

Why Was It Europeans Who Conquered the World?

Philip T. Hoffman
Caltech (pth@hss.caltech.edu)
March 21, 2012

By the eighteenth century, Europeans dominated the military technology of gunpowder weapons, which had enormous advantages for fighting war at a distance and conquering other parts of the world. Their dominance, however, was surprising, because the technology had originated in China and been used with expertise in Asia and the Middle East. To account for their prowess with gunpowder weapons, historians have often invoked competition, but it cannot explain why they pushed this technology further than anyone else. The answer lies in the peculiar form that military competition took in western Europe: it was a winner take all tournament, and a simple model of the tournament shows why it led European rulers to spend heavily on the gunpowder technology, why the technology was advanced as a result, and why political incentives and military conditions made the rest of Eurasia fall behind.

The attached paper can stand alone, but it is part of a larger, book length project. The book seeks to explain why it was Europeans who conquered the world, and not someone else, such as the Chinese, the Japanese, the Ottomans, or South Asians. The consequences were huge, from colonialism to the slave trade and even the Industrial Revolution.

Part of the argument turns on the simple static tournament model that is the focus of the paper. The next question is then explaining why the key exogenous parameters in the model (in particular, the political costs that rulers faced in mobilizing resources for war) happened to be different in major Europe countries, and different at precisely the time when gunpowder weapons were militarily useful and had enormous potential to be improved via learning by doing. Those conditions meant that European rulers would push the gunpowder technology further than rulers elsewhere in the world, and the resulting technological gap would allow Europeans to plant colonies and fortresses in far away parts of the world.

Why were these key parameters so different in Europe? That question goes beyond the scope of the paper, but the answer turns out not to be geography, contrary to what Jared Diamond and others have argued. Rather, it was the unintended consequence of Europe's history since the collapse of the Roman Empire. That history could have been very different, and so could the histories of the other major Eurasian civilizations. It is in fact easy to imagine plausible counterfactuals in which someone else would have conquered the world. The issues involved in such counterfactuals go well beyond mobilizing resources for war or the size of states, for they also hinge on matters of politics, of culture and religion, and of social and economic policy. European governments, for instance, let civilians carry and use arms and placed relatively few limits on their ability to create organizations to trade or colonize abroad. Policy elsewhere in Eurasia was not so permissive. The unintended consequence was that it was much easier for civilians in Europeans to create colonies, and much harder for civilians in East Asia or the Middle East to do the same.

Research for this paper was supported by NSF Grants 0433358 and SES-0649062 as part of the Global Prices and Incomes Project.

In the “great divergence” debate over when and why Europe forged ahead of the rest of Eurasia, one topic that seems to have been overlooked—namely, violence, or at least violence with gunpowder weapons. In this domain, Europe possessed an undeniable comparative and absolute advantage, early on: European states were simply better at making and using artillery, firearms, fortifications, and armed ships than powers in other parts of the world and they had this advantage long before 1800. They used this gunpowder technology to wage war at home and to establish outposts abroad. The result was that by 1800 Europeans had conquered some 35 percent of the globe and were preying upon lucrative trade routes as far away as Asia. They took control of even more territory in the nineteenth century.¹ There were certainly other forces that worked in their favor as well, including the diseases that they introduced into vulnerable populations, and there were limits to what firearms could do.² Nonetheless, the gunpowder technology clearly played a large role in European conquest. Why then was it the Europeans who came to dominate this technology, and not the Japanese, the Ottomans, or the Indians, who all used it with expertise? Or why wasn’t it the Chinese, who had invented it?

This question has attracted a number of gifted military historians, but the closest they come to a deeper explanation is the claim that military competition in Europe gave the Europeans an edge. The argument has been formulated most cogently by Paul Kennedy, who points to Europe’s competitive markets and persistent military rivalries. In his view, while military rivalry created an arms race, competitive markets fostered military innovation and kept one country from establishing an empire.³

But Kennedy’s story of competition is not the final answer, for it leaves far too much unexplained. To begin, competitive markets do not always stimulate innovation.

The clearest example comes from agriculture in early modern Europe, which had highly competitive markets but witnessed virtually no productivity growth.⁴

Nor do ongoing military rivalries always promote innovation. They failed to do so in eighteenth-century India and southeast Asia. The case of India, as we shall see, is particularly illuminating. Like Europe it had markets and incessant warfare, and the combatants were quick to adopt the latest weapons and tactics. The innovations, however, by and large originated in the West.

The answer lies with the peculiar form of competition in which European rulers were engaged. It was a winner-take-all tournament that spurred rulers to spend enormous sums on using the gunpowder technology in the continent's incessant wars. In the process, the technology was advanced via learning by doing. Elsewhere, however, political and military conditions were not conducive to improving the gunpowder technology. That is why the Europeans pushed the technology further than anyone else and why the rest of the world had trouble catching up.

Understanding why requires a look at the political, military, and fiscal incentives rulers faced, both in Europe and in other parts of Eurasia. We will start with Europe before 1800 and use it to motivate a simple tournament model, which will then be applied to the rest of the world and then to Europe after 1800. The model's predictions are borne out by quantitative and qualitative evidence; other explanations—including the argument about competition—fail such a test. The model thus gives us a deeper understanding of why Europeans came to dominate a technology that made world conquest possible.

1. Rulers and their incentives in Europe before 1800

The states that coalesced in Europe in the waning days of the Middle Ages by and large had a single purpose, at least if we judge by what they levied taxes and borrowed money for. That purpose was clearly warfare. In the major powers, some 40 to 80 percent of the budget went directly to the military, to defray the costs of armies and navies that fought almost without interruption (Table 1). The fraction of the budget devoted to war climbed even higher—to 95 percent in France during the 30 Years War—if we add sums spent subsidizing allies or paying of the debts of past wars.⁵

In early modern Europe, decisions about war typically lay in the hands of a ruler such as a king or a prince. He would of course be advised by councilors and influenced by elites, and an influential minister might sometimes be dictating most of the decisions. But the assumption that a king or prince made the decisions about war is not far from historical reality. Even in eighteenth-century Britain, where Parliament and the cabinet decided whether to commence hostilities, the choices about the conduct of the war once it had begun were ultimately up to the king.⁶

What then made European kings take up arms? That question has to be answered if we are to understand what the tournament was. In Europe's major powers, the rulers often won control of warfare in the process of assembling their states in the late Middle Ages or the sixteenth century. In modern terms, they provided the public good of defense in return for taxes. That public good was precious, as anyone who suffered through the horrors of the 100 Years War in France or the 30 Years War in central Europe could testify. But the rulers of early modern Europe likely provided far more defense than their

average subject would have wanted. They went on the offensive too, and not just to protect their kingdoms.

The reasons were not hard to understand. The kings and princes had been raised to fight one another, with toy soldiers, pikes, and firearms as children and actual training in their youth. Advisers like Machiavelli might tell them that princes “ought to have no object, thought, or profession but war.” Their own fathers would teach them that war was a path to glory, a means to “distinguish [kings] . . . and to fulfill the great expectations . . . inspired in the public,” in the words of Louis XIV’s instructions for his son. For them, fighting had gone beyond the needs of defense and become, in the words of Galileo, a “royal sport.”⁷

Glory did recede as a motive for war in the eighteenth century, when the major powers might fight simply to preserve their reputation, to gain commercial advantage, or to snatch territory from weaker neighbors. But war was still “what . . . rulers did.” It continued to appeal to them, just as it long had attracted much of the European aristocracy.⁸

For the major monarchs of early modern Europe, victory was thus a source of glory or a way to enhance their reputation. Grabbing territory from small neighbors did augment their resources and help strategically, but the thirst for glory and the drive to bolster their standing could push them to spend large sums even on small bits of terrain. Their goals may seem bizarre, but there are certainly modern analogues—the race to get a man on the moon, or, to take a non governmental example, college athletics. And although the kings might lose small amounts territory themselves, they faced no major downside risk to their thrones, at least in the larger states, for loss in battle in anything

but a civil war never toppled a major monarch from his throne, at least in the years 1500-1790.⁹

It now becomes clearer why the early modern rulers fought so much. What impels states to engage in hostilities is something of a mystery, at least to many economists and political scientists, who rightly ask why leaders do not simply agree to give the likely victor what he would win in a war and then spare themselves the lives and resources wasted in battle. The literature offers several reasons why such agreements prove unattainable, and why leaders go to war instead, despite all the devastation it causes.¹⁰ Although all of these reasons apply to early modern Europe, two of them seem to fit the continent's history like a glove.

The first was that the leaders making decisions about war—early modern Europe's kings and princes—stood to win a disproportionate share of the spoils from victory but avoided a full share of the costs. They—not their subjects—were the ones who basked in glory or who burnished their military reputations when their armies were victorious. But they bore few of the costs, which fell disproportionately on their subjects. When the leaders' incentives are that biased, it can be impossible to reach any sort of bargain to avoid war, even if the leaders trade resources to compensate one another.¹¹

There was a second obstacle to peaceful agreement as well—the difficulty of dividing the spoils of war that the early modern princes and kings were fighting over. Glory could not be divvied up. In fact, it simply vanished if there was no fighting, making the peaceful exchange of resources potentially more expensive than fighting. The same held for reputation; it too could only be earned on the battlefield. Commercial advantage would not be easy to share either, if, as was often the case, it involved a trade

monopoly. And territory posed similar problems, when it offered a strategic advantage or if sovereignty or religious differences were at stake. Then even trading other resources might not work. In negotiations to end the Great Northern War between Russia and Sweden, for example, the Tsar Peter the Great told his envoy in 1715 that he would not consider giving back Riga and Swedish Livonia because that would threaten nearby Petersburg and all his other conquests in the war and thus potentially cost him more than the Swedes could ever conceivably give him in return.¹² Religious strife could make negotiation itself impossible if it meant dealing with enemies of the faith.¹³

These obstacles to peace were not unique to early modern Europe, so they cannot be the reason why Europe came to dominate the gunpowder technology. They were at work elsewhere too, because foreign policy in other parts of Eurasia was often in the hands of kings, emperors, or warlords who could be as obsessed with glory as their European counterparts.¹⁴ But the biased incentives facing the European princes and the indivisible spoils in their wars do at least explain why early modern Europe was wracked by virtually constant hostilities. Not that all rulers would have taken up arms. Some countries were too small, and, others like the Netherlands in the eighteenth century, were big enough to fight but tended to bow out, or at least not enter a particular conflict.

