Research Note: Innovation, productive power, and war.

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Abstract

Strategic research on technology and war mainly models innovation as a shock to relative power. But modern technologies are built to raised productivity (i.e. how much states can extract from what they contest). Does the basic logic of innovation, arming and war hold up once we account for productivity gains? I show that even in a simplistic, complete-information model of innovation, bargaining and war, productivity gains substantially alter the basic results past theory find. Deterrence can fail with complete information, creating a risk of war. But productivity gains also create strong incentives for welfare-enhancing innovation in peace. These differences in the simplistic model carry through to affect extensions with imperfect monitoring and costly peace. For example, states will invest in innovation that shifts power against them, or openly admit to tension-causing innovation that they could plausibly conceal. States are also disadvantaged by arms control agreements that prevent innovation, and find monitoring protocols less useful. These results clarify modern tensions that US defense planners wrestle with that existing theories cannot explain in areas including UAS, AI, or cyber.

The world is on the cusp of revolutionary innovations in AI (Garfinkel and Dafoe, 2019), 3D-printing (Volpe, 2019), robotics (Lin-Greenberg, 2022), gene-editing (Pratt, 2023), and battery power. What are their implications for international conflict? The strategic literature on technology and war assumes innovation affects relative power (eg Debs and Monteiro, 2014; Spaniel, 2019; Schram, 2020). Tensions arise from imperfect monitoring (Wolford, Reiter, and Carrubba, 2011; Bas and Coe, 2016), or if states must spend a lot to sustain their arms in peace (Powell, 2010). Policy-focused analysts rely on these insights to offset security concerns from modern innovations (Kerr, 2023; SCSP, 2022; Kania, 2020). This seems reasonable because these theories well-explain patterns of innovation, arming, and war that surround historical innovations (eg Miller, 2014; Bell, 2015; Sechser and Fuhrmann, 2017).

But innovations that concern defense planners today are expected to raise productivity of contested issues as much, or more, than shift power. Modern innovations spread quickly, allowing many to enjoy these productivity gains (Horowitz, 2010; Fuhrmann and Horowitz, 2017). Existing theories of innovation and war do not account for these productivity implications. Would the classic predictions hold up if they did?

Following Sechser, Narang, and Talmadge (2019)'s approach, this theory note develops a strategic model that accounts for the productivity implications of modern innovations. To start, I add productivity gains to the simplest, two-period, complete information model of innovation and war. Even in this simplistic model, productivity gains substantially alter strategic incentives in two ways. First, productivity gains enhance incentives for innovation in ways that shifting power cannot. In standard theories, a state's expectation of larger offers tomorrow caused by shifting power, is off-set by smaller concessions today (Powell, 1999). This disincentivizes costly innovation in peace unless bargaining is constrained (Debs and Monteiro, 2014). Productivity gains are harder to exploit in bargaining because they accrue in both peace or war. As a result, we can support innovation under surprisingly broad conditions. Second, productivity gains exacerbate incentives for preventive war caused by shifting power because all states expect enormous gains from the amount they control tomorrow (similar to Powell, 2006; Monteiro and Debs, 2020). This makes states sensitive to small changes in the expected size of future concessions. If innovation means that the future is incredibly prosperous, then there is not enough wealth today to compensate for even small losses caused by small (non-zero) power shifts. As a result, a novel equilibrium that includes deterrence failure, innovation and war.

I extend this simplistic model twice to match two main strands of research into innovation, arms racing, and war: monitoring problems (eg Arena and Wolford, 2012; Coe and Vaynman, 2019) and inefficient militarization (eg Powell, 2010). Productivity implications alters the conventional results that these theories produce. Against the standard monitoring logic, the ease of monitoring a rival's innovations holds no implications for arms control, and imposes no barriers upon it. Against the costly peace logic, states will invest in costly research that shifts power against them to recover productivity gains. I use modern empirical examples to illustrate how (a) the standard logics continue to apply for innovations that do not raise productivity that much; and (b) the mechanisms that my theory generates better explain critical innovations that raise productivity and shift power.

1 Innovation and Conflict: what has changed

Historically, the national security apparatus has funded research into innovations designed to affect war-fighting. These innovations include nuclear weapons, submarines, the Iron-clad ships, and the satellite.[1] Following this historical trend, past theories of innovation and war have focused on how innovation shifts power (eg Debs and Monteiro, 2014; Bas and Coe, 2016). I argue that modern innovations that interest defense planners hold two kinds of productivity implications. I focus on two implications that are not fully captured by existing theories of innovation and international competition. First, defense planners today expect that modern innovations will raise productivity of contested issues. Holding the state of technology constant the productivity of a territory is the amount of value a state can extract from it.[2] I define a technology's productivity implications as the extent that a new innovation alters the amount of value a state can extract from a contested territory. For example, the green revolutions raised crop yields by almost 300% (Pingali, 2012). Once those technologies became available they tripled the amount states can extract from the Golan Heights, Niger Delta, or other fertile lands that are contested. This is true whether the states won the territory outright in war, or if they negotiated it in peace.

To be clear, productivity is different from absolute gains (Powell, 1991), or the guns butter trade

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[1] Even though the satellite had huge economic implications, program officers at the time did not anticipate them. In fact, the Air Force discontinued the CORONA program because of concerns that Congress would perceive it as wasteful spending. CIA picked up the program partly because their budgeting was classified.

[2] This fits the economic definition of productivity as the rate of output per unit input (Kendrick, 1961).

off (Powell, 1993), which all assume each state holds a private allocation of resources that it can choose to consume for a direct profit, invest in military power, or invest in trade. Absolute gains raise each state's private resource allocation. Also to be clear, not all modern military investment yields productivity implications. Governments still invests heavily in novel weapons systems (e.g, the F-22, or India's investment in the Agni-VI) that mainly affect military power. I fully expect the logic of standard arms racing and innovation theory to apply to these cases.

Second, the role that the government plays in the innovation process has changed substantially in the post-Cold War world. The government can still influences whether certain technologies are developed because it funds early stage innovations that are too financially risky for firms to pursue. However, the Government holds less control over who can exploit these innovations once the concept is proven. Thus, in modern times, a rival state can adopt a technology to both extract value from territory in peace, and enhance their war fighting technology. As Brown and Singh (2018) argue, even when the US government advances the innovations of US firms, "foreign investors, including those from China, are able to invest in the newest and most relevant technologies gaining experience with those technologies at the same rate as the U.S. does."

For example, In-Q-tel, the CIA's hedge fund, provides angel investing to US firms that pursue unprofitably risky innovations with vital social welfare and national security implications (Yannuzzi, 2000). In 2005 alone, In-Q-Tel invested $150 Million in 90 companies. Their portfolio covers bio-engineering, agriculture, additive manufacturing, renewable energies, batteries, cyber security and computing power. In-Q-Tel often funds unattractive financial investments. In 2007 "Forterra Systems Inc., a California startup focused on virtual reality, was in need of money and its products didn't have much commercial appeal. Then funds came in from a source based far from Silicon Valley: In-Q-Tel"(Paletta, 2016). Of course, In-Q-Tel hopes that the firms it funds take on classified contracts later in their evolution. However, once a US firm makes a major discovery, US adversaries such as China, Iran and Russia quickly learn that innovation has happened (Yannuzzi, 2000).

