. Overall, we hope that a broader investigation of international organizations will help explain what types of mechanisms can reduce the likelihood of military conflict.

9. Appendix: An Equilibrium in which States Create Private Information

We show in the text that, unless a strong condition is satisfied, the only possible equilibria of this game are ones in which states generate private information (mix over levels of military capacity) and go to war with positive probability. While it is not the main purpose of this paper to characterize particular equilibria, we characterize here one type of equilibrium of the game with the “take-it-or-leave it” bargaining protocol in which the states generate private information. In this equilibrium, the players mix over levels of military accumulation. The first state’s offer is constant in its level of accumulation, so that the offer reveals no information to the second state about the first state’s capabilities. The second state always rejects the offer, so that the states always go to war.

We denote the mixed accumulation strategies by $F_1(\cdot)$ and $F_2(\cdot)$ and look for an equilibrium in which the support of state i ’s accumulation strategy is $[0, \bar{m}_i]$.¹⁹ Remember that with this bargaining protocol the first state makes an offer, a_1 . Either the second state accepts the offer, the first state’s payoff is a_1 and the second state’s payoff is $a_2 = 1 - a_1$, or the second state rejects the offer and the states go to war. We look for an equilibrium in which state 1’s offer a_1 is constant in its military accumulation m_1 (and off-the-path beliefs are constructed below), so that its offer is completely uninformative. If the offer is uninformative, then the vetoer, state 2, will accept an offer a_1 iff

$$1 - a_1 \geq \int w_2(m_2, m_1) dF_1(m_1).$$

Solving for the minimal value of m_2 that satisfies this inequality yields the rule: accept if $m_2 \leq m_2^*(a_1) := \sup\{m_2 : 1 - a_1 \leq \int w_2(m_1, m_2) dF_1(m_1)\}$. Let a_1^* be the offer that the first state makes in equilibrium. We cannot have an equilibrium with $m_2^*(a_1^*)$ in the interior of the support of F_2 . This is true because in such an equilibrium 2 would have an incentive to deviate in the first stage by putting $F_2(m_2^*(a_1^*))$ mass on 0 and no density on the interval

¹⁹This means that player i selects m_i from a distribution function that is strictly increasing on the interval $[0, \bar{m}_i]$.

$(0, m_2^*(a_1^*))$. This deviation is desirable because it costs less and capacity between 0 and $m_2^*(a_1^*)$ has no value as state 2 never goes to war if her capacity is in this interval. This conclusion implies that, in such an equilibrium, we need to have $m_2^*(a_1^*) \in \{0, \bar{m}_2\}$ – that is, state 2’s decision about acceptance when a_1^* is offered is unrelated to its investment in capacity. If player 1 makes an offer that player 2 accepts with positive probability regardless of its chosen level of capacity, we cannot have an equilibrium in which $m_2 > 0$ with positive probability.

Accordingly, in the equilibrium, the first state must make an offer that the second state always rejects, regardless of the capacity the second state has acquired. This requires that

$$1 - a_1^* \leq \int w_2(0, m_1) dF_1(m_1).$$

By assumption 1, such an offer exists.

We need to verify that there is no profitable deviation for the proposer (no alternative offer that would make the proposer better off than its posited equilibrium strategy, given the off-the-path beliefs). The expected utility of the offer a_1^* to the proposer is

$$\int w_1(m_1, m_2) dF_2(m_2).$$

The best case of off-the-path beliefs to support this conjectured equilibrium has the veto player, 2, believing that the proposer is weak after an alternative proposal ($a_1 \neq a_2^*$); since player 2 would rather fight a weak player 1, it will want to reject most deviant offers. Thus, suppose that following $a_1 \neq a_1^*$ the vetoer places probability 1 on $m_1 = 0$. In this case, a profitable deviation, a_1' exists iff (1) it would be accepted by a vetoer with some level of capacity, m_2 , i.e.,

$$1 - a_1' > w_2(m_2, 0)$$

and (2) the proposer prefers the lottery over acceptance (which occurs when 2 has a low value of m_2) and war (which happens when 2 has a high value of m_2) to war with all possible types – which happens if 1 does not deviate. This preference requires that state 1 prefer getting a_1' to

having a war with the types that would accept a'_1 . Let $m'_2(a'_1) = \sup\{m_2 : 1 - a \geq w_2(m_2, 0)\}$ denote the highest type vetoer that will accept offer a'_1 with these beliefs. Accordingly, for the deviation to be desirable we need

$$a'_1 > \frac{1}{F_2(m'_2(a'_1))} \int_0^{m'_2(a'_1)} w_1(m_1, m_2) dF_2(m_2)$$

for some m_1 .²⁰

These two conditions imply that a profitable deviation exists iff for some m_1 there is an a'_1 satisfying

$$1 - w_2(0, 0) > a'_1 > \frac{1}{F_2(m'_2(a'_1))} \int_0^{m'_2(a'_1)} w_1(m_1, m_2) dF_2(m_2).$$