2. A simple tournament model

A model inspired by the conflicts in early modern Europe can help explain why Europe's kings and princes advanced the gunpowder technology and why rulers

elsewhere in Eurasia lagged behind. We will sketch the model first, and then show that it fits the evidence both in early modern Europe and in other parts of Eurasia.

The requisite model has to explain decisions about going to war and military spending. Otherwise it cannot make sense of all the fighting in Europe and all the resources that went into it. It also has to account for improvements in military technology, so that we can isolate differences between Europe and Asia.

A simple model drawn from the economic literature on conflict and tournaments provides a tractable starting point.¹⁵ Although more complex models do a better job of accounting for the patterns of war and peace and of military spending that we see in the modern world, they have less to say about military technology, or about the virtually constant war that ravaged early modern Europe and parts of Asia as well.¹⁶

Consider two risk neutral early modern rulers who are considering whether or not to go to war. Winning the war earns the victor a prize P , which might be glory or territory or a commercial advantage. For the sake of simplicity, we assume the loser gets nothing, but the model will remain essentially the same if the ruler pays a penalty for losing or for failing to defend his kingdom against attack.¹⁷

To have a chance of getting the prize, the rulers have to take the steps that many early modern rulers did if they wanted to win wars. First, they have to establish an army or a navy and set up a fiscal system to pay the military's bills. We can interpret that as paying a fixed cost b , which is assumed the same for both rulers. They also have to devote resources ($z_i \geq 0$ for ruler i) to winning, which we can think of as the taxes raised to pay for supplies, weapons, ships, fortifications, and military personnel. Revenues from the rulers' personal possessions, though usually less significant, would count too, and so

would conscription and commandeered resources, although they too were typically less important, at least in early modern Europe. We will adopt a common functional form from the conflict literature and assume that the probability of ruler i winning the war if both decide to fight is $z_i/(z_1 + z_2)$. The odds of winning are then proportional to the ratio of the resources they each mobilize.¹⁸

Resources carry an average variable cost c_i , which may be different for the two rulers; therefore, assume that $c_1 \leq c_2$. For simplicity, assume the average variable cost c_i is constant for all levels of resources z_i .¹⁹ These costs are political: they include opposition to conscription and higher taxes, and resistance by elites when taxes revenues they control are shifted to the central government. If these costs are too high or the expected gains from victory too low, a ruler may simply decide that it is not worth fighting. He can then sit on the sideline, as the Netherlands did in the eighteenth century. A ruler who opts out in this way expends no resources z_i and avoids paying the fixed cost b as well, but he has no chance of winning the prize. Making him pay a penalty for not defending himself against attack will only lower the fixed cost b and leave the model unchanged.

We assume that the rulers first decide, simultaneously, whether or not to go to war. They then choose the resources to expend, z_i . If only one ruler is willing to go to war, he has to pay the fixed cost b involved in setting up an army, navy, and fiscal system, but he is certain to win the prize because he faces no opposition. He therefore devotes no resources z_i to the military and wins $P - b$. If both go to war, then ruler i can expect to earn:

$$\frac{Pz_i}{\sum_1^2 z_j} - c_i z_i - b \quad (1)$$

The first term in the expression is simply the probability that ruler i wins times the value of the prize P , and the next two terms are just the cost of resources z_i that he mobilizes and the fixed cost b .

The resulting game has a subgame perfect equilibrium. Only the ruler with the lower political costs (ruler 1) goes to war if $P > b$ and $P < b(1 + c_2/c_1)^2$. Ruler 2 sits on the sidelines, because with his higher political costs, his expected winnings would not be enough to defray the fixed cost. Ruler 1 and obviously ruler 2 as well spend nothing on the military, and so there is no actual fighting. We will consider that outcome to be peace, even though ruler 1 has set up a military and a fiscal system to fund it.

Both rulers go to war if

$$P \geq b(1 + c_2/c_1)^2 \quad (2)$$

Inequality (2) is necessary and sufficient for there to be war in equilibrium; it will hold when the prize is valuable, the fixed cost is low, and ratio of average variable costs c_2/c_1 is near 1 (the ratio is always greater than or equal to 1 since $c_2 \geq c_1$ and it will be near 1 when both rulers face similar political costs for mobilizing resources).

Inequality 2 ensures that military spending will be positive, but it does not guarantee that it will be large, which will be important for learning by doing. To see when military spending will be big, consider the comparative statics of the equilibrium with war. In that equilibrium, ruler i will spend

$$z_i = \frac{P}{C} \left[1 - \frac{c_i}{C} \right] \quad (3)$$

on the military, where $C = c_1 + c_2$, while total military spending will be

$$Z = z_1 + z_2 = P/C \quad (4)$$

So total military spending Z will only be large if, in addition to (2), P/C is big, or, in other words, if the prize is valuable and the rulers' political costs for mobilizing resources are low. Finally, the probability that ruler i wins the war will be

$$(1 - c_i/C) \quad (5)$$

which will be higher for a ruler with a low average variable cost c_i .

We will also suppose that the two rulers do not repeat this game. They play it once, at the outset of their reigns, and we interpret the decision to go to war as a choice not about a single conflict, but rather about being bellicose or not for their entire time on the throne. If they are bellicose (if inequality 2 holds), they will fight one another repeatedly throughout their time on the throne; if not, their reigns will be peaceful. Other rulers may play the game too, including their successors, and one might therefore worry that concern for their heirs would create a repeated game. Foreign policy, however, was dictated by short term interests and changed enough from ruler to ruler to make this a reasonable assumption.²⁰ Furthermore, although other equilibria would in theory exist if the game were repeated, they could vanish if the prize were glory or victory over an enemy of the faith. By contrast, playing the strategy described above at each stage would

always be an equilibrium in the repeated game; with it there would be nothing to be gained by making the game repeated.

We thus have a model with war, military spending, and peace as well—namely, when one ruler wins the prize without any opposition and no resources are actually spent on fighting. How do improvements to military technology fit in? The technology used will be determined by a ruler's opponents. In western Europe that was the gunpowder technology, but as we shall see, it was not the only military technology, and it was not effective against some enemies.

Whatever the military technology is, we will suppose (at least for now) that it progressed via learning by doing. Rulers fought wars and then used what worked against the enemy. That was typically how military technology advanced in the early modern world, whether it was weapons, organization, or tactics. The learning could take place during a war, or afterwards, when losers could copy winners and revise what they did. Conflicts in the late fifteenth century, for example, gave rise to lighter and more mobile artillery that could be mounted in and fired from gun carriages.

The learning extended to organization as well. French and English commanders who battled against Spain in the sixteenth century, for example, learned to appreciate the Spanish infantry's training, discipline, and small group cohesion. They urged their own countries to adopt the same organization.²¹

It is true that there were also conscious attempts to improve early modern military technology. King Philip II of Spain, for example, rewarded military inventors.²² But such efforts themselves were often triggered by successes and failures on the battlefield, such as when the French sought to make lighter and more mobile field artillery after a

defeat in the Seven Years War.²³ Learning by doing dominated, at least until the eighteenth century, although we will relax that assumption when we turn to the nineteenth century.

One reasonable way to conceive of the learning is to assume that it depends on the resources spent on war. Greater military spending gives a ruler more of a chance to learn, and rulers anywhere can do it—it is not peculiar to one corner of the world. We can model the relationship by assuming that each unit of resources z spent gives a ruler an independent chance at a random military innovation x , where x has an absolutely continuous cumulative distribution function $F(x)$ with support $[0, a]$. If we ignore the fact that z is not an integer, then spending z is like taking z draws from the distribution, and the ruler who spends z will obtain an innovation with a probability based on the distribution $F^z(x)$. If both rulers draw from the same distribution, as would be reasonable to suppose if they are fighting one another and using the same military technology, then the highest realized value of x in their war will come from a distribution $F^Z(x)$, where $Z = z_1 + z_2 = P/C$ is total military spending. We will interpret this best innovation as an advance in military technology. As Z increases, the expected value of this best innovation will therefore rise, and x will converge in probability to a , which can be interpreted as the limit of available knowledge. Greater knowledge will therefore make for more innovation, like more military spending. Finally, if there is no war, there is no spending or learning, so in that case we can assume that $x = 0$.

Innovation is then an inadvertent byproduct of fighting wars, but what if the rulers intentionally seek to improve the military technology? If the innovation proceeds via learning by doing through the process of spending on war, then the probability of having

the best innovation will be exactly the same as the probability of winning the war, given by expression (1) above.²⁴ Winning the tournament for the best innovation will be the same as winning the war, with identical incentives, so there will be no difference, provided innovation comes from learning by doing.

So far this tournament is not repeated, but what happens if successive pairs of different rulers from the same two countries play the game over time, say once per reign? Let us assume that each pair of rulers can copy the best innovation from the previous round, which seems reasonable if they learn from experience. It also fits what happened in early modern Europe, where military innovations spread through espionage, efforts to copy what was successful, and Europe's longstanding market for weapons and military skills. Professional soldiers had every incentive to adopt the most effective tactics, hardware and organization. In such a situation, no ruler will have any technological lead over his rival at the start of a new round of the tournament. If the limits of available knowledge do not change and if the successive pairs of rulers continue to draw from the same distribution and fight each round, then after n rounds the military technology will have a distribution $F^Z(x)$, where Z is now the total amount expended over the n rounds of the tournament. If the technology is ancient, then x will be so close to a that innovation slows to a halt, as typically happens with learning by doing.²⁵ It will also stop if wars are not fought. But if the technology is relatively new, then there will still be room for continued innovation, and the tournament will work like an idealized prize system that puts winning ideas into the public domain.

In that case, military innovation will be sustained and will not slow until the limits to knowledge begin to bind. But that will not happen if these limits change, either

through the learning by doing or in the nineteenth century through advances in engineering and science. Suppose, for instance, that learning in each round of the tournament shifts the support of the distribution F for the rulers in the next round to $[w, w + a]$, where w is the value of the best innovation in the round that has just been played. Suppose too that the successive pairs of rulers confront the same costs and prize. They will continue fighting, and if x has expected value $E(x)$ after one round, then after k rounds of fighting, its expected value will be $k E(x)$. The rate of technical change in the military sector ($E(x)$ per round, or ruler's reign) will not slow, nor will there be any limit to improvements. On the other hand, if the fighting stops—say because the fixed costs b increase—then even this sort of technical change will screech to a halt.