IARPA and DARPA similarly provide seed funding to many early-stage private sector projects (Matheny, 2016). For example, the integrated circuits of semi-conductors that make-up a micro-chip were first developed in the 1960s. But researchers had not constructed chips that were powerful enough for modern computing. The barrier was in developing machine-tools that could efficiently place an enormous number of semiconductors on a single circuit board. It was not clear how to build these machine-tools, and the concepts were too expensive for private firms to pursue. The Department of Defense funded the development of the machine-tools so they could purchase approximately 10 high-powered chips. Once the machine tools were designed and built, it was easy to produce many advanced micro-chips. Within a year, Japan, had developed a similar technology (NRC, 2009).[3]

To be clear, scholars have illustrates the perverse affects of productivity gains in other strategic contexts. In the comparative context, Robinson, Acemoglu, and Johnson (2005) show increasing the pie causes rebellion in the context of elite-mass bargaining. But they require a hold-up problem to generate bargaining failure. We do not observe the hold-up problem in the international context I study. Bell and Wolford (2014); Carey, Bell, Ritter, and Wolford (2022) similarly examine the implications of oil discovery on different coups and domestic repression. My theory also holds insight for territories rich in natural resources. But the logic is different in the internationalist innovation context. It is hard for discovery theories to explain why recent battery innovations have only now raised the risk of conflict over Cobalt mines in the Congo. These mines were constructed 100 years ago, and even today there is no pre-existing hold-up problem between the rebels and the central government. My theory explores if battery innovation causes tension because it independently made it easier for rebels to operate away from a base, and made cobalt mining more lucrative.

Others study the internationalist context but model productivity gains from investments in economic infrastructure, not innovation. Powell (2006) includes productivity gains, but omits shifting power. He finds that if exogenous shifts in pie are a sufficient cause of war. I show that once we introduce features common in innovation models (e.g. delayed, costly investment) that raising the value alone is insufficient to cause war. Monteiro and Debs (2020) examine economic exchange between a hegemon and a local state. They assume that the hegemon can chose to extract resources from a rival's local economy after bargaining is complete. This extra step, which does not apply in modern Sino-American contests and other innovation cases, generates the commitment problem that drives their mechanism. They also assume states face investment trades-offs between the military and productive value of investments (appropriate for investments in improving infrastructure, or building many tanks). But investments in novel innovations do both. Also, they model productive

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[3] The evolution of this public-private model is not unique to the United States. "Chinese participation in venture-backed startups is at a record level of 10-16% of all venture deals" between 2015 and 2017 (Brown and Singh, 2018, foreword).

investments as state-specific, private goods. As just argued, many modern innovations generate knowledge that many states can utilize for productivity gains.

Putting it altogether, these theories give us important clues that productivity gains can hold concerning implications for national security. But the implications are not clear for innovation and international bargaining in the shadow of war. After all, states can anticipate the foreign policy consequences of their innovations. When they believe that innovation will cause war it should deter them (Debs and Monteiro, 2014). If a state profits substantially from costly innovation, then the other may extract that value from the foreign policy contest (Powell, 1999). This may diminish incentives for innovation in the first place. Different still, states may see no need for war because they gain so much from peace (Glaser, 2010).

2 Strategic Implications

In what follows, I show that productivity substantially alters our predictions in two steps. First, I introduce productivity implications into a simplistic two-period, complete information model of innovation and war. Second, I consider two empirically salient extensions commonly studied in the literature.

2.1 Simplistic model

I study a bargaining model of war an innovation between A (she) and B (he). It unfolds over two periods. I subscript period-relevant variables as $t \in 1, 2$. I model national security implications of innovation as increasing A's ability to win at war. Therefore, if A invests, A's probability of victory shifts over time from $p_1 = p \to p_2 = p + \Delta$ (the shift in power caused by innovation is Δ). I model the productivity implications of innovation as follows. We assume that the initial pie is worth $\pi_1 = 1$, and the value of the pie in the second period is worth $\pi_2 = \pi \geq 1$. Finally, I assume that A incurs a cost of innovation $m \geq 0$. If A chooses not to invest in a novel innovation, then $p_1 = p_2, \pi_1 = \pi_2 = 1$.

The sequence of moves in the first period is as follows. A decides to invest in a novel technology or not. Regardless of A's choice, B makes an offer q_t (the game continues) or selects war (game moves to war sub-game). A accepts B's offer (players accrue period 1 payoffs and period 2 starts)

Table 1: Utilities

	Peace	1st period war	2nd period war.
A	$q_1 + \delta(q_2\pi_2) - rm$	$p_1 - w + \delta(p_1\pi_2 - w) - rm$	$q_1 + \delta(p_2\pi_2 - w) - rm$
B	$1 - q_1 + \delta((1 - q_2)\pi_2)$	$(1 - p_1) - w + \delta((1 - p_1)\pi_2 - w)$	$1 - q_1 + \delta((1 - p_2)\pi_2 - w)$

Note: q_1, q_2 are offers, chosen strategically. p_2, π_2 depend on both innovation, and war choices. r is an indicator function equal to 1 if A selects research.

or selects war (game moves to war sub-game). Period 2 is identical except A cannot invest in a novel technology.[4]

War declared at t triggers a costly lottery that A wins with probability p_t and B wins with $1 - p_t$. Players pay a common cost w for war. I restrict my attention $p_1 - w, 1 - p_1 - w > 0$. to prevent some corner conditions in the technical analysis.

I make the standard assumption that war is a costly lottery, and the winner controls the contested issue henceforth (eg Powell, 1999; Spaniel, 2019; Debs and Monteiro, 2014). These assumptions are substantively appealing for two reasons. First, once a state decisively wins a war they consolidate power over a territory, or drive political change in the rival, and this robs their rival of a second opportunity to fight.[5] Second, even in limited conflicts p represents a pre-war *expectation* of victory. There is uncertainty over who will win because we do not know how two militaries will interact in battle. But this information is learned in battle. Thus, once a war is fought, states dramatically alter their expectations about future wars. By contrast, and as detailed above, I still assume that the productivity value of research persists after war, because welfare enhancing innovations creates technology and knowledge that states can utilize if the win in war, or if they negotiate in peace.

Turning to payoffs. A's ideal division of the issue is 1 and B's is 0. Each player's utility from peace is the distance from their ideal division to the agreed settlement (I notate a settlement q_t) weighted by the productive value of the issue in dispute (π_t). Player's accrue utility at the end of each period and, in the first period, discount second period utilities by δ. Table 1 describes first period expected utilities.

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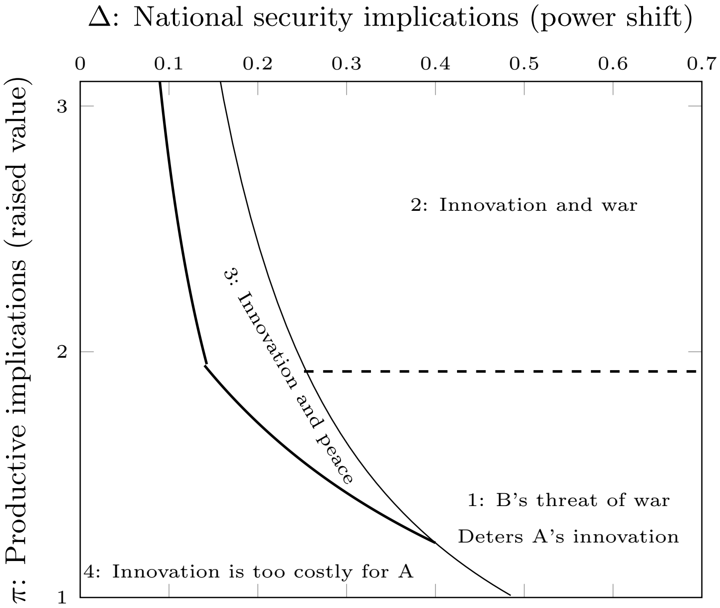
[4] This is without loss of generality because second period investment is always off-path.

[5] Some empiricists analyze targeted strikes (Kreps and Fuhrmann, 2011). While an appropriate interpretation of conflict in some models. It is inconsistent with models of war that assume the victor gets the contested issue (including any application of Fearon, 1995) because targeted strikes do not directly force concessions.