The left-most term applies because if $1 - a'_1 > w_2(m_2, 0)$ for some m_2 then $1 - a'_1 > w_2(0, 0)$. Intuitively, the presence of a desirable deviation, a'_1 , requires that the first state (player 1) can be sure to get enough strong types to take the bargain $1 - a'_1$. This hinges on relative comparisons of w_1 and w_2 . When the vetoer gets relatively low values from war, then such a deviation is profitable. In contrast, if the vetoer gets relatively high values of war, then such a deviation is not desirable. We can go one step further on the condition. Since $m'_2(\cdot)$ is a decreasing function and the integrand is decreasing in m_2 (condition 1), the right-hand side of the inequality is increasing in a'_1 . Thus, the existence of such an a'_1 requires that for some m_1

$$1 - w_2(0, 0) > \frac{1}{F_2(m'_2(0))} \int_0^{m'_2(0)} w_1(m_1, m_2) dF_2(m_2).$$

Since condition 2 implies that $w_1(\mathbf{m}) < 1$ (which implies that $F_2(m'_2(0)) = 1$) the above is equivalent to: for some m_1

$$1 > w_2(0, 0) + \int w_1(m_1, m_2) dF_2(m_2).$$

²⁰Note that in characterizing a PBE, we must rule out deviations in which 1 selects a particular level of m_1 and bargains in a particular way. Consistency of beliefs does not require that off the path beliefs are consistent with the type most likely to deviate. Refinements like universal divinity address issues of this form, but we focus on unrefined PBE.

Accordingly, a sufficient condition for the existence of pooling in the take-it-or-leave-it bargaining protocol is:

$$1 \leq w_2(0, 0) + \int w_1(m_1, m_2) dF_2(m_2) \text{ for every } m_1, \quad (\text{A1})$$

This condition is compatible with assumptions 1 and 2. In the case of the war payoffs that are discontinuous and symmetric, given by 3.3, the condition requires that F_1 first-order stochastically dominate F_2 .

Finally, if pooling occurs in the bargaining setting, then the expected utility to state i from accumulation m_i given the strategy $F_j(\cdot)$ is

$$\int w_i(m_i, m_j) dF_j(m_j) - \beta_i m_i.$$

Indifference requires that the above expression is constant in m_i . In the differentiable case this requires that F_j solve

$$\int \frac{\partial w_i(m_i, m_j)}{\partial m_i} dF_j(m_j) = \beta_i. \quad (\text{A2})$$

Thus, given the linear costs, the equilibrium mixtures over capital investment must be of a form that makes state i 's expected payoff to war linear in her accumulation.

Thus, when condition (A1) is satisfied and the $w_i(\cdot)$ functions are differentiable, the game has an equilibrium in which states mix over levels of accumulation of military capacity according to the implicit condition (A2), choose not to reveal their levels of capacity through their bargaining strategies, and go to war (with probability 1). That is, states create private information about their military capacity and go to war.

References

- Banks, J. S. (1990, August). Equilibrium behavior in crisis bargaining games. American Journal of Political Science 34(3), 599–614.
- Bendor, J. and T. H. Hammond (1992). Rethinking allison’s models. American Political Science Review 86(2), 301–22.
- Blainey, G. (1973). The Causes of War. New York: The Free Press.
- Fearon, J. D. (1992). Threats to Use Force: Costly Signals and Bargaining in International Crises. Ph. D. thesis, University of California, Berkeley.
- Fearon, J. D. (1995). Rationalist explanations for war. International Organization 49, 379–414.
- Fey, M. and K. W. Ramsay (2005). Mutual optimism and war.
- Fudenberg, D. and J. Tirole (1990). Moral hazard and renegotiation in agency contracts. Econometrica 58(6), 1279–1319.
- Jervis, R. (1978, January). Cooperation under the security dilemma. World Politics 30(2), 167–214.
- Keohane, R. O. (1984). After Hegemony. Princeton: Princeton University Press.
- Kydd, A. (2000, November). Arms races and arms control: Modeling the hawk perspective. American Journal of Political Science 44(2), 228–244.
- Levontoglu, B. and A. Tarar (2005). War and incomplete information. paper presented at the Annual Meeting of the American Political Science Association.
- Morrow, J. D. (1989a). Capabilities, uncertainty, and resolve: A limited information model of crisis bargaining. American Journal of Political Science 33(4), 941–972.
- Morrow, J. D. (1989b). A twist of truth: A reexamination of the effects of arms races on the occurrence of war. Journal of Conflict Resolution 33, 500–529.

- Palfrey, T. R. and H. Rosenthal (1985). Voter participation and strategic uncertainty. American Political Science Review 79(1), 62–78.
- Powell, R. (1993). Guns, butter, anarchy. American Political Science Review 87, 115–132.
- Powell, R. (1999). In the Shadow of Power. Princeton: Princeton University Press.
- Powell, R. (2004a). Bargaining and learning while fighting. American Journal of Political Science 48(2), 344–361.
- Powell, R. (2004b, May). The inefficient use of power: Costly conflict with complete information. American Political Science Review 98(2), 231–242.
- Schultz, K. (1998). Domestic opposition and signaling in international crises. American Political Science Review 92(4), 829–844.
- Slantchev, B. (2003, February). The power to hurt: Costly conflict with completely informed states. American Political Science Review 97, 123–133.
- Slantchev, B. (2005). Military coercion in interstate crises. forthcoming in the American Political Science Review, 99:4 .
- Wagner, R. H. (2000, July). Bargaining and war. American Journal of Political Science 44, 469–84.