Fixed frontiers to knowledge are more realistic for the early modern world, at least up until the eighteenth century. By the nineteenth century, however, the frontiers were clearly moving.²⁶ If we assume fixed limits as a reasonable approximation throughout early modern Eurasia, then what matters for sustained improvements to military technology are continued war with large military expenditures, and a new military technology, such as the gunpowder technology, which was ripe for improvement via learning by doing.

The assumption here is that the winning technology spreads after every round of the tournament. If it does not and if some rulers therefore lack the latest military advances, then they will fall behind and stand a greater chance of losing against rulers who possess the cutting edge technology. Having the winning technology, though, does not make the playing field perfectly even. Even with it, a ruler with high costs c_i will

stand less of chance of winning against a low cost opponent, and if the difference in costs is big enough, he will simply avoid conflict.

Suppose now there are two technologies that are effective against different enemies. Gunpowder weapons, for example, worked well in early modern European warfare, whether on land or at sea. But until at least the seventeenth century they were relatively ineffective against the nomads who threatened China, portions of south Asia and Middle East, and even parts of eastern Europe that bordered the Eurasian steppe. The mounted nomads had no cities to besiege, and they were too mobile to be targets for artillery, except when it was fired from behind the walls of fortifications. Sending the infantry chasing after them would demand too many provisions, since they could simply ride off into the steppe and live off the land. Muskets gave no advantage, because they could not easily be fired from horseback, and while pistols could, their range was limited. When fighting the nomads, the best option, at least for a long time, was simply to dispatch cavalry of mounted archers—essentially the same weapons the nomads themselves utilized. That was an ancient technology, which dated back to roughly 800 BC. In the early modern world, with fixed limits to knowledge, it could no longer be improved, although it would still be useful in war.²⁷

Suppose then that a ruler fights only nomads. He will use primarily mounted archers, and only a little of the gunpowder technology, and because he spends practically nothing on it, he will not advance it. If one of his successors finds himself confronting an enemy against whom gunpowder weapons are useful, then he will try to acquire the latest gunpowder weapons from abroad because his realm will lag behind. The story will be similar for a ruler who fights on two fronts, spending a fraction g of his resources on the

gunpowder technology and $l - g$ on mounted archers. He will improve the gunpowder technology, but at a lower rate because he spends only gz_i on it, not z_i , and his successors too may want to import the latest gunpowder weapons because they lag behind.

This simple tournament model is certainly open to criticism. To begin with, the rulers are either bellicose, or they do not fight at all, either because they face no opposition or because they sit on the sidelines. The model does not generate more complex patterns of arming and fighting, as a repeated game might.²⁸ But that simple pattern does describe many rulers in the early modern world. Second, because the model pits only two rulers together at any one time, it glosses over the knotty problem of alliances. Yet that too is not as great a problem as it might seem. The underlying tournament model can be extended to more than 2 rulers, and when it is, the insights remain the same. What in fact matters is that there are two who are willing to fight rather than just one; having more than two is unimportant.²⁹ As for alliances, sometimes they were determined well in advance of any hostilities and confirmed by a marriage. Those it would be reasonable to treat as exogenous. The other alliances could simply be considered another means of mobilizing resources, which leaves the model unchanged so long as the average variable cost remains constant.

One final problem concerns these average variable costs c_i . These costs, which are political, cannot be observed directly. But tax rebellions, or elite opposition or defections when resources were mobilized for war would be evidence that they were high. So too would low tax levels in war time. The reason is that in the equilibrium with war, the ratio c_2/c_1 of the political costs the two rulers face will (from equation 3) simply equal the inverse ratio z_1/z_2 of the resources they mobilize. Tax revenues were usually

the biggest component of the resources z_i that were mobilized for war; conscription and revenues from the ruler's possessions contributed much less in most cases. So if two rulers were fighting one another, the one with lower tax revenues would have a higher average variable cost c_i . (Of course if the difference between their average variable costs was too large, then the two would not go to war, because inequality (2) would fail to hold.) And even if rulers were not fighting one another, a higher average variable cost would, from equation 3, imply a lower taxes in war time, although the lower taxes could also result from a less valuable prize or from differences in an enemy's average variable cost.

3. Where in early modern Eurasia will the gunpowder technology be advanced?

Despite its simplicity, the tournament model does make useful predictions about when there will be war and when there will be advances in military technology, in particular the gunpowder technology. We will have war if inequality (2) holds—in other words, when the value of the prize is higher, when opponents' costs c_i are similar, and when fixed costs b are smaller. Opponents' costs will be similar if rival countries are of roughly the same size and face similar resistance to tax levies or conscription. The fixed costs will be small if setting up an army, a navy, or a fiscal system does not entail heavy expenses. That would certainly be the case if some of the fixed costs are sunk because a tax bureaucracy was already in place, naval dockyards had already been built, or a system had already been established for drafting soldiers, commandeering ships, or supplying provisions. The fixed costs would likely be modest too if the two rulers'

realms lay near one another, for fighting a distant country would entail setting up a big invasion force. War will persist if the inequality holds for successive generations of rulers.

Without war, there will be no learning by doing and no improvement in military technology. If the fighting halts, so will advances in military technology, and the resources mobilized z_i will decline too. War will be likely to stop if the fixed costs rise, or if a ruler annihilates his opponents and conquers their realms. His successors will then have no nearby rivals, and their only potential adversaries will be further away and so entail larger fixed costs. It will simply not be worth fighting them.

Continued war, which is guaranteed by (2), is, however, only a necessary condition for sustained productivity growth with the gunpowder technology. It is not sufficient. For that, three other conditions must hold as well. First, the resources Z spent on war must be large, for otherwise there will be little learning by doing even though the rulers are in the equilibrium with war. In that equilibrium $Z = P/C$ so for Z to be big the prize P must be large relative to the sum C of the average variable costs of the two rulers.

Second, the warring rulers must use the gunpowder technology heavily. If not, learning by doing with the technology will be minimal. Rulers who do not employ the gunpowder technology because it is ineffective against their enemies will not advance it, and those who adopt it only part of the time will improve it only modestly.

Third, the rulers must be able to acquire the latest innovations in the gunpowder technology at low cost. If not, they will lag behind leaders who have or can get the cutting edge technology easily. The technological gap between the leaders and the laggards will widen over time if successive rulers spurn the gunpowder technology or

warfare in general. If one of laggards suddenly goes to war and faces an enemy against whom the gunpowder technology is effective, then he will try to import it from the technological leaders. If he can import it quickly, he will catch up, and if his political costs c_i are low, he will stand a good chance of defeating his opponent. But if there are obstacles to acquiring the gunpowder technology, then the gap between the leaders and laggards will persist, and it will grow even larger if the limits to knowledge shift.

These three additional conditions are necessary for advances with the gunpowder technology, and together with inequality (2) they are sufficient. When and where do all four of them hold? Let us start with the second of the additional conditions—that the rulers use the gunpowder technology heavily. It clearly applies to western Europe and Japan, but it fails in China, for 97 percent of the time China was engaged in war involving nomads against whom firearms long remained impotent (Table 2). In confrontations with nomads, the older technology of mounted archers was more effective. The western Europeans, by contrast, fought no wars against nomads.

Not that China shunned the gunpowder technology altogether. It in fact gained in appeal in the early seventeenth century, when an arms race began to develop in East Asia. As the Ming dynasty, beset by rebellions and under attack by the Manchus, fell into decline, its troops fought and defended besieged cities with muskets and artillery. Their opponents replied in kind. But when the Ming dynasty collapsed and China was unified under the Qing dynasty (1644-1911), the nomads remained the new dynasty's major enemy well into the eighteenth century, and against them the gunpowder technology was still ineffective because it continued to strain supply lines to the breaking point.³⁰

Russia, the Ottoman Empire, and the various powers waging war in India faced similar problems with enemies who kept them from focusing on the gunpowder technology. Until the middle of the seventeenth century, the Russians' major land enemy were nomadic Tatars. Firearms were of some use against them, particularly if deployed from behind fortified lines, but cavalry armed with bows and sabers was the major weapon, as in China. The Ottomans emphasized cavalry too, because much of their conflict involved frontier skirmishes and raiding. Even in the eighteenth century over 77 percent of their army was cavalry, versus under 27 percent in France. As for India, until the eighteenth century, warfare there too made heavy use of cavalry.

In addition, both the Ottomans and Russia had to funnel resources into another ancient technology with limited potential for improvement via learning by doing—galley warfare. Galleys, which dated back to classical times, were ideally suited to amphibious warfare in the light winds of the Mediterranean. They were also important for Russia on the Black Sea and the Baltic. Galleys did grow more effective in the Middle Ages and in the early sixteenth century they acquired ordnance that made it possible to smash ship hulls. But then the limits to what learning by doing could do to improve this aged technology were reached. Only a few guns could be added without taxing the oarsmen; with little room to store water for the oarsmen, the galleys' range was severely restricted; and they were vulnerable to heavily armed sailing ships.³¹

In short, the requirement that rulers rely almost exclusively on the gunpowder technology would work against innovation in the Ottoman Empire. It would lead to the same prediction for India before the eighteenth century, for China, except in the waning days of the Ming Dynasty, and for Russia, at least before the late seventeenth century,

when the Tatars ceased being a major threat. Japan and Western Europe, by contrast, would be more fertile ground for innovation.

Japan, however, would eventually run afoul of inequality (2), which predicts that war will stop if one ruler annihilates his opponents and conquers their realms. Without war, learning by doing stops, and so do advances in military technology. The resources mobilized z_i decline too. Such an outcome never occurred in early modern Europe, which was always fragmented and torn by conflict. But that is precisely what took place in Japan when it was unified under the Tokugawa Shogunate (1603-1867).