Figure 1: Equilibria as a function of the effects of innovation



2.1.1 Analysis

I solve for subgame perfect equilibria (SPE). See Appendix A.1 for technical details. Table 2 summarizes the four, unique, SPE the cover the entire parameter space. As Figure 1 plots these equilibribria as a function of technology's two main effects: productivity and shifting power. Three of these equilibria appear in the classic model: A does not want to invest, B 's threat of war deters A, A innovates and B makes a peaceful offer. As is standard, we observe the three classic results under expected parameter-ranges when the productivity gains are low. But once productivity gains are sufficiently large, a threshold emerges (the dashed line). Above this line, incentives shift substantially. As a result, we never observe deterrence. Rather, a novel equilibrium arises wherein deterrence fails, leading to innovation and war. Noticed the dashed line is horizontal. This means that B's incentive for war is increasing in productivity gains holding the rate of shifting power constant. First, I describe the core logic behind the novel result (innovation and war) from both states' perspectives. Second, I explain important changes in the logic of well-known equilibria that I can still sustain when productivity gains are large.

To start, we characterize B's incentive for war.

Table 2: Description of all equilibria

	Description	B's 1st period strategy	A's 1st period strategy.
1	War deters innovation	B fights iff A invests	A is motivated to innovate by the shift in military power. But A knows that research will trigger war. Therefore, A does not innovate.
2	Innovation, war	B fights iff A invests	A is motivated to innovate to both shift power and raise the value of the issue in dispute. A invests knowing that it will trigger war, because the productive gains are large.
3	Innovation, peace.	B always offers.	A weighs the cost of innovation against the gains, and decides to innovate.
4	A doesn't want to innovate	B always offers.	A weighs the cost of innovation against the gains, and decides not innovation.

Result 1. When a novel technology will shift power in A's favor at least a little bit ($\Delta > 0$), then B's incentives for preventive war are strictly increasing productive potential of technology. When

$$\Delta\pi > \frac{p + w(1+2\delta)}{\delta} \tag{1}$$

holds, B prefers preventive war, to letting A innovate in peace.

If power shifts against B by Δ, then B expect to get Δ less of the issue in the second period. How much B cares about conceding that additional amount is moderated by how much B can extract from the issue. The more that B extracts (π_2 is larger), the more B is sensitive to what she will be forced to give up. As a result, the more B must compensate A in the present to make up for the future loss. If a novel technology is expected to revolutionize economic productivity, then the future value of the issue in dispute dwarfs the present value of that issue. There is simply not enough present day value to compensate B for B's expected future loss.[6]

A closer look at equation 1 yields an important insight. Against models that study exogenous shifts in productivity (Powell, 2006), productive gains require power shifts (i.e., $\Delta > 0$) to cause war. The reason is that productivity amplifies incentives for war holding the rate of shifting power constant. This amplification affect could explain why rapid power shifts are not necessary for war when productivity gains are large. When productivity gains are large, create incentives for war so long as they hold even minimal affects on expectations for victory in war.

Of course, this does not mean war is assured. The conventional result is that war never appears on the path with complete information because B's threat of war deters A's innovation (Debs and Monteiro, 2014). Thus, to confirm that we should expect to see innovation and war, we need to

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[6] The result is different from Powell (2006) in that productivity gains are not a sufficient cause of war. They require at least a minor shift in power.

also establish that A would invest knowing that it will trigger war.

Result 2: Deterrence depends on the productivity implications of national security innovation. If a technology shock will shift power by so much that B's threat of preventive war is credible (condition 1 is satisfied), then deterrence hinges in the following condition:

$$\pi > \frac{m}{\delta p} + 1 \tag{2}$$

- When it is violated, and consistent with Debs and Monteiro (2014) and others, A is deterred by B's threat, and we see neither war nor innovation.
- When it holds, deterrence fails. A pursues a novel innovation and B enacts preventive war.

Why is A willing to research and face preventive war, given that A is unable to benefit from the shift in power that technology will generate? The reason is that innovation raises the amount that both states can extract in peace, or following victory in war. A is willing to incur a research cost and fight a war if she expects that technology will dramatically increase the productive potential of the issue in dispute. Innovation creates wealth for future generations so that states will prefer to pursue it and raise the risk of war.

There are several interesting features of condition 2. First, war is increasing in the productive gains of the technology shock (π). This is troubling because B's incentives for war are also increasing in π. As visualized in Figure 1, it follows that when the productive and national security implications of technology are both high, then the world is dangerous: B has an incentive to fight, A has an incentive to invest and face war. Second, condition 2 does not depend on shifting power (Δ) because war prevents power from shifting and so players do not factor this in. Third, the condition is increasing in the initial distribution of power (p_1). The reason is that A's profits from the increased productive power of the contested issue if A wins in war. If A does not invest, A does not derive these benefits. Thus, the more A expects to win, the more A wants to raise the productive power of the issue she will get.

Before moving on, I want to emphasize that high productivity also influences the logic of well-known peaceful equilibria. In models that do not account for productivity gains, A faces strong disincentives to invest if B will make a peaceful offer. If A chooses to innovate, both states anticipate a power shift in the second period. B exploits this by offering A less in the first period. As a result, at the moment when A considers innovation to shift power, A anticipates that she will pay the cost (m), but knows that B will extract her expected future gains in the present bargain. As a result, A never selects innovation. This technical result is substantively unattractive because we frequently observe national security research and innovation. To avoid it, most theories either focusing on the substantively rare case where B's first period offer is 0, artificially constrain first-period bargaining (such as an immovable status quo) (Coe, 2018; Powell, 1999), or assume a unilateral step after bargaining.[7] But absent these constraints researchers cannot easily sustain innovation and peace. This basic challenge is visualized in Figure 1. Unlike other models, I place no constraints on bargaining. Therefore, I cannot support innovation and peace when there are no productivity gains ($\pi = 1$).[8] But you will also notice that I can sustain innovation and peace when $\pi > 1$.

Result 3: Innovation (v. no innovation) in peacetime is always possible when productivity gains are high. B cannot rob A of future productivity gains through first period bargaining. Thus, as the productivity gains increase, A will innovate absent any constraints on B's offer. A's incentives to innovate in peacetime are characterized by: $m < \delta p(\pi - 1)$.

Like the classic result, B can rob A of all the value that comes from the shift in power. This is why Δ does not affect A's incentive to innovate. But unlike the standard result, B cannot rob A of the productivity gains ($\pi - 1$) because A can utilize technologies to extract value from contested goods whether A wins them in war, or negotiates them in peace. This result follows based on my substantively motivated assumption that states can utilize innovation to extract value under a broad range of conditions. As noted above, this assumption is also necessary to sustain innovation and war.[9] Thus, changes in the practice of innovation that make the productivity gains available to all present a double-edged sword. On the one hand, they can exacerbate incentives for war. But on the other, they generate stronger incentives for states to innovate in the first place. If these goods were private, we would see neither war nor innovation.

2.1.2 Robustness: War damages the pie

One concern is that war damages a contested territory. This may reduce incentives for war. Appendix A.3 assumes that war has a fixed cost (w) and also damages the pie by $\theta < 1$. Consistent with this intuition, when war severely damages the productivity gains (θ is small) we cannot sustain war in equilibrium. However, B can also explain the expectation of damage caused by war to extract

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[7] Even though they allow for productivity gains, Monteiro and Debs (2020) assume those gains are private, and this causes a similar result.

[8] I focus on conditions where B's first period offer must exceed 0.

[9] We can sustain similar results if productivity gains are part-private, meaning that one state accrues more productivity than the other from innovation.

a larger concession. Therefore when the damage caused by war is severe, we also never observe costly innovation. Thus, in cases where we observe innovation into highly productive technologies, we should expect a heightened risk of war.

It is also notable that the damage to *future productivity* may be limited in critical cases. For example, Saddam Hussein set Kuwaiti oil fields on fire to destroy their value. Despite his best efforts, he destroyed less than 1% of Kuwait's reserve.[10] These limits also apply even to especially destructive wars. For example, citizens fled manufacturing cities across Europe during the Second World War. But after the war finished, citizens often re-populated the same cities, returning the productive value to them for the victors to extract wealth from. When they didn't, the Soviets successfully patriated German scientists (and industrial machines) and forced them to advance the Soviet economy (Siddiqi, 2009). Of course, war causes damage. But putting these empirical and theoretical concerns together, that damage may be appropriately modeled as a large fixed-cost (w, in my model).

2.2 Re-visiting common extensions

The core model illustrates a core strategic logic given the simplest set of assumptions. A vast literature complicates this basic framework to yield more realistic predictions. But these more specific theories all rest on the mechanisms generated by the core model. I have just shown that adapting the core model to account for productivity gains creates new strategic dynamics. This raises a question: Do the empirical predictions that follow in more realistic models continue to apply when productivity gains are large? In what follows, I re-visit two strands of research into innovation and war: monitoring problems, and inefficiencies cause by peace. Neither extension I report exhaustively tests the nuanced arguments made in these vast literature. But each extension does show that key features of the mechanisms required to support monitoring problems and the costly peace do not bare out when productivity gains are large.

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[10] `https://www.health.mil/Military-Health-Topics/Health-Readiness/Environmental-Exposures/GulfLINK/The-Gulf-War-Story`.

2.2.1 Investments necessary to sustain your position in peace

One set of studies examine the peace-time costs of innovation to generate two novel results. First, states fight to avoid the costs of arming when the inefficiencies created by arming (m, in my model) exceed the costs of war (w, in my model) (eg Powell, 2010). Second, states may offer foreign policy concessions to disincentives their rival from arming when power shifts are moderate, and states can lock in a deal that will survive in future periods (eg Spaniel, 2019).

These theories are united by a key (and reasonable) insight: like war, peace-time militarization is costly. But modern innovations both costs upfront research, and raises future productivity.[11] Can these productivity gains off-set concerns about inefficient militarization?

Each costly peace argument relies on a specific set of substantively motivated assumptions to yield its specific result. I cannot consider all of them directly. In Appendix A.2.2, I model an extreme case that generates incentives that should not arise in any of them. I assume that B has the option of costly research into an innovation that will shift power against him. Thus, if B chooses to innovate, he pays an upfront cost today, and expects a smaller offer tomorrow. In any costly peace theory, B would never invest under this condition. Even in this extreme case, I show that when the productivity gains are large, B will actively pursue costly innovations that shift power against himself. The reason is simple. Wars and grand bargains are designed to avoid the costs of peace. But when research creates innovation, it generates an unappreciated benefit. When the productivity gains are large, states prefer to incur all the costs that innovation can carry rather than live in the dark ages (a world without advanced technologies).

This insight sheds light on the United States' recent choice to re-interpret the Missile Technology Control Regime's (MTCR) implications for unmanned aerial systems (UAS). The MTCR's purpose is to control the spread of technologies that could deliver weapons of mass destruction (Feickert, 2003). It is designed to deal with existing and emerging technologies that are critical for advanced delivery (Brockmann, Bromley, and Héau, 2022, p24). Schedule 1 systems are the most tightly controlled. Members are not allowed to sell these technologies to any entity outside of the other

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[11] I argued above that In-Q-tel, etc. invest in technology that is too financially risky for a private firm to pursue. Thus, one might then wonder if the productivity gains ever are large relative to the research costs? There is a nuance here. Firms are interested in private profit. The government is interested in social welfare. This includes the overall economic growth distributed across all firms that can use the innovation, and healthcare or social benefits that may accrue.

suppliers, even if those outside entities have developed this technology on their own (Feickert, 2003). Schedule 1 systems initially included the key components (and full systems) useful for constructing ICBM, cruise missiles and certain IRBM missiles, as well as UAS with a ranges beyond 300km.[12] Analysts agree that the uncontrolled sales of all these weapons, including UAS, disadvantages powerful states in possession of WMD technology relative to agents that seek out WMD systems (Feickert, 2003). Despite this fact, the US began to discuss downgrading UAS systems around 2012. In 2018 the US first formally motioned to move UAS to schedule 2, and remove range restrictions. In 2020, the US unilaterally interpreted slower UAS to constitute a schedule 2 system (Brockmann et al., 2022; Kerr, 2023). This policy persists with the change in administration (Kerr, 2023). Other states have followed the US interpretation.

Why would the US promote the transfer of weapons technologies that they believe can advantage their adversaries? Proponents of change explain that "the obligations generated by MTCR membership are placing unfair or self-defeating restraints on US arms exports" (Brockmann et al., 2022, p23). The reason is that many non-member states, including China and Pakistan, sell these systems openly. Restricting UAS gives outsized control over the nature of UAS proliferation to MTCR non-members (Penney, 2020). Critics have pushed back asserting that purchasers "could convert some types of UAS into cruise missiles," and that "hostile governments or non-state actors could use UAS for disseminating chemical and biological agents" (Kerr, 2023). But most importantly, they see relaxing the restrictions on UAS "could legitimize a future MTCR decision to relax controls on conventionally armed Category I ballistic and cruise missiles" (Kerr, 2023). After all, it is also true that non-regime members have developed cruise missiles and ICBMs. Any MTCR member could make the same argument to ease restrictions on these systems.

My theory expects that MTCR members will overturn restrictions that will shift power against them when the productivity gains grow large. Industry experts argue that a confluence of advances in AI, robotics, wireless internet, and batteries circa 2010 dramatically altered how UAS could be used (Mazur, 2016). But controls on the most sophisticated systems limited innovation and commercial use (Mazur, 2016). It is clear that the productivity implications played a factor in the US decision-making. As the Bureau of Industry and Security of the Department of Commerce

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[12] A UAS is a system that is pilot-controlled post-launched. It is different from cruise missiles that rely on AI to adjust trajectory post-launch as targt conditions change.

explained in their notice to consider petitions for sale of UAS, president Trump's interpretation of the MTCR, "reflects a reasonable approach to technological change and the protection of the national security and *economic interests* of the United States" (emphasis mine).[13] Further consistent with my theory, the US limited its focus to UAS. Even though the US could profit from the sale of cruise missiles and ICBMs creating direct economic incentives, they continue to schedule these items because they hold little productivity implications.

2.3 Monitoring Problems.

Others argue that inefficiencies in monitoring cause severe tensions in theories of innovation and war. If B can only imperfectly observe A's military investment, then B does not know if A has invested or not. This creates incentives for A to secretly invest in the hopes B will not catch her. But B realizes A's incentives, generating pressures for preventive war. In the end, imperfect monitoring means we can only support mixing equilibria where A invests with probability, and B engages in preventive wars even when B holds no evidence of A's investment (Bas and Coe, 2016). Others advance this argument to show that states should seek out arms control agreements with stringent monitoring protocols, and unilaterally invest in intrusive monitoring technologies (Wolford et al., 2011). But also that these agreements are hard to sustain (Coe and Vaynman, 2019). All of these dynamics are most likely to follow when A's research into a novel innovation is: (a) easy to conceal from a rival state (especially if it is a dual-use technology (Vaynman and Volpe, 2024)); and (b) is expected to alter war fighting potential between states.