Japan had suffered through generations of devastating civil war until three victorious warlords finally unified the fragmented country under what became the rule of the Tokugawa Shoguns. By crushing opposition and rewarding loyalty, the Tokugawa then fashioned a regime that eliminated internal strife. Peace made the populace better off, but it left the Shogun with no one else to fight. In terms of our model, it was as though Japan's ruler was in a tournament with no other contestants. He had would have had no reason to devote resources to war or to advance the gunpowder technology, which had been heavily used in Japan ever since firearms were introduced in 1543. One might of course wonder why he or the warlords who united the country did not turn to foreign conquests once they had vanquished their domestic enemies. One of the warlords, Toyotomi Hideyoshi, actually did try to invade Korea (and via Korea, China) in 1592 and 1597, but failed, because he "lacked the resources" needed to carry out such an operation—in particular, a large navy. Other Japanese leaders were "unenthusiastic" about the operation and "quickly" withdrew from Korea after Hideyoshi died. They seemed to realize that an invasion without adequate resources was unrealistic. They

knew, in other words, that successful military competition against foreign powers entailed a large fixed cost (relative to the size of the prize), including the expense of building a powerful navy. That fixed cost—the b in the tournament model—ruled out the possibility of foreign war and thus halted improvements to the gunpowder technology.³²

As in Tokugawa Japan, inequality (2) would have also discouraged China from fighting distant wars in which the gunpowder technology might have been more useful than it was against nomads. For much of its history, China was a large unified empire and much bigger than neighboring states. The emperors (and the officials who advised them) would therefore have found themselves in a situation akin to that of the Tokugawa Shoguns: warfare abroad (including invading Japan) would have required building an effective navy or fighting distant land battles. That would have meant paying a prohibitively high fixed cost b , which would have made such wars unattractive.

What about the two other conditions for improving the gunpowder technology: that the ratio P/C of the value of prize to the sum of the average variable costs be high, and that rulers be able to acquire the latest innovations at low cost? The requirement that P/C be high clearly handicapped the Ottoman Empire in the eighteenth century. The Ottomans were fighting European states (so in terms of the model they were contending for the same prize P), but their tax revenues were lower than in eighteenth-century Europe. They collected less than the median for major European powers, less than what one of their major opponents, the Austrians raised, and less than what their other chief enemy, the Russians, mobilized, at least after 1750.³³ It follows that the Ottomans had a higher average variable cost of mobilizing resources than in Europe and that there were unlikely to be the ones advancing the gunpowder technology. Their high cost of

mobilizing resources would also imply (from 5) that they had little chance of defeating European rulers in the eighteenth century even if they imported the latest weapons and tactics.

As for the European rulers, their average variable costs of mobilizing resources were not only lower than in the Ottoman Empire (at least after 1700), but likely lower than in China too. Per capita tax rates in war time were much higher in Europe than in China (Table 3), and although the difference could simply reflect a less valuable prize in China or the nature of China's enemies, it fits claims that tax revenue in China was constrained by the threat of revolt and by elites who could more easily siphon off tax revenue in larger empire.³⁴ Another sign that the average variable cost were low in Europe is that taxes were high relative to GDP, at least in the eighteenth century, when we can make such comparisons for France and England. By then France was spending 5 to 10 percent of its GDP on military resources, and Great Britain even more—perhaps as much as 28 percent.³⁵ For countries that were still poor by modern standards, these figures are quite high. For comparison, at the end of the Cold War, the United States was devoting 5 percent of its GDP to the military, and the USSR perhaps 10 percent.³⁶

Like Europe, Japan before the Tokugawa Shogunate might have also faced low average variable costs. The evidence is indirect—the armies Japanese warlords raised were big relative to the population—but it would what one would expect in wartime when P/C was large.³⁷ By the eighteenth century, the Russians too likely had a low average variable cost too and a high value for P/C . They were by then fighting the western Europeans for the same prize, and although their per-capita tax revenues were still lower than in the west, the czars—thanks to the reforms of Peter the Great (1682-

1725)—could draft serfs into the military, cutting the average variable costs of fielding a military force.³⁸ By contrast, western leaders had to wait for the wars of the French Revolution to conscript troops on that scale

Finally, India's leaders were hobbled by high average costs of mobilizing resources and by a lower value of the prize they were fighting for, all of which reduced their ratio P/C . The Indian case is in fact a telling one. In the eighteenth century, the subcontinent was convulsed by virtually constant warfare among the leaders and states that arose as the Mughal Empire disintegrated. The unremitting hostilities imply that inequality (2) was satisfied, and the armies were fighting with gunpowder weapons and could easily have acquired leading innovations from one another in what was an active market for military goods and services.³⁹ But the one remaining condition required for advancing the gunpowder technology—that P/C be high—failed to hold.

On the one hand, political costs C of mobilizing resources were high. Tax revenues for India are lacking, but it is clear that the new states that emerged on the subcontinent were struggling to gain control of resources that remained under local control, as had been the case under the Mughals.⁴⁰ In addition, the value of the prize P was reduced by conflict within powerful Indian families over succession to a throne or rights to rule.⁴¹ Strife of this sort, which after the late Middle Ages was rarer in Europe, cut the value of the prize for victors in India, by raising the odds that a prince or other ruler would be unable to enjoy fruits of winning. The prize was large enough to get the rulers to fight, but not large enough relative to the average variable costs of fighting to get them to mobilize a large amount of resources Z . Since they were not mobilizing

many resources, the model would predict that their wars would generate little or no innovation.

The Indian case shows why unending warfare and highly developed markets for military goods were not enough to obtain advances in the use of gunpowder. If they had been enough, then eighteenth-century India should in fact have been an innovator, not a laggard. Our model, by contrast, predicts the opposite, because with high political costs and strife over rights to rule the Indian rulers would in equilibrium use small amounts of military resources and thus fail to innovate. If the model is correct, then it also helps explain why the East India Company became a dominant military power India. It simply had lower average variable costs of using the military and thus was willing to use more military resources in equilibrium. Not only could it draw on its own financial system to fund its military ventures, but it had also gotten control of the wealthy Ganges plain in northwestern India and won support for higher taxes there by offering elites a land market in return for higher levies. Elite cooperation and more wealth to tax would mean a lower c_i and, from expression 5, a greater chance of winning wars. It would be no surprise then that the Company conquered much of the subcontinent, simply by hiring away the best officers and their troops.⁴²

The only remaining condition is that rulers be able to acquire innovations at low cost. The barriers to doing so are clear. In the early modern world, embargos would not have been the major obstacle, since enforcement was difficult. But distance alone hampered the diffusion of the latest skills, weapons, and tactical innovations, even if mercenaries and weapons makers were willing to work for foreign masters.

Technological gaps could then have increased if learning by doing persisted in one part of

Eurasia and stopped in another. All rulers potentially could have advanced the gunpowder technology, but if they fell behind, catching up would have been difficult.

Some parts of the technology, after all, were just hard to transfer, which would have widened the gaps between laggards and leaders. The reason was that they involved a number of complementary skills or changes, and rulers had to acquire the whole package if they wanted the innovation. One of the improvements to French artillery in the eighteenth century, for instance, was a shift to manufacturing them by boring a solid casting instead of using a mould with a hollow core. Boring made cannons more accurate and cut the number rejected in initial testing. But adopting the technique required careful training and supervision of whole teams of skilled workers. The Swiss cannon founder who perfected the process complained that if business declined and some of his employees departed he would have a hard time finding and training replacements when demand picked up again. And so, when he was asked to export the process to France's ally, Spain, he contracted to import a whole group of skilled workers and even obtained the right to impose heavy penalties on any of them who quit.⁴³

Hiring the cannon founder alone was thus insufficient. The king of Spain needed all the supporting skills, or else he had to wait until a skilled team could be assembled and whipped into shape. Other advances required organizational changes—the small groups in the sixteenth-century Spanish infantry, for example, or the system of rewards on British ships that incited officers and men to victory at sea. Putting such changes into practice could easily have provoked opposition and so taken time. Transferring the innovations would have been even slower if they depended on complementary skills, such as navigation or metal working, that were scarce in the civilian economy.

Gunpowder innovations would spread most easily, we would therefore expect, when enemy powers were small and near one another and when military goods, services, and ideas could move between them with relative freedom. That was the case in India, and perhaps in Japan before the Tokugawa Shogunate as well, since the battling Japanese warlords were close enough to one another to at least copy what worked. And it was certainly the case in western Europe.

Western Europe is also the only part of Eurasia that satisfies all of the other conditions required for advancing the gunpowder technology, and it does so throughout the entire early modern period. No other Eurasian powers can meet that standard. The model would therefore predict that western Europe would be a leader in advancing the gunpowder technology. The other Eurasian powers would have lagged behind. Could they have caught up by importing European innovations when needed? They would all have had an incentive to buy the latest military technology from western Europe if it was more effective militarily, and the Europeans did in fact export their arms and expertise to places as far away as China.⁴⁴ But wholesale transfer of the cutting edge technology would have been hampered by distance alone in South or East Asia. If it was difficult to move a whole team of cannon makers from to Spain, how much harder would it have been to get them to India or China? The obstacles would have been much higher, because of the distance, the risks of ocean travel, and the difficulties of getting Europeans to settle in an alien place.

Russia and the Ottoman Empire would have a somewhat easier time of it, since they were closer to western Europe. Yet even with the imports, we would predict that anemic tax revenues would keep the Ottomans from defeating the Europeans after 1700.

The Russians, by contrast, could be expected to do much better, at least after the late seventeenth century. Not only could they import the technology more easily than distant Asian powers, but they could now focus on fighting with gunpowder weapons and mobilize enormous resources by drafting serfs.

4. Testing the model's implications in early modern Eurasia

We can test the model's implications for early modern Eurasia. If we begin with western Europe, we would expect to see innovation and productivity growth in the military sector. That certainly fits the literature on the military revolution, but there is also quantitative evidence supporting this prediction too, for we can measure the rate at which the productivity of the technology was increasing. The yardsticks used underestimate the productivity growth, because they fail to capture advances in tactics or provisioning that were an integral part of the gunpowder technology. They also have trouble with naval warfare, where western Europe's lead was perhaps greatest. The reason is that warships had variety of different goals, which varied over time. Firepower dominated the eighteenth century, but speed, range, and an ability to fight in inclement weather were also important, particularly in wars of economic attrition that were the focus of much early modern naval warfare.⁴⁵

Yet despite all these difficulties, the evidence that military productivity was advancing in early modern Europe is clear. Suppose, for example, that we ignore the other goals navies pursued and take firepower, measure by the weight of the shot, as our sole yardstick of naval output, which we can divide by shipboard labor and capital to get

an index of total factor productivity. In the English navy, this index was rising at a rate of 0.4 percent per year between 1588 and 1680, a period when firepower was gaining in importance.⁴⁶ Such a rapid growth was virtually unheard of in preindustrial economies, where total productivity was typically increasing at 0.1 percent per year or less in major sectors of the economy, if it grew at all.⁴⁷

Nor was productivity growth limited to naval warfare. On land the effective firing rate per French infantryman jumped by a factor of 6 or more between 1600 and 1750, as bayonets made it possible to replace pike men and matchlocks were supplanted by flintlocks with ramrods and paper cartridges. The higher firing rate translated into labor productivity growth of 1.5 percent per year, which rivals overall labor productivity growth rates in modern economies and far exceeds what one would expect for preindustrial economies.⁴⁸

Still another sign of rapid productivity growth was the falling price of weapons. The prices of cannons, muskets, and pistols tumbled relative to the price of other manufactured goods and relative to the cost of the relevant factors of production. Using the dual, we can estimate productivity for weapons manufacturing in early modern France and England. The median total factor productivity growth rate over periods ranging from the late fourteenth century to the late eighteenth century turns out to have been 0.6 percent per year, a rapid pace even at the outset of the Industrial Revolution.⁴⁹

What about the model's implications for the rest of early modern Eurasia? Although we lack similar figures for productivity, we can test the predictions against the historical record. If we begin with Japan, the model predicts improvements to the gunpowder technology until the Tokugawa Shogunate gained power in the early

seventeenth century, when warfare and innovation should have stopped and tax collections should have tapered off.