Based on this research, analysts have sounded the alarm over the implications of artificial intelligence for Sino-American conflict. AI holds the potential to shift power substantially, and it is next to impossible to monitor whether and how a rival is investing in these military capabilities (Gregory, 2023). Noting these technical features, analysts knowledgeable of theory are worried that monitoring tensions will cause Sino-American war and arms racing by mis-calculation.[14] These analysts are calling on the US and China to find ways to control the military applications of AI or risk enormous arms races and accidental war (Kania, 2020; Boulanin, 2020).

But policy statements do not fit the basic strategic logic of the monitoring problem in two

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[13] https://www.federalregister.gov/documents/2021/01/12/2020-27983/change-to-the-license-review-policy-for-unmanned-aerial-systems-uas-to-reflect-revised-united-states

[14] `https://time.com/6255952/ai-impact-chatgpt-microsoft-google/`.

key ways. First, the logic of imperfect monitoring drives states to conceal their innovation efforts. Against this core feature of the logic, China has widely publicized its 'New Generation Artificial Intelligence Development Plan' (2017).[15] This plan calls for a multi-billion investment in military applications of AI every year till 2030. AI also "features prominently in China's most recent (2019) defense white paper... (Gregory, 2023)."

Second, and to the chagrin of academic defense analysts, both the US and Chinese governments appreciates the risk that AI poses, but neither seeks out arms control. Instead, they fully accept the inevitability of a multi-billion dollar investment in military applications of artificial intelligence. The Chinese commitments are described above. On the US side, Congress' National Security Commission on Artificial Intelligence commissioned a bipartisan, Special Competitive Studies Project on Artificial Intelligence. That peak-body released preliminary findings in 2022 (SCSP, 2022). They acknowledge that an AI arms race will cause tension over Taiwan (p17) among other issues (ch 5). But still, they make no mention of arms control, or establishing norms to limit the military applications of AI. Instead, it calls for the Offset-X Strategy, which involves a concentrated and systematic investment in AI (pp133-138).

Why doesn't China seek to conceal its AI investments to gain an edge, and given that they have not, why don't both states seek arms control agreements with intrusive monitoring components to off-set the strategic tensions that AI arms race will inevitably cause? To address these questions, Appendix A.2.1 reports the monitoring problem with productivity implications. My model is identical to Debs and Monteiro (2014)'s monitoring problem with the added assumption that innovation causes productivity gains.

The model reveals that imperfect monitoring, and residual uncertainty about another's program does not exacerbate tensions when the productivity gains are large. Specifically, we cannot sustain a mixed strategy equilibrium even if A's research is imperfectly observed, so long as π exceeds the threshold described in result 1. All equilibria are identical to those described in the baseline model. The Challenger always innovates for any level of imperfect monitoring. The Defender knows that and always fights a war. The Defender would never engage in costly monitoring to verify the Challenger is pursuing innovation because he knows that the Challenger is.

To understand why my result is different it is important to consider what drives the standard

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[15] Translated at `https://digichina.stanford.edu/work/full-translation-chinas-new-generation-artificial-intelligence-`

result. The classic monitoring problem arises because A only wants to innovate if A does not face war. As stated in result 2, productivity gains alleviate A's tension because A prefers innovation and war to no innovation at all. Thus, A is willing to innovate no matter how large the risk is that B will discover A's program. B understands A's incentives. Thus, B simply assumes that A has always pursued military applications of AI whether B observes A's research or not. It follows that the entire logic of the monitoring problem degenerates.

If we were to extend the model further, B would never spend resources to monitor A's program, and neither state would seek out arms control because both value the productivity gains and expect that the other will continue their research. This basic result exactly fits China's decision to publicize its AI arming, and the US decision to avoid arms control. It explains why they make these choices even after projecting billion dollar investments in military applications of AI each year for decades, and knowing that they will amplify strategic tensions.

In fact, a closer look at the policy documents makes clear that elites understand that how productivity gains partially offset their expenditure and military risk. Chapter 7 of the SCSP report titled "The technologies that will drive future American competitiveness," characterized the "multi-trillion dollar" returns to the US economy that will come from national security-led investments in AI technologies (p170).

3 Conclusion

It is tempting to assume that theoretical arguments that well-fit historical cases will fit future cases. But the rigorous theories of innovation and conflict we know (eg Bas and Coe, 2016; Debs and Monteiro, 2014) identify clear scope conditions. A largely untested condition is that productivity gains are omitted. In this theory note, I show how the strategic tensions are different when the productivity gains are large. Specifically, the incentives for both innovation and war are more fundamental than existing research expects. This means that stronger monitoring regimes, grand bargains, or independent institutions may not help powerful states avoid the heightened risk of either arms racing or war as effectively as they did in the past (e.g Fuhrmann and Lupu, 2016; Glaser, 2015; Vaynman and Volpe, 2024). Thus, policymakers should seek out new tools that off-set the risk of war that results from innovation, but also appreciate that some risk is necessary if we are to sustain highly productive innovation.

Another implication is that modern innovations will only raise the risk of conflict for territories that will become valuable as modern innovations come to fruition. This is different from past work that suggests features of technologies themselves (e.g., whether they are dual-use, whether they are costly to develop) raise the risk of general war. This difference is important. It means that even if incentives for war are stronger when the productivity gains are large, that the inefficiencies they create are likely confined to single-issue conflicts.

The strategic logics I illuminate also provoke novel theoretical questions. One question surrounds the welfare affects of security competition. Indeed, even arms racing could, counterintuitively, amplify productivity through investment that could not rationally be sustained from economic incentives alone. We see this unintentional affect from Cold War investments into US highway networks, and the satellite. The difference today is that the government expects public investments into renewable technology, batteries, AI, and gene editing, will hold enormous economic advantage even though they will cause security tension. Another question surrounds how we can tailor hassling responses, such as covert operations, to reduce security tensions caused by productive innovations but also maintain the value we derive from them (Schram, 2022).

In a similar vein, theorists should consider unique features of certain crisis scenarios in the context of modern innovations problems. For example, I argued that it is rare that war substantially damages the productive worth of territory. But if it did, then we would observe innovation and no war, maximizing our productivity. Taiwan semi-conductor plants provide a unique and complex strategic challenge. Unlike many other territories, the US could destroy the balance of the productivity gains in Taiwan by destroying these plants during war. But it is not clear that the US can commit to destroying them even once war starts, because doing so would rob them the opportunity to profit if they win. Some audience cost may resolve the commitment problem to destroy. This might explain why National Security Adviser to the President, Robert C. O'Brien, recently stated publicly that "The United States and its allies are never going to let those factories fall into Chinese hands." Exploring these logics in detail will generate more nuanced policy advice as we navigate a tense but welfare-enhanced world that follows from highly productive innovation.

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A Appendix

First we solve the main model in the manuscript. Second, we formalize the two extensions discussed in section 2.2. Finally, we consider a robustness to the main model that assumes war both imposes a fixed cost and damages the pie.

A.1 Basic model

The sequence of moves is described in the text. I notate A's strategy as follows $s^A(r \in 0, 1, w_t \in 0, 1)$. Where r is A's research choice. w_t is A's choice to fight a war (1) or not (and accept peace) (0) in period t. I notate B's strategy as follows $s^B(q_t \in [0, 1], w_t \in a, w)$. Where w_t is B's choice to fight a war in period t and q_t is B's offer in period t.

We structure the proof as follows. First, we show that there is a unique on-path bargaining sub-game that starts in the second period conditional on state-power. This result gives us expected values for allowing bargaining to continue to the second period. From this result, we compute A's minimum demand in the first period, given A's expectation of what happens in the second period. Second, we completely characterize the SPE for the model. We'll show that the equilibria are unique under the assumption that A always accepts an offer when indifferent.[16]

A.1.1 Preliminaries

In the second period, A prefers peace to war if

$$q_2 \pi_2 \geq p_2 \pi_2 - w$$

The offer that leaves A indifferent with war is:

$$q_2^* = p_2 - w/\pi_2$$

To be clear, p_2, π_2 are condition on first period choices. In any sub-game where this comparison is valuable (i.e. no first period war), there are two values it can take on. In one, the technology

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[16] This assumption allows me to omit a technical analysis of knife edge conditions.

shock occurs and $p_2 = p_1 + \Delta, \pi_2 = \pi$. In the other the technology shift does not occur and $p_2 = p_1, \pi_2 = 1$. Either way,

> **Lemma A.1** *The following second period strategies are part of every SPE.* $s^B(q_2 = q_2^*|p_2, w_2 = a), s^A(w_2 = w|q_2 < q^*, w_2 = a|q_2 \geq q^*)$ *Players' second period utilities from these on-path actions are:*

$$U_2^A(q_2^*) = p_2\pi_2 - w$$

$$U_2^B(q_2^*) = \pi_2(1 - p_2) + w$$

Remark Second period war cannot appear on the equilibrium path.

The proof is well known. The one subtle difference is that the standard way to compute A's minimum demand assumes that $\pi_2 = 1$. This result, consistent with other models where the value for the pie varies shows that A's minimum demand changes with π. This, in turn impacts the total expected utilities of players in the second period.

This unique second period result, allows me to compute A's unique minimum demand in the first period. The offer that leaves A indifferent with war in the first period depends on whether or not the technology shock will happen. If A chooses not to research ($r = 0$), then A's minimum demand in the first period is the standard $q_1^*|r = 0 = p_1 - w$.

If A pursues research ($r = 1$), then the first-period offer that leaves A indifferent with war is characterized by:

$$q_1 + \delta(\pi p_2 - w) = p_1 - w + \delta(\pi p_1 - w)$$

$$q_1^*|r = 1 = p_1 - w - \delta\pi\Delta$$

For ease, we just write this as q_1^*. To be clear, this value is negative if:

$$\frac{p - w}{\delta} < \Delta\pi$$

This is critical, because the most that B can extract in the first period is $U_1^B(q_1 = 0) = 1$. Thus, B's preference for preventive war over peace if A invests is:

$$1 + \delta(\pi(1 - p_1 - \Delta) - w) > 1 - p_1 - w + \delta(\pi(1 - p_1) - w)$$

It follows that B prefers preventive war if:

$$\Delta\pi > \frac{p + w(1 + 2\delta)}{\delta}$$

This is condition 1 as stated in the manuscript. Note we can only satisfy this condition if $q_1^* < 0$.[17]

A.1.2 Equilibria.

We first focus on the condition where B's threat of war is credible.

Proposition A.2 ***Deterrence:*** *If condition 1 and*

$$\pi < \frac{m}{\delta p_1} + 1 \tag{3}$$

holds, then there is a unique SPE with the following first period strategies $S^A(r = 0, w_1 = a | q_1 \geq p_1 - w, w_1 = w | q_1 < p_1 - w), s^B(w_1 = w | r = 1, w_1 = a | r_1 = 0, q_1 = p_1 - w | r = 0, q_1 = 0 | r_1 = 1)$. *On the path, A does not invest and accepts* $q_1 = p_1 - w$. *Off the path, B selects preventive war if A invests.*

Condition 1 tells us that B's threat of war is credible. A's choice is derived from A's preference for innovation and war. Assume B's threat of war is credible, then A is willing to invest if:

$$p_1 + w - m + \delta(p_1\pi - w) > (p_1 - w)(1 + \delta)$$

This is violated if condition 3 holds as desired. This result is identical to the result described in Debs and Montiero. We now turn to the novel case:

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[17] To some degree, this represents a departure from past models because they generate B's preference for war when $q_1^* > 0$. But to do it, they rely on an immovable status quo, or a restriction on the timing of the offer. I do not constrain bargaining beyond limiting it to the contested issue. As a result, I can only generate incentives for preventive war when $q_1^* < 0$.

Proposition A.3 ***Innovation and war:*** *If condition 1 holds but 3 is violated, then the unique SPE is innovation and war. In it, A invests, B selects first period war. Off path, if A does not invest, A accepts* $q_1 \geq p_1 - w$ *and rejects otherwise. B offers* $q_1 = p_1 - w$.

The only difference from proposition A.9 is that A invests and faces war. We showed that this holds when condition 3 is violated. In classic models, we never observe this condition because war always deters investment because A never profits from the shift in power. We get innovation and war because A also factors in the productivity gains. The intuition is provided in the manuscript.

We now turn to the case where B's threat of war is not credible. The salient question is: when is the benefit of innovation and an offer greater than the cost of research?

Proposition A.4 ***Innovation and peace:*** *Suppose condition 1 is violated, and either one of the following two pairs of conditions hold: (a)* $q_1^* > 0$ *and* $m < \delta p(\pi - 1)$*; or (b)* $q_1^* < 0$ *and* $m < \delta\pi\Delta - p + w$*. Then the unique SPE is* $s^A(r = 1, w_1 = w|q < q_1^*, w_1 = a \text{ otherwise}), s^B(w_1 = a, q_1 = \max(q_1^*, 0)|r = 1, q_1 = p - w|r = 0)$.

Here a nuance arises in my results that departs from existing work on technology and shifting power. Existing theories assume some bargaining constraint. One reason is that it prevents B from offering A her minimum demand. This turns out to be critical. Afterall, if B can offer A her minimum demand, then A cannot benefit in expectation from the shift in power.

In my theory, this restriction is not necessary because the productivity gains can shift how much utility A extracts from her minimum demand.

To see it, consider any case where $q_1^*|r = 1 > 0$. If A invests, her expected utility at the moment that she accepts an offer is:

$$p - w - \delta\pi\Delta - \delta p(\pi - 1) + \delta(\pi(p + \Delta) - w) = p - w + \delta(p\pi - w)$$

As is standard, q_1^* robs A of her expected gains from shifting power. However, unlike the standard result, it does not rob A of her gains from expected differences in productive potential. The reason is that A's minimum demand hinges on instant war and not the expectation of how her minimum demand will change in the future if she does not select war. It follows that at the moment A considers how choice to invest, she invests if: $p - w + \delta(p\pi - w) - m > (p - w)(1 + \delta)$.

This solves for $m < \delta p(\pi - 1)$ as stated in the equilibrium.

When $q_1^* < 0$, we get the standard result that looks like the constraint on bargaining. Here A invests if $-m + \delta(\pi(p + \Delta) - w) > p - w + \delta(p\pi - w)$. This solves for $m < \delta\pi\Delta - p + w$ as stated in the equilibrium

Proposition A.5 ***A does not want to invest (and peace).*** *If condition 1 is violated and both of the condition pairs identified in proposition A.11 are violated, then the following strategies describe the unique SPE.* $s^A(r = 0, w_1 = w | q_1 < p_1 - w, w_1 = a | q_1 \geq p_1 - w)$, $s^B(w_1 = 0, q_1 = p_1 - w | r = 0, q_1 = \max(q_1^*, 0) | r = 1)$.

The equilibria follows from proposition A.11. It simply changes A's on path behavior from investment to no investment, and B's corresponding best reply offers from $q_1 = \max(q_1^*, 0)$ to $q_1 = p_1 - w$. The first difference follows because the pairs of conditions identified in proposition A.11 are what is required for A to prefer investment over no investment given that B offers A her minimum demand. The second difference follows from the first difference.

A.2 Extensions

A.2.1 Imperfect monitoring

We adjust the model using the following sequence of moves.