Those predictions match the historical record. Before the Tokugawa, the Japanese had discovered—some twenty years earlier than Europeans—the key tactical innovation (volley fire) that allowed infantry soldiers with slow loading muskets to maintain a nearly continuous round of fire. With the Tokugawa, that sort of innovation stopped, and so, as we know, did war.⁵⁰ And over time tax revenues declined as fraction of agricultural output.⁵¹ A cultural explanation cannot account for this sudden change, for Japanese continued to have a strong attachment to martial values. One might fear that this line of argument simply repeats the story of how the Tokugawa Shoguns banished guns. But in fact the shoguns did not ban firearms. Although they disarmed the population, they kept their own guns and required them for lords too.⁵²

Historical evidence also confirms the model's implications for China and eighteenth-century India. Both would have been expected to lag behind western Europe in developing the gunpowder technology, even though China was the birthplace of firearms and India would have been fertile ground for advances in gunpowder technology if the traditional argument about competition were correct. Both should also have tried to import weapons and expertise from Europe when the gunpowder technology proved useful.

That is exactly what happened. In China officials recognized that European weapons were superior, and they sought designs and expertise from the Portuguese or the Jesuits in both the Ming and the Qing dynasties.⁵³ Military leaders in eighteenth-century India followed much the same path. They readily adopted new weapons and tactics in

their unending wars, but they did not break new ground in their use. The innovations, by and large, came from western Europe with renegade experts, mercenary officers, and imports of weapons.⁵⁴

The model implies that Russia and the Ottoman Empire would also have been less likely to advance the gunpowder technology and that both would have imported weapons and military expertise from western Europe, up until the eighteenth century. Then their paths would diverge. High political costs c_i would make the Ottomans drop further back and cut their odds of winning wars, particularly against western powers. The reverse would happen for the Russians.

That is what happened. Military historians argue that the Ottomans fell behind western Europe in the late seventeenth century, particularly in field warfare. Although the Ottomans had a large artillery industry, they imported expertise from western Europe. By the eighteenth century, they dropped from the ranks of the great powers in Europe and were more likely to lose wars.⁵⁵ Russia, by contrast, joined the great powers in the eighteenth century, after importing western officers, shipwrights, cannon founders, and military architects. It increasingly began to win wars against western European powers.⁵⁶

The divergence between Russia and the Ottoman Empire is difficult to square with the argument that wars alone led to gunpowder innovations because both were frequently engaged in conflicts. That argument also fails to explain why all the wars in war-torn eighteenth-century India failed to advance the gunpowder technology. The tournament model can. It can also account for why China lagged behind, even though it was the birthplace of the gunpowder technology, and why Japan suddenly stopped

improving the gunpowder technology, a shift that cannot be reconciled with a cultural argument. It also fits Eurasian evidence about military victories, trends in taxation, and the flow of military goods and services. And with a simple modification, it can help us understand why the gap in military technology between Europe and the rest of Eurasia grew even wider in the nineteenth century.

5. Nineteenth-century Europe

After 1815, the incessant warfare that had bedeviled Europe virtually disappeared. Diplomats at the Congress of Vienna had fashioned a coalition that discouraged wars within Europe, and the coalition endured until late in the century. The rest of the world and warfare in the colonies was another matter. Some battles were fought, but by the standards of the past, they were short and relatively bloodless, allowing the continent to bask in peace until the onset of World War I (Table 1).⁵⁷

With warfare subsiding, did the tournament fade away too? It might seem so. Nonetheless, military technology continued to evolve. Rifled handguns and artillery replaced smooth bore muskets and cannons, and steam powered gunboats and armored battleships took the place of sailing ships—advances that gave the Europeans an even bigger edge in colonial wars.⁵⁸

An extension of our model can explain why, one that takes into account three critical changes. First, glory had receded as a goal rulers pursued, having succumbed to Enlightenment attacks and the devastating experience of the Napoleonic era.⁵⁹ And as the century wore on, foreign policy came under control of statesmen or legislative leaders

who stood to lose more from war than an Old-Regime monarch. The result (in addition to a possible reduction in the value of the prize P) was that it was much easier for leaders to negotiate and therefore avoid war.

To incorporate that possibility into the model, have two rulers or statesmen who have paid the fixed cost b and are willing to go to war go ahead and mobilize their resources z_i . But then allow them to negotiate over dividing the prize P before they actually begin fighting.⁶⁰ If they can both agree to a division, they can split the prize P accordingly, but if not, they have to fight as in the original model, with the winner receiving a prize dP ($0 < d < 1$) that is reduced by the damage done by war. If their agreement can be enforced by the resources they have mobilized, then they will reach a settlement. The tournament will have the same equilibrium as before, but with this difference. The rulers will act as if the prize is reduced to dP , and they will no longer actually fight, even when they both arm and pay the fixed cost b . Instead, they will mobilize a total amount of resources Z , which in equilibrium equals dP/C and live out an armed peace. War may still break out, because of other obstacles to a settlement, but it should be less frequent. That fits nineteenth-century European history fairly closely.

The second major change in the nineteenth century were political and administrative reforms that cut the political cost c_i of mobilizing resources. During the Napoleonic Wars, states pushed centralization of their fiscal systems further than ever before, and later in the century representative assemblies gained a voice in fiscal decisions. Cumulatively, the reforms made it easier to raise taxes and hence diminished the political cost c_i of mobilizing resources and the total cost C .⁶¹ Patriotism and conscription had the same effect. Although these political changes (as we have seen)

may have diminished the value of P , the lower C could offset the smaller prize. The nineteenth-century statesman would thus be more likely to negotiate peaceful settlements, but they could marshal far more resources $Z = P/C$ when the hostilities actually broke out.

There was one final critical difference in the nineteenth century: it was now clear that military technology could be advanced not just via learning by doing, but by research. Although some research had always been done, it grew more common in the eighteenth century, as the Enlightenment encouraged the collection of useful knowledge. That made it possible to improve military technology without actually fighting. The task became even easier in the nineteenth century, with the growth of engineering know how during the Industrial Revolution.⁶²

When, for instance, the French navy added steam warships in the early 1840s, British leaders grew fearful of a possible invasion and quickly jumped into a naval shipbuilding race with France. In a short time, the arms race and the research it triggered led both the British and French navies to adopt the the screw propeller, which was less vulnerable to gunfire than the initial method of steam propulsion, paddle wheels. Yet Britain and France did not go to war to begin the process. They relied on research, including an 1845 tug of war in Britain between a steamship with a screw propeller and another one with paddle wheels.⁶³ Similar research, spurred by fear of potential enemies, led (along with advances in useful knowledge during the Industrial Revolution) to better handguns, artillery, and fortifications, all in the midst of what was, for Europe, a time of peace.⁶⁴

More useful knowledge would relax the limit a to what learning by doing could do, but the model also has to incorporate decisions about research, which made it possible to innovate even in peace time. Let us consider then our two nineteenth-century rulers or statesmen who mobilize military resources z_i to use in either fighting or enforcing a peaceful settlement. Instead of equating z_i directly with taxes, assume that $z_i = f(x_i, y_i)$ is produced by spending tax revenues on x_i units of the existing military technology (each at a cost w_i) and y_i units of research on an improved technology (each at a cost r_i), with w_i and r_i reflecting both their relative scarcity in the economy and the political costs of raising revenue. Suppose, for the sake of simplicity, that the production function f is common to all rulers and constant returns to scale, and that each ruler takes his w_i and r_i (which may vary from country to country) as given. Then a ruler who decides to pay the fixed cost b in our modified tournament will choose x_i and y_i to maximize his expected payoff, given the possibility of a peaceful settlement and the actions of his adversary. It is easy to show that he will minimize the cost of producing the resources z_i that he mobilizes, that this cost will equal $c_i(w_i, r_i)z_i$ where $c_i(w_i, r_i)$ is the average variable cost of z_i , and that he will choose the same level of z_i as in the original model, except that the prize will now be reduced to dP and c_i will now be an increasing function of w_i and r_i . The equilibrium conditions of the model will remain the same, and if the two rulers do agree to a peaceful settlement, then they will still mobilize $Z = dP/C$ for the military. That is the same amount they would mobilize in war, and although the reduced prize dP will diminish Z , conscription and tax reforms will increase it by cutting the political portion of C .

How will innovation be affected? In the original model, innovation was only possible with war, but research should make it feasible under the sort of armed peace that prevailed in the 1800s. One might assume, though, that research in peacetime would be less effective than the learning by doing that takes place with war. Let us suppose then that research works like military expenditure divided between two different military technologies so that in an armed peace it is the share $s = r_i y_i / c_i (w_i, r_i) z_i$ of research spending in the military budget that drives innovation. In such an armed peace, a leader who mobilizes z in military resources will then have an innovation x distributed as $F^{sz}(x)$, while if he is at war, the distribution is $F^z(x)$. If two rulers with the same share s are in an armed peace, then the best innovation to emerge from their research will have a distribution $F^{sZ}(x)$, where $Z = dP/C$. As in the original model, the incentives to improve military technology via research will be no different from the incentives to win a potential war.

With this modification, what would the model lead us to expect for innovation in the nineteenth century? Since leaders were no longer obsessed with glory, the prize dP would be smaller, but C would be reduced by political reforms, and it would drop even more if the cost of research fell, as it likely did thanks to the advances in knowledge during the Industrial Revolution. Z , as a result, much be just as big as it was during early modern wars, or even larger, which could offset the effect of s on the distribution of innovations during an armed peace. The advances in science and engineering would also shift the support of the distribution F and relax the constraint imposed by the old limits to knowledge a . The armed peace would then generate as much innovation as in the past, or even more.