- A decides to secretly invest or not (private).
- If A invests, Nature reveals it to B with probability α, and keeps A's secret with $1 - \alpha$. Else (A does not invest), Nature is dormant.
- B decides to make an offer (bargaining continues) or fight a war (terminal).
- Model continues as original.

Payoffs are identical. This imperfect monitoring problem is identical to the innovation studied by Debs and Monteiro (2014) and a simpler variant of the innovation studied by Bas and Coe (2016); Wolford et al. (2011) and others.

The strategy sets are the same, but incomplete information allows states to condition strategies differently. We abuse notation a little by writing $\alpha = 1$, meaning B observes investment, and $\alpha = 0$, meaning B does not observe an investment. Focusing on B's war choice, let $x = pr(w_1 = 1|\alpha, s^A), 1-x = pr(w_1 = 1|\alpha, s^A)$. Turning to A's research choice, let $y = pr(r = 1|s^B), 1 - y = pr(r = 0|s^B)$.

Analysis

We solve for Pure Bayesian Equilibrium. The purpose of the analysis is to bound the mixing equilibria studied by past scholars. As Debs and Monteiro (2014) note, we can only support one kind of mixing equilibrium with plausible refinements. That is an equilibrium in which A researchers with probability, B always selects war if $\alpha = 1$, and selects war with probability if $\alpha = 0$.[18] Thus, we first characterize this equilibrium. Define an optimal war mixing probability as:

$$x^*|\alpha = 0 = pr(w_1) = 1 = 1 - \frac{\frac{m}{\delta} - (\pi - 1)p}{(1-\alpha)\pi\Delta}$$

And an optimal research probability as:

$$y^* = pr(r = 1) = \frac{2w(1+\delta)}{(1-\alpha)\delta\Delta\pi + \alpha 2w(1+\delta)}$$

Proposition A.6 *If* $y^* \in (0, 1), x^* \in (0, 1)$ *the following strategies characterize a PBE. In the first period,* $s^A(r = y^*, w_1 = 0|q_1 \geq p - w \& r = 0, w_1 = 0|q_1 \geq \max(q_1^*, 0) \& r = 1, w_1 = 1 otherwise.).s^B(w_1 = x^*, q_1 = p - w)$. *Second period strategies are characterized by Lemma A.8.*

We've shown, A's minimum demand depends on whether or not she has invested. If A has not invested, then her minimum demand is $p - w$. If she has, it is $q_1^* < p - w$. In equilibrium, B wants to achieve peace iff $r = 0$. Thus, B's serious (meaning offers he wants A to accept) offers must concede at least $p - w$.[19] Given this insight, A's is indifferent between research and not if:

$$(1-\alpha)(x(p-w+\delta(p\pi-w))+(1-x)(p-w+\delta(\pi(p+\Delta)-w)))+\alpha(p-w+\delta(p\pi-w))-m = x(p-w)(1+\delta)+(1-x)(p-w)(1+\delta) \tag{4}$$

This solves for x^*, as desired.

Turning to B's incentives. B's posterior belief $\beta|\alpha = 1 = 1$. $\beta|\alpha = 0 = \frac{y(1-\alpha)}{1-y+y(1-\alpha)} = \frac{y(1-\alpha)}{1-y\alpha}$.

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[18] As we discuss in a moment, there are other outcome equivelent equilibria.

[19] There is an outcome equivalent equilibrium where B never selects war, instead, B mixes over the offer $0, p - w$, and A rejects $q = 0$ iff, $r = 1$.

Given that B has observed $\alpha = 0$, B is indifferent between war and not if:

$$\beta(1-p-w+\delta(\pi(1-p)-w))+(1-\beta)(1-p-w)(1+\delta) = \beta(1-p+w+\delta(\pi(1-p-\Delta)+w))+(1-\beta)(1-p+w)(1+\delta) \tag{5}$$

This gives us $\beta = \frac{2w(1+\delta)}{\delta\Delta\pi}$. Subbing on β and solving for y gives us y^*.

Remark Condition 3 sets one boundary for $x^* \in [0,1]$. It follows we cannot support this mixed strategies when condition 3 is violated.

Notice, for $x \in (0,1)$, it must be that $\delta(p(\pi-1)+\Delta\pi(1-\alpha)) > m > \delta(\pi-1)p$. The right-hand side, rearranges to condition 3.

Proposition A.7 *If condition 3 holds, then the pure strategy equilibria described in proposition A.11 A.10 are the only equilibria that can survive the intuitive criterion.*

First, we must establish that A.11 A.10 hold given imperfect monitoring and off-path beliefs. In both equilibria, A invests. Because A's investment is imperfectly observed, it follows that B can observe both $\alpha = 1, \alpha = 0$. There are no off-path beliefs. Thus, we need not consider them. It follows that we can support both in equilibrium.

Second, we must establish that we cannot support any other equilibrium. We've just shown we cannot support a mixed strategy equilibrium. But could we support another pure strategy equilibrium. Conjecture an equilibrium in which A does not invest. In the parameter ranges that support proposition A.10, A strictly prefers investment no matter what B does. It follows, that we could not support a pure strategy equilibrium in which A does not invest. For some ranges in proposition A.11, A prefers research iff B selects peace. However, B strictly prefers peace no matter what A does. It follows, that we cannot support an equilibrium in which B plays $w_1 = 1$ in any sub-game.

Finally, we contrast welfare in these two equilibrium as the productive value of innovation increases.

Remark In the mixing equilibrium described in proposition A.6, x^* is increasing in π, and y^* is decreasing in π. Further, EU^B is increasing in π and EU^A is constant in π.

Taking the partial of x^* wrt π: $\frac{m}{\delta(1-\alpha)\Delta\pi^2}$, strictly positive. Taking the partial of y^* wrt π is trivially negative. Notice that the RHS of 4 does not depend on y, or any other function of π. As a result, in this equilibrium A is strictly indifferent with war given no investment.

Remark In the pure strategy equilibria described in A.11 A.10, raising π strictly increases welfare of both players. Innovation is certain and war is certain in A.10 and certainly avoided in A.11.

Substantively this means that in the parameter ranges in which π is low enough that we can support a mixing equilibrium, we see that raising the productive value both increases the risk of war, but decreases the chance of innovation. This survives until we hit a cut-point on π wherein innovation becomes certain. At that moment, both states' welfare is strictly increasing in innovation and war is either certain or not.

A.2.2 B's incentives to invest in innovation that shifts power against him

The model is different because B holds the option to innovate and A does not. Therefore, I make the following change to how I notate player strategies: $s^A(w_t \in 0, 1)$, I notate B's strategy as follows $s^B(r \in 0, 1, q_t \in [0, 1], w_t \in a, w)$. The only difference is that r no longer appears in A's action space, and now appears in B's.

This has the following corresponding change to payoffs

$$EU_1^A(war_1) = p_1 - w + \delta(p_1\pi_2 - w)$$

$$EU_1^A(war_2) = q_1 + \delta(p_2\pi_2 - w)$$

$$EU_1^A(peace) = q_1 + \delta(q_2\pi_2)$$

$$EU_1^B(war_1) = 1 - p_1 - w - rm + \delta((1 - p_1)\pi_2 - w) - -rm$$

$$EU_1^B(war_2) = 1 - q_1 + \delta((1 - p_2)\pi_2 - w) - rm$$

$$EU_1^B(peace) = 1 - q_1 + \delta((1 - q_2)\pi_2) - rm$$

Analysis

The model is identical once investment happens. Thus, the baseline proofs after B's initial choice for investment work out all the SPE in this extension. All we need to consider is B's initial incentive to invest. First, we must consider B's incentive to invest knowing it will cause war. This happens if:

$$1 - p - w - m + \delta(\pi(1 - p) - w) > (1 - p + w)(1 + \delta)$$

$$\pi > 1 + \frac{2w(1 + \delta) + m}{\delta(1 - p)}$$

When this is satisfied, B invests knowing that it will trigger a preventive war. We get an equilibrium that is identical to the action set described in proposition A.10 the only difference being that B (not A) invests on the path.

When it is violated, B anticipates war and does not want to invest. We get an equilibrium that is identical to the action set described in proposition A.9 the only difference being that B (not A) does not invest on the path.

When B prefers an offer to war following an initial investment, B's incentive to invest hinges on whether $q^* > 0$ or not. Assume that $q^* > 0$, then B invests if:

$$1 - p + w + \delta\pi\Delta + \delta(\pi(1 - p - \Delta) + w) - m > (1 - p + w)(1 + \delta)$$

$$\pi > 1 + \frac{m}{\delta(1 - p)}$$

When B's threat of war is not credible, and $q_1^* < 0$, then B wants to invest in innovation if:

$$1 + \delta(\pi(1 - p - \Delta) + w) - m > (1 - p + w)(1 + \delta)$$

$$\pi > \frac{m - p + w + \delta(1-p)}{\delta(1-p-\Delta)}$$

We can use these conditions to replace the pair of conditions described in proposition A.11. When either pair is satisfied, we get the behaviors described in proposition A.11. When they are violated, we get the equilibrium behaviors described in proposition A.12.

A.3 Robustness: War damages the pie

We change the model so that if either player declares war, the pie is damaged in that moment and evermore by a resolution parameter $\theta \in (0,1)$. Adjusted payoffs are reported in Table 3.

Table 3: Utilities

	Peace	1st period war	2nd period war.
A	$q_1 + \delta(q_2\pi_2) - rm$	$p_1\theta - w + \delta(p_1\theta\pi_2 - w) - rm$	$q_1 + \delta(\theta p_2\pi_2 - w) - rm$
B	$1 - q_1 + \delta((1-q_2)\pi_2)$	$(1-p_1)\theta - w + \delta((1-p_1)\theta\pi_2 - w)$	$1 - q_1 + \delta((1-p_2)\theta\pi_2 - w)$

The proof is identical to the baseline model. We follow the same structure, but mainly focus on the effects of θ.

We will substantiate the following claim. First, if θ is small it means B's threat of war is not credible, but it also means that A never innovates.

A.4 Preliminaries

In the second period, A prefers peace to war if $q_2\pi_2 \geq p_2\pi_2\theta - w$. Thus, The offer that leaves A indifferent with war is:

$$q_2^* = p_2\theta - w/\pi_2$$

Lemma A.8 *The following second period strategies are part of every SPE.* $s^B(q_2 = q_2^*|p_2, w_2 = a), s^A(w_2 = w|q_2 < q^*, w_2 = a|q_2 \geq q^*)$ *Players' second period utilities from these on-path actions are:*

$$U_2^A(q_2^*) = p_2\theta\pi_2 - w$$
$$U_2^B(q_2^*) = \pi_2(1 - p_2\theta) + w$$

If A pursues research ($r = 1$), then the first-period offer that leaves A indifferent with war is characterized by:

$$q_1 + \delta(p_2\theta\pi_2 - w) = p_1\theta - w + \delta(\pi\theta p_1 - w)$$

$$q_1^*|r = 1 = p_1\theta - w - \delta\theta\pi\Delta$$

For ease, we just write this as q_1^*. It is negative if:

$$\frac{p\theta - w}{\delta\theta} < \Delta\pi$$

Thus, B's preference for preventive war over peace if A invests is:

$$1 + \delta(\pi(1 - (p_1 + \Delta)\theta) + w) < (1 - p_1)\theta - w + \delta(\pi\theta(1 - p_1) - w)$$

It follows that B prefers preventive war if:

$$\Delta > \frac{1 - (1 - p)\theta + w(1 + 2\delta) + \delta\pi(1 - \theta)}{\delta\pi\theta} \tag{6}$$

This is equivalent to condition 1 in the manuscript.

Re-writing the condition in terms of θ

$$\theta > \frac{1 + \delta\pi + w(1 + 2\delta)}{1 - p + \delta\pi(1 + \Delta)}$$

then taking $\pi \to \infty$, we can find always find a π such that B's threat of war remains credible iff $\theta > \frac{1}{1+\Delta}$.

A.5 Equilibria.

All proofs are identical to the baseline model. So we just state equilibria and the conditions we use to derive them.

Starting again with equilibria where B's threat of war is credible. A is willing to invest if:

$$p_1\theta - w - m + \delta(p_1\theta\pi - w) > (p_1\theta - w)(1 + \delta)$$

$$\pi < \frac{m}{\delta p_1 \theta} + 1 \tag{7}$$

Proposition A.9 ***Deterrence:*** *If condition 6 and 7 holds, then there is a unique SPE with the following first period strategies* $S^A(r = 0, w_1 = a | q_1 \geq p_1\theta - w, w_1 = w | q_1 < p_1\theta - w), s^B(w_1 = w | r = 1, w_1 = a | r_1 = 0, q_1 = p_1\theta - w | r = 0, q_1 = 0 | r_1 = 1)$. *On the path, A does not invest and accepts* $q_1 = p_1\theta - w$. *Off the path, B selects preventive war if A invests.*

Proposition A.10 ***Innovation and war:*** *If condition 6 holds but 7 is violated, then the unique SPE is innovation and war. In it, A invests, B selects first period war. Off path, if A does not invest, A accepts* $q_1 \geq p_1\theta - w$ *and rejects otherwise. B offers* $q_1 = p_1\theta - w$.

Proofs follow from baseline identically.

Turning now to the conditions where B's threat of war is not credible.

Proposition A.11 ***Innovation and peace:*** *Suppose condition 6 is violated, and either one of the following two pairs of conditions hold: (a)* $q_1^* > 0$ *and* $m < \delta\theta p(\pi - 1)$*; or (b)* $q_1^* < 0$ *and* $m < \theta(\delta\pi(p + \Delta) - \pi\theta(1 + \delta)) + w$. *Then the unique SPE is* $s^A(r = 1, w_1 = w | q < q_1^*, w_1 = a \text{ otherwise}), s^B(w_1 = a, q_1 = \max(q_1^*, 0) | r = 1, q_1 = p - w | r = 0)$.

Proposition A.12 ***A does not want to invest (and peace).*** *If condition 6 is violated and both of the condition pairs identified in proposition A.11 are violated, then the following strategies describe the unique SPE.* $s^A(r = 0, w_1 = w | q_1 < p_1\theta - w, w_1 = a | q_1 \geq p_1\theta - w)$, $s^B(w_1 = 0, q_1 = \theta p_1 - w | r = 0, q_1 = \max(q_1^*, 0) | r = 1)$.

Proofs follow from baseline. For emphasis, I write out A's incentive for innovation over not in the interior case:

$$p\theta(1 + \delta) < p\theta - w - \delta\theta\pi\Delta + \delta(p\theta\pi + \Delta\theta\pi - w)$$

$$\frac{m}{p(\pi - 1)} > \theta$$

We now consider this condition jointly with B's incentive for war. This allows us to ask, when would we ever see a scenario where A is willing to undertake national security innovations, but B's threat of war is not credible given the amount that war damages the productive value of the pie?

$$\frac{m}{p(\pi-1)} > \frac{1+\delta\pi+w(1+2\delta)}{1-p+\delta\pi(1+\Delta)}$$

Setting to one side, and taking the FOC wrt π:

$$\frac{\partial}{\partial\pi} = \frac{\delta(1-p-(\Delta+1)\left((2\delta+1)\,w+1\right))}{\left((\Delta+1)\,\delta\pi+1-p\right)^2} + \frac{m}{p\cdot(\pi-1)^2}$$