Thus, despite less time spent at war, the major European military powers were still competing in a tournament in the nineteenth century. Their effort were now devoted more to military research and to building up the potential of their armed forces than to actual fighting, at least within Europe itself. Imperial wars, however, were not ruled out by nineteenth century diplomacy, and thanks to the military innovations that the ongoing tournament produced (rifles and steam gunboats are prime examples) it was now much easier to acquire colonies.⁶⁵

6. Conclusion

The tournament model of Europe's wars yields a deeper understanding of why Europeans pushed the gunpowder technology of firearms, fortifications, and armed ships further than anyone else. Exogenous political and military conditions drove the rulers of western Europe's major powers to raise taxes and to spend heavily on this technology in fighting unending wars. The result was sustained innovation via learning by doing, all before the Industrial Revolution. When leaders' incentives shifted in the nineteenth century, the equilibrium outcome was armed peace, but when coupled with political changes and the advances in knowledge during the Industrial Revolution, that was enough to drive even more innovation.

Elsewhere, political and military conditions blocked such an outcome. In Japan, unification under the Tokugawa Shogunate snuffed out a similar tournament and removed incentives to funnel resources into the gunpowder technology. The story was similar in China, for it too, most of the time, was a large, unified empire. Furthermore,

the gunpowder technology was not effective against its major enemy, nomads from the north. The technology was of little use either in Russia's early wars, or against some of the Ottoman Empire's adversaries. In addition, by the eighteenth century, the Ottoman Emperors faced heavy political obstacles to raising taxes. So did the leaders whose forces battled in unending wars in eighteenth-century India.

The implication, according to the model, is that all of these parts of Eurasia would fall behind western Europe in developing the gunpowder technology, and that the gap would grow over time, particularly in countries far from the leaders in western Europe, because distance would slow the transfer of innovations, particularly if packages of complementary skills were involved. Both quantitative and qualitative evidence bears out this and the other predictions the model makes and argues against alternative explanations for Europe's dominance of the gunpowder technology. The argument about competition, for example, cannot explain why all the wars in eighteenth-century India failed to make it a center of military innovation, nor why Russia rose to become a major power.

Europe's lead was not foreordained. Learning by doing would have been possible anywhere before the Industrial Revolution, provided that the exogenous political and military conditions were right. If, for example, the Mughal Empire had disintegrated earlier, then the rulers and leaders who arose in its place might have had time to develop fiscal systems and stable dynasties before the British conquest. They might then have been at the forefront of gunpowder technology, and India might even have remained independent. Similarly, if the Mongols had not conquered China, then it might have remained divided, and the successors to the southern Song emperors might have had

more of an incentive to funnel resources into the gunpowder technology. China, the birthplace of gunpowder, might not have fallen behind.

But Europeans ended up dominating this technology, which allowed them to wage war at a distance. They were not posting huge infantry armies abroad, at least before the nineteenth century. But they could dispatch ships armed with cannons to prey upon trade in places as far away as Southeast Asia, and for protection, ship maintenance, and essential supplies of water and fresh food, the ships could rely upon European style fortresses, which, when built in Asia or the Americas, could be defended with a relatively small force. The fortresses thus complemented the naval forces and allowed the Europeans to hold critical trading posts and to protect what land they conquered without sending large numbers of officers and men abroad, an expensive undertaking given the high mortality rates during long voyages. And further technological innovation in the nineteenth century made it possible to extend the conquests and create colonial empires.⁶⁶

Table 1
Frequency of War in Europe

Period	Average Percentage of Time Principal European Powers Were at War
1550-1600	71
1600-1650	66
1650-1700	54
1700-1750	43
1750-1800	29
1800-1850	36
1850-1900	23

Source: Wright 1942, 1: Tables 29, 45, 46; Levy 1983 leads to similar results.

Note: The principal European powers are defined as France, Austria, Great Britain, Russia, Prussia, Spain, Netherlands, Sweden, Denmark, Turkey, and Poland.

Table 2: Frequency of Foreign War in China and Europe, 1500-1799

Country	Percent of time country is at war against foreign enemies, 1500-1799
China:	
all wars	56
excluding wars against nomads	3
France	52
England/Great Britain	53
Spain	81
Austrian dominions	24

Source: Micheal Clodfelter, Warfare and Armed Conflicts: A Statistical Reference to Casualty and Other Figures, 1500-2000 (McFarland & Company, 2002); Quincy Wright, A Study of War, 2 vols. (University of Chicago Press, 1942); Peter N. Stearns, The Encyclopedia of World History, page 376-381; and James Kung (personal communication of the figures for China).

Note: Excluding wars against nomads does not change the figures for the western European countries because they did not fight wars against nomads. The data for this table were collected by Margaret Chen, except for those for China, which were kindly furnished by James Kung. Chen also collected figures for China from Chinese sources, and her numbers were similar to Kung's.

Table 3: Annual per-capita taxation in China, England, and France, 1578 and 1776
(in grams of silver)

		1578	1776
China	Total	6.09	8.08
China	Portion under central government control	3.56	7.03
England	Portion under central government control	10.47	180.06
France	Portion under central government control	16.65	61.11

Source: For the French revenue and population figures, see Hoffman and Norberg 1994, 238-239 and the sources listed there. For England, the revenue figures come from data collected by P. K. O'Brien and P. A. Hunt and posted at the European State Finance Data Base that Richard Bonney has assembled (<http://www.le.ac.uk/hi/bon/ESFDB/dir.html>); and from evidence gathered by Mark Dincecco and made available at the Global Price and Income Group web site at <http://gpih.ucdavis.edu/> and in Dincecco 2009. The population figures are taken from Wrigley, Schofield et al. 1989, Table A3.1. For China the sources are Huang 1998 ; Myers and Wang 2002 ; Liu 2009 ; and the Global Price and Income History Group (gpih.ucdavis.edu) for units, silver equivalents, and prices of grain in China.

Note: The figures for England and France are decennial averages. For China, they are upper bound estimates that involve the following assumptions: the population is 175 million in 1578 and 259 million in 1776; the grain levy in 1578 is converted to silver at 1 shi equals 0.6 taels of silver; the service levy in 1578 is worth 10 million taels per year; the portion of taxes under central government control in 1578 includes taxes sent to Beijing or Nanjing, plus 25 percent of the service levy; 87 percent of the taxes are under central government control in 1776. China was at war in 1578 and 1776, which might have raised tax levels. For the sake of comparison, England was at war throughout the 1570s and 7 years out of 10 in the 1770s; France fought 3 years of 10 in the 1570s and 5 years of out 10 in the 1770s.

Bibliography

- Agoston, G. (2005). Guns for the Sultan: Military Power and the Weapons Industry in the Ottoman Empire. Cambridge, Cambridge University Press.
- Alavi, S. (1995). The Sepoys and the Company: Tradition and Transition in Northern India 1770-1830. Oxford, Oxford University Press.
- Alder, K. (1997). Engineering the Revolution: Arms and Enlightenment in France, 1763-1815.
- Anisimov, E. V. (1993). The Reforms of Peter the Great: Progress through Coercion in Russia. London, M E Sharpe.
- Atwell, W. (1988). The T'ai-ch'ang, T'ien-ch'i, and Ch'ung-chen reigns, 1620-1644. The Cambridge History of China. J. K. Fairbank and D. C. Twitchett. Cambridge, Cambridge University Press. 8: 585-640.
- Barfield, T. J. (1989). The Perilous Frontier: Nomadic Empires and China. Oxford, Blackwell.
- Barua, P. (1994). "Military Developments in India, 1750-1850." Journal of Military History 58(4): 599-616.
- Bell, D. A. (2007). The First Total War: Napoleon's Europe and the Birth of Warfare As We Know It. New York.
- Berry, M. E. (1982). Hideyoshi. Cambridge, MA, Harvard University Press.
- Berry, M. E. (1986). "Public Peace and Private Attachment: The Goals and Conduct of Power in Early Modern Japan." Journal of Japanese Studies 12(2): 237-271.
- Berry, M. E. (2005). "Presidential Address: Samurai Trouble: Thoughts on War and Loyalty." The Journal of Asian Studies 64(4): 831-847.
- Black, J. (1998). War and the world: Military power and the fate of continents, 1450-2000. New Haven, Conn., Yale University Press.
- Bonaparte, N.-L. and I. Favé (1846-72). Etudes sur le passé et l'avenir de l'artillerie. Paris.
- Boudriot, J. and H. Berti (1994). Les vaisseaux de 50 et 64 canons: Etude historique 1650-1780. Paris, ANCRE.
- Brandt, Loren, Debin Ma and Thomas G. Rawski. 2011. "From Divergence to Convergence: Re-evaluating the History Behind China's Economic Boom." Paper, Economic History Department, London School of Economics.
- Brito, D. L. and M. D. Intriligator (1985). "Conflict, War, and Redistribution." The American Political Science Review 79(4): 943-957.
- Brown, P. C. (1993). Central Authority and Local Autonomy in the Formation of Early Modern Japan. Stanford, Stanford University Press.
- Brzoska, M. (1995). World Military Expenditures. Handbook of Defense Economics. K. Hartley and T. Sandler, Elsevier: 45-67.
- Chase, K. W. (2003). Firearms : A Global History to 1700. Cambridge, UK ; New York, NY, Cambridge University Press.
- Cipolla, C. M. (1965). Guns, sails and empires: technological innovation and the early phases of European expansion, 1400-1700. New York, Pantheon Books.
- Clark, G. (2007). A Farewell to Alms: A Brief Economic History of the World. Princeton, Princeton University Press.
- Clodfelter, M. (2002). Warfare and Armed Conflicts: A Statistical Guide to Casualty and Other Figures, 1500-2000. Jefferson, North Carolina, McFarland.
- Cooper, R. G. S. (2003). The Anglo-Maratha Campaigns and the Contest for India. Cambridge, Cambridge University Press.
- Corvisier, A. and e. al (1997). Histoire militaire de la France. Paris, Presses Universitaires de France.
- Dincecco, M. (2009). "Fiscal Centralization, Limited Government, and Public Revenues in Europe, 1650-1913." Journal of Economic History 69: forthcoming.
- Esper, T. (1969). "Military Self-Sufficiency and Weapons Technology in Muscovite Russia." Slavic Review 28(2): 185-208.
- Fearon, J. D. (1995). "Rationalist explanations for war." International Organization 49: 379-414
- Finer, S. E. (1997). The History of Government. Oxford.
- Fletcher, Erin and Murat Iyigun. 2010. "The Class of Civilizations: A Cliometric Investigation." Paper, Institute for the Study of Labor, University of Colorado.

- Franke, H. (1974). Siege and Defense of Towns in Medieval China. Chinese Ways in Warfare. F. A. Kiernan and J. K. Fairbank. Cambridge, MA, Harvard University Press: 151-201.
- Fullerton, R. L. and R. P. McAfee (1999). "Auctioning Entry into Tournaments." The Journal of Political Economy(3): 573-605.
- Garfinkel, M. R. and S. Skaperdas (2007). Economics of Conflict: An Overview. Handbook of Defense Economics. T. Sandler and K. Hartley. Amsterdam, Elsevier. 2: 649-709.
- Glete, J. (1993). Navies and Nations: Warships, Navies and State Building in Europe and America, 1500-1800. Stockholm, Almqvist & Wiksell International.
- Gommans, J. (2003). Mughal Warfare: Indian Frontiers and High Roads to Empire, 1500-1700. London, Taylor and Francis.
- Gommans, J. and D. H. A. Kolff, Eds. (2001). Warfare and Weaponry in South Asia 1000-1800. Oxford, Oxford University Press.
- Goodman, D. C. (1988). Power and Plenty: Government, Technology and Science in Philip II's Spain. Cambridge, Cambridge University Press.
- Guilmartin, J. F. (1974). Gunpowder and Galleys: Changing Technology and Mediterranean Warfare at Sea in the Sixteenth Century. Cambridge, Cambridge University Press.
- Guilmartin, J. F. (1983). "'The Guns of the Santissimo Sacramento'." 24(4): 559-601.
- Guilmartin, J. F. (1988). "Ideology and Conflict: The Wars of the Ottoman Empire, 1453-1606." Journal of Interdisciplinary History 18(4): 721-747.
- Guilmartin, J. F. (2002). Galleons and Galleys. London, Cassell.
- Hall, B. S. (1997). Weapons and warfare in renaissance Europe : gunpowder, technology, and tactics. Baltimore, Md., Johns Hopkins University Press.
- Harding, R. (1991). Amphibious Warfare in the Eighteenth Century: The British Expedition to the West Indies, 1740-1742, The Royal Historical Society (Woodbridge, UK).
- Headrick, D. R. (1981). The Tools of Empire: Technology and European Imperialism in the Nineteenth-Century. New York-Oxford, Oxford University Press.
- Headrick, D. R. (2010). Power over Peoples: Technology, Environments, and Western Imperialism, 1400 to the Present. Princeton, Princeton University Press.
- Hellie, R. (1971). Enserfment and Military Change in Muscovy. Chicago, University of Chicago Press.
- Hoffman, P. T. (1996). Growth in a Traditional Society. Princeton, Princeton University Press.
- Hoffman, P. T. (2011a). "Prices, the military revolution, and western Europe's comparative advantage in violence." Economic History Review 64(S1): 39-59.
- Hoffman, P. T. (2011b). Why Was It Europeans Who Conquered the World? Pasadena, California Institute of Technology.
- Hoffman, P. T. and J.-L. Rosenthal (1997). The Political Economy of Warfare and Taxation in Early Modern Europe: Historical Lessons for Economic Development. The Frontiers of the New Institutional Economics. J. N. Drobak and J. V. C. N. Nye. San Diego: 31-55.
- Huang, R. (1970). "Military Expenditures in Sixteenth-Century China." Oriens extremus 17: 39-62.
- _____. 1998. "The Ming Fiscal Administration." The Cambridge History of China. J. K. Fairbank and D. C. Twitchett. Cambridge, Cambridge University Press. 8: 106-171.
- Jackson, M. O. and M. Morelli (2007). "Political Bias and War." American Economic Review 97(4): 1353-1373.
- Jackson, M. O. and M. Morelli (2009). "Strategic Militarization, Deterrence and Wars." Quarterly Journal of Political Science 4: 279-313.
- Jackson, M. O. and M. Morelli (2011). The Reasons for Wars--An Updated Survey. Handbook on the Political Economy of War. C. Coyne and R. Mathers. New York, Elgar.
- Josson, H. and L. Willaert, Eds. (1938). Correspondance de Ferdinand Verbiest de la compagnie de Jésus (1623-1688) Directeur de l'obervatoire de Pékin. Brussels.
- Kennedy, P. M. (1987). The Rise and Fall of the Great Powers : Economic Change and Military Conflict from 1500 to 2000. New York, Random House.
- Kolff, D. H. A. (1990). Naukar, Rajput and Sepoy: The Ethnohistory of the Military Labour Market in Hindustan, 1450-1850. Cambridge, Cambridge University Press.
- Kotilaine, J. T. 2002. "In Defense of the Realm: Russian Arms Trade and Production in the Seventeenth and Early Eighteenth Century." The Military and Society in Russia: 1450-1917, ed. Eric Lohr and Marshall Poe. Leiden.
- La Noue, F. d. (1587). Discours politiques et militaires du seigneur de la Noue. Basel.

- Lavery, B. (1983-1984). The Ship of the Line. London, Naval Institute Press.
- Levy, J. S. (1983). War in the Modern Great Power System, 1945-1975. Lexington, Kentucky, University Press of Kentucky.
- Liu, G. W. (2009). The Nexus of Power: Warfare, Market, and State Formation in Late Imperial China, 1000-1600. Utrecht, World Economic History Conference.
- Lorge, P. (2005). War, Politics and Society in Early Modern China: 900-1795. London, Routledge.
- Lucas, R. E. (1993). "Making a Miracle." Econometrica 61(2): 251-272.
- Lynn, J. A. (1997). Giant of the grand siècle : the French Army, 1610-1715. Cambridge ; New York, Cambridge University Press.
- Lynn, J. A. (2000). International Rivalry and Warfare. The Eighteenth Century. T. C. W. Blanning: 178-217.
- Mallett, M. E. (1974). Mercenaries and Their Masters: Warfare in Renaissance Italy. Totowa, Rowman and Littlefield.
- Martin, C. and G. Parker (1999). The Spanish Armada. Manchester, Manchester University Press.
- Mathias, P. and P. O'Brien (1976). "Taxation in Britain and France, 1715-1810: A Comparison of the Social and Economic Incidence of Taxes Collected for the Central Government." Journal of European Economic History 5: 601-650.
- Mattingly, Garrett. 1968. "International Diplomacy and International Law." The New Cambridge Modern History, ed. R. B. Wernham. Cambridge.
- McBride, M. and S. Skaperdas (2007). Explaining Conflict in Low-Income Countries: Incomplete Contracting in the Shadow of the Future. Institutions and Norms in Economic Development. M. Gradstein and K. A. Konrad. Cambridge, MA, MIT: 141-161.
- McNeill, W. H. (1964). Europe's Steppe Frontier. Chicago, University of Chicago Press.
- Minost, L. (2005). "Jean II Maritz (1711-1790): La fabrication des canons au XVIIIe siècle." Cahiers d'Etudes et de Recherches du Musée de l'Armée hors-série numéro 2: 1-287.
- Mokyr, J. (2002). The gifts of Athena : historical origins of the knowledge economy. Princeton, [N.J.], Princeton University Press.
- Murphey, R. (1983). The Ottoman Attitude Towards the Adoption of Western Technology: The Role of Efrenco Technicians in Civil and Military Applications. Contributions à l'histoire économique et sociale de l'Empire ottoman. J. L. Bacqué-Gramont and P. Dumont. Louvain: 287-298.
- Myers, R. H. and Y.-C. Wang (2002). Economic Developments, 1644-1800. The Cambridge History of China. J. K. Fairbank and D. C. Twitchett. Cambridge. 9: 563-646.
- Needham, J. (1954). Science and Civilisation in China. Cambridge, Cambridge University Press.
- Pamuk, S. and K. Karaman (2010). "Ottoman State Finances in European Perspective, 1500-1914." Journal of Economic History 70(3).
- Parker, G. (1996). The Military Revolution: Military Innovation and the Rise of the West, 1500-1800. Cambridge ; New York, Cambridge University Press.
- Parrot, D. (2001). Richelieu's army: war, government, and society in France, 1624-1642. Cambridge, Cambridge University Press.
- Parry, V. J. and M. E. Yapp, Eds. (1975). War, Technology, and Society in the Middle East.
- Parthasarathi, Prasanna. (2011). Why Europe Grew Rich and Asia Did Not: Global Economic Divergence, 1600-1850. Cambridge.
- Paul, M. C. (2004). "The Military Revolution in Russia, 1550-1682." Journal of Military History 68(1): 9-45.
- Perdue, P. C. (2005). China Marches West: The Qing Conquest of Central Eurasia. Cambridge, MA, Harvard.
- Pettegree, A. (1988). "Elizabethan Foreign Policy." The Historical Journal 31(4): 965-972.
- Pintner, W. M. (1984). "The Burden of Defense in Imperial Russia, 1725-1914." Russian Review 43(3): 231-259.
- Powell, R. (1993). "Guns, Butter, and Anarchy." The American Political Science Review 87(1): 115-132.
- Pryor, J. R. (1988). Geography, Technology, War: Studies in the Maritime History of the Mediterranean, 649-1571.
- Reischauer, E. O., J. K. Fairbank, et al. (1960). A History of East Asian Civilization. Boston., Houghton Mifflin.
- Rodger, N. A. M. (2004). The Command of the Ocean: A Naval History of Britain, 1649-1815.

- Rossabi, M. (1998). The Ming and Inner Asia. The Cambridge History of China. D. C. Twitchett and F. W. Mote. Cambridge, Cambridge University Press. 8: 221-271.
- Roy, Kaushik. "The Hybrid Military Establishment of the East India company in Suth Asia: 1750-1849." Journal of Global History. 6:195-218.
- Roy, T. (2010). Rethinking the Origins of British India: State Formation and Military-fiscal Undertakings in an Eighteenth Century World Region. Beijing, Centre for China in the World Economy, Tsinghua University.
- Schroeder, P. (1994). The Transformation of European Politics, 1763-1848. Oxford, Oxford University Press.
- Smith, T. C. (1958). "The Land Tax in the Tokugawa Period." The Journal of Asian Studies 18(1): 3-19.
- Sng, Tuan-Hwee. 2011. "Size and Dynastic Decline: The Principal Agent Problem in Late Imperial China 1700-1850." Paper, Princeton University, Niehaus Center for Globalization and Governance.
- Spence, J. D. (1969). To Change China: Western Advisers in China, 1620-1960. Boston,, Little.
- Stearns, Peter N. ed. 2001. The Encyclopedia of World History. Boston.
- Subrahmanyam, S. (1987). "The Kagemusha Effect: The Portuguese Firearms and the State in Early Modern South India." Moyen orient et océan indien, XVIe-XIXe siècles 4: 97-123.
- Tilly, C. (1990). Coercion, Capital and European States, A.D.990-1990, Blackwell.
- Totman, C. (1980). "Review of Giving Up the Gun: Japan's Reversion to the Sword, 1543-1879. By Noel Perrin." The Journal of Asian Studies 39(3 (May)): 599-601.
- Väth, A. (1991). Johann Adam Schall von Bell S. J. Missionar in China, kaiserlicher Astronom und Ratgeber am Hofe von Peking 1592-1666. Nettetal, Steyler Verlag.
- Waley-Cohen, J. (1993). "China and Western technology in the late 18th century." The American Historical Review 98(5): 1525 -- 1544.
- Washbrook, David. "Progress and Problems: South Asian Economic and Social History c. 1720-1860." Modern Asian Studies 22, 1: 57-96.
- Williams, R. (1972). The Works of Sir Roger Williams. Oxford, Oxford University Press.
- Wright, Q. (1942). A Study of War. Chicago, University of Chicago Press.
- Wrigley, E. A., R. S. Schofield, et al. (1989). The population history of England, 1541-1871 : a reconstruction. Cambridge, Cambridge University Press.

-
- 1 Headrick 1981 ; Parker 1996, 5; Headrick 2010.
 - 2 Black 1998.
 - 3 Kennedy 1987, 16-24
 - 4 Hoffman 1996.
 - 5 Hoffman and Rosenthal 1997; Tilly 1990
 - 6 Harding 1991, 28-30; Lynn 2000; Rodger 2004, 242; Mallett 1974, 88; Pettegree 1988.
 - 7 Louis-XIV and Sonnino 1970, 124; Machiavelli 1977, 247; Hale 1985, 29-32.
 - 8 Lynn 2000 ; Bell 2007, 29-35.
 - 9 Hoffman 2011b, Table 2. Losses in war did cost ministers their position.
 - 10 Brito and Intriligator 1985 ; Powell 1993 ; Fearon 1995 ; Jackson and Morelli 2011.
 - 11 Jackson and Morelli 2007.
 - 12 Anisimov 1993, 244-245.
 - 13 Mattingly, "International Diplomacy," p. 156. For the impact of past religious strife, see Fletcher and Iyigun 2011.
 - 14 See, for example, Berry 1982, 215-216.
 - 15 The model below is adapted from Fullerton and McAfee 1999 and Garfinkel and Skaperdas 2007 .
 - 16 For an excellent review of the conflict literature, see Garfinkel and Skaperdas 2007. The insightful model of Jackson and Morelli 2009 takes into account both spending and the decision to go to war, and it can explain more complex patterns of war and peace and military spending. But it says relatively little about the effect of changes in the cost of war, which will be important in what follows.
 - 17 If losers pay a penalty d that they can avoid by sitting out the war, then the model is identical, but with the prize raised to $P + d$ and the fixed cost b described below increased to $b + d$. If the penalty only applies when the ruler sits out the war and fails to defend his realm against attack, then the only difference is that the fixed cost decreases to $b - d$.
 - 18 Garfinkel and Skaperdas 2007
 - 19 Adding constraint on the amount of resources a ruler could mobilize would not change things greatly, but it would allow the ruler of a large country to offset his opponent's lower average variable cost.
 - 20 Mattingly 1968; Lynn 2000 185-186.
 - 21 La Noue 1587, 320-322, 352-357; Bonaparte and Favé 1846-72, 1: 65, 72; Williams 1972, c-civ; Hall 1997, 121-122; Parrot 2001, 42-43
 - 22 Goodman 1988, 123-141.
 - 23 Alder 1997
 - 24 Fullerton and McAfee 1999 .
 - 25 Lucas 1993
 - 26 Mokyr 2002
 - 27 McNeill 1964 ; Esper 1969 ; Hellie 1971 ; Barfield 1989 ; Rossabi 1998 ; Chase 2003 ; Gommans 2003 ; Agoston 2005, 58-59, 191; Lorge 2005 ; Perdue 2005 . In the nineteenth century, firearms became much more effective against against nomads Headrick 2010, 281-284.
 - 28 See, for example, Jackson and Morelli 2009 .
 - 29 As Fullerton and McAfee show, that someone designing such a tournament can attain any level of Z (and hence any expected value of innovation) at lowest cost by with only two contestants.
 - 30 Here I am relying on Needham 1954, 5, part 7: 398-407; Franke 1974 ; Atwell 1988 ; Lorge 2005 ; Perdue 2005 and ongoing research by Bozhong Li and Guanglin Liu.
 - 31 For this and the preceding paragraph, see Agoston 2005, 191, 202-203; Esper 1969; Glete 1993, 114-115, 139-146, 310, 706-712; Gommans 2003; Gommans and Kolff 2001; Guilmartin 1988; Guilmartin 2002, 106-125; Hellie 1971; Lynn 1997, 528-529; McNeill 1964; Parry and Yapp 1975; Paul 2004; Pryor 1988.
 - 32 Smith 1958 ; Reischauer, Fairbank et al. 1960, 1:614-615; Berry 1982, 207-217; Berry 1986, 207-217; Brown 1993 ; Parker 1996, 140-143; Guilmartin 2002, 182-190; Chase 2003, 175-196; Berry 2005.
 - 33 Pamuk and Karaman, 2010.
 - 34 Huang 1970, 1998; Sng 2011; Brandt et al 2011.
 - 35 Kennedy 1987 Table 2; Mathias and O'Brien 1976 , Table 5. French military expenditures are assumed to range from 45 to 85 percent of tax revenues.
 - 36 Brzoska 1995 , Table 3.
 - 37 Finer 1997 3: 1088.
 - 38 Hellie 1971 ; Pintner 1984
 - 39 Kolff 1990 ; Gommans and Kolff 2001 ; Gommans 2003. Although the Mughal Empire did use gunpowder weapons, it was more reliant on cavalry than the Europeans.
 - 40 Barua 1994; Stein 1984; Washbrook 1988; Alam and Subrahmanyam 1994.
 - 41 Gommans 2003 .
 - 42 Alavi 1995 ; Gommans and Kolff 2001 ; Cooper 2003 ; Gommans 2003; Roy 2010 .

43 Alder 1997, 39-46; Minost 2005.

44 Hoffman 2011a.

45 Guilmartin 1974, 253-254; Guilmartin 1983 ; Glete 1993, 58-61.

46 Capital here is computed from displacement, and labor from the crew sizes for the English navy as a whole. The data are taken from Martin and Parker 1999; and Glete 1993, 186, 195, 205, except for the factor shares (0.496 for capital and 0.503 for labor), which are derived from 1744 construction and crew labor costs in Boudriot and Berti 1994, 146-152. For the importance of firepower, see Glete 1993; Guilmartin 2002; Martin and Parker, 33-36.

47 For examples, see Hoffman 1996 ; Clark 2007. One might argue that the English navy was simply specializing in firepower at the expense of speed or range—in other words, that it was moving along a frontier of output possibilities while productivity remained constant. But by the late 1500s it had already begun to emphasize bombardment as an alternative to the boarding that had been the customary goal in naval battles, and the 1588 data in fact come from ships that were already specialized in firepower—the heavily armed flotilla that defeated the Spanish Armada.

48 Hoffman 2011a, Table 3

49 Hoffman 2011a. An alternative calculation yields an even higher median rate of 1.1 percent per year.

50 Parker 1996, 18-19, 140-143; Chase 2003, 175-196; Berry 2005.

51 Smith 1958.

52 For the source of the story (Noel Perrin's Giving up the Gun) and a review that sets the facts straight, see Totman 1980 .

53 Jossion and Willaert 1938 ; Needham 1954, 5, part 6; Spence 1969, 15, 29; Franke 1974 ; Vāth 1991, 111-115; Waley-Cohen 1993 ; Lorge 2005, 125-128 and Li Bozhong, personal communication.

54 Kolff 1990 ; Gommans and Kolff 2001 ; Gommans 2003; Roy 2011. Even defenders of Indian military prowess admit that the advances with the gun powder technology by and large came from the West. See Subrahmanyam 1987 ; Barua 1994 ; Alavi 1995, 24-25; Cooper 2003, 31-32, 42-44, 289-294; Parthasarathi 206-213.

55 Levy 1983, (who the great powers were); Murphey 1983 ; Agoston 2005, 10-12, 193-194, 201. The Ottomans lost 30 percent of 23 wars in the years 1500-1699 and 56 percent of 9 wars in 1700-99 ($p = 0.09$, one sided).

56 Cipolla 1965 ; Hellie 1971 ; Levy 1983 ; Pintner 1984 ; Anisimov 1993 ; Paul 2004, Kotilaine 2002. Russia did develop an arms industry during the seventeenth and eighteenth centuries, but arms imports continued up to the 1780s. Russia lost 36 percent of 11 wars in 1500-1699 and 12 percent of 17 wars in 1700-1799 ($p = 0.06$, one sided).

57 Schroeder 1994, vii, 574-575, 581, 799-803. In Table 1, most of the wars in the years 1800-1850 were fought before 1815. If they are removed, the number of years at war drops sharply.

58 Headrick 2010.

59 Schroeder 1994 ; Bell 2007 . One sign of glory's waning hold was the diminishing frequency with which the word (and its French equivalent) appeared in books, according to a search (conducted on August 5, 2011 with ngrams.googlelabs.com) of books scanned by Google.

60 The extension to the model here is adapted from Garfinkel and Skaperdas 2007 , which contains more realistic variations; see also McBride and Skaperdas 2007 .

61 Dincecco 2009.

62 Mokyr 2002.

63 Lavery 1983-1984, 1: 155; Glete 1993, 443-446, 450, 455; Corvisier and al 1997, 2: 490-497. The results of the Crimean War (1853-1856) did play a role in winning over decision makers.

64 See, for example, Corvisier and al 1997, 2: 476-477, 483-499.

65 Headrick 1981 .

66 Headrick 1981 ; Headrick 2010 .