10-11-2018

The Supply Side Determinants of Territory and Conflict

Jordan Adamson
Chapman University, jadamson@chapman.edu

Erik O. Kimbrough
Chapman University

The Supply Side Determinants of Territory and Conflict

Jordan Adamson * Erik O. Kimbrough † ‡

Original Draft: October 15, 2017
This Draft: October 11, 2018

Abstract

What determines the geographic extent of territory? We microfound and extend Boulding's "Loss of Strength Gradient" to predict the extensive and intensive margins of conflict across space. We show how economies of scale in the production of violence and varying costs of projecting violence at a distance combine to affect the geographic distribution of conflict and territory. We test and probe the boundaries of this model in an experiment varying the fixed costs of conflict entry. As predicted, higher fixed costs increase the probability of exclusive territories; median behavior closely tracks equilibrium predictions in all treatments.

Keywords: conflict, territory, experiments
JEL Classification: D74, C9, P48

* Affiliation: Smith Institute for Political Economy and Philosophy, Chapman University. Email: Jadamson@chapman.edu. Homepage: https://sites.google.com/view/jordan-adamson.

† Corresponding Author. Affiliation: Smith Institute for Political Economy and Philosophy, Chapman University, and Department of Economics, Simon Fraser University. Email: ekimbrough@gmail.com. Homepage: https://sites.google.com/site/erikkimbrough.

‡Thanks to conference participants at Contests: Theory and Evidence (2018) and the Experimental Economics World Meeting (2018), to seminar participants at the Economic Science Institute Brown Bag Series at Chapman University, Dan Kovenock, David Rojo-Arjona and Roman Sheremeta for comments and suggestions.

1 Introduction

In this paper, we explore how the different costs of conflict determine the size and shape of territory. We develop a model that provides a microfoundation for the classic "loss-of-strength gradient" introduced by Boulding (1962), in which the ability to project power decreases with distance. Under the model, the cost structure associated with entering and engaging in conflict at a distance determines the scope of territory, with parameters determining whether and to what extent each location is contested or controlled by a single actor. We then take the model to the laboratory, where we conduct two sets of experiments. We first test the predictions of the theory directly under the conditions specified in the model, then subsequently under conditions of Knightian uncertainty about the underlying conflict technology. The first set of experiments allows us to test equilibrium and comparative static predictions of the theory. The second set of experiments probes the boundaries of the theory by allowing us to observe conflict behavior when the precise nature of the incentives for conflict are not fully known to the contestants (as in conflicts outside the lab). Behavior is strikingly consistent with the predictions of the theory under both information conditions.

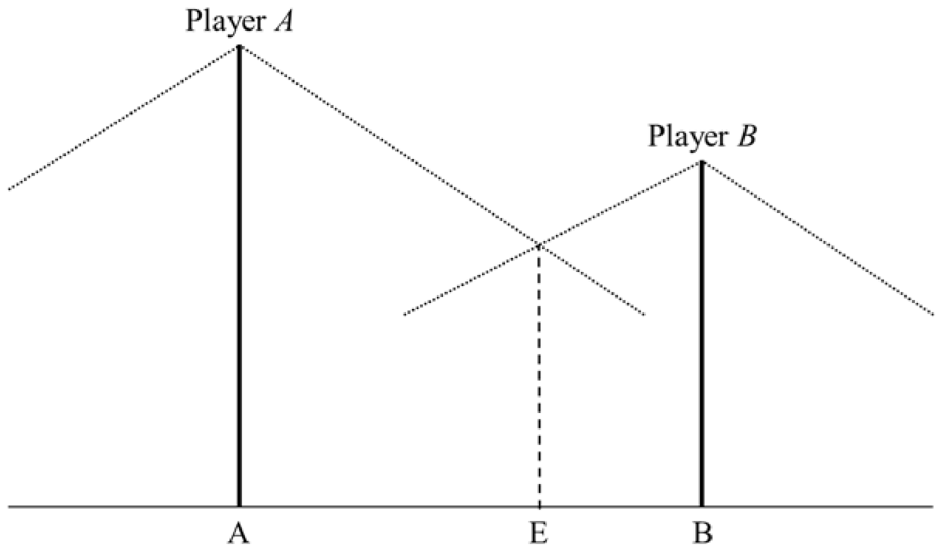
Outside of economics, territory is a central concept in the academic study of conflict. In political science, anthropology, and biology, a large literature is devoted to understanding the nature and scope of territory (Mitani et al., 2010; VanValkenburgh and Osborne, 2012; Vasquez, 2012; Toft, 2014; Johnson and Toft, 2014; Glowacki et al., 2017; Bonadonna et al., 2017). Yet territory has been understudied by the economic literature on conflict.[1] This is surprising not only because much conflict is territorial, but also because economic factors are thought to be a fundamental cause of territorial conflict, and economic reasoning is often implicitly employed to explain territorial extent. It is all the more surprising since the basic relationship between territory and the projection of power at a distance was laid out by economists long ago (Boulding, 1962; Tullock, 1983).

In Boulding's theory, which is reminiscent of Hotelling's (1929) theory of spatial competition, contestants each have a "base" located at some point in space (e.g. at points along a line, see Figure 1). The "power" or conflict capacity of an agent is represented graphically by the height of the bar at their base. Contestants project power from their base, with their capacity to project power diminishing with distance. Boulding's model defines territorial boundaries as the point in space where the power of contestant A is equal to the power of contestant B, i.e. point E in the figure. To the left of E, we have A's territory, and to the right of E, we have B's territory. This framework has intuitive appeal, and yet to our knowledge no one has yet provided a microfoundation for Boulding's model. Thus the primary contribution of our

[1](See e.g. Findlay and Lundahl, 2016) who states "While the study of frontiers has a place in the fields of history, geography, and political science, it has been almost completely ignored in economics." Thus, "an important goal for future studies is to link mechanistic models of boundary formation with the cost-benefit approach." (Adams, 2001).

model is to reinvigorate the study of territory in economics by microfounding and extending the intuitive theory introduced by Boulding (1962).

Figure 1: Boulding's Model of Territory



Like Boulding's, our model is explicitly spatial, so that geographic constraints and variation are allowed to play a role in determining the distribution of conflict and territory. Failure to account for the spatial element in conflict has been identified as a major gap in conflict theory by economists (Kimbrough et al., 2017), biologists (Rusch and Gavrilets, 2017) and political scientists (Hansel in Vasquez, 2012, p. 22).[2] One exception is the literature on Blotto Games, which analyzes constrained troop allocation across spatially distinct battlefields (Kovenock and Roberson, 2012). Since the complexity of these games has prevented intuitive predictions about territory, our approach starts with a simple (Tullock) objective function widely used in conflict theory.[3] Agents compete in contests for resources that are located at points in space. We introduce spatial variation via "the great principle of the further the weaker" (Boulding, 1962) in order to generate simple comparative statics for the distribution of conflict and territory. We then generalize this model both analytically and experimentally, showing analytically how analogous predictions arise under general contest success functions and richer geographies and showing experimentally that the model organizes observed behavior under the conditions of the theory and under boundary conditions more similar to those in which conflicts occur outside the lab.

[2]For instance, even though the famous hawk-dove game was designed with the study of territory in mind (Smith and Price, 1973) it is non-spatial. Rusch and Gavrilets (2017), in his review of biological contests, argues that "Although many of the models reviewed [...] identify territory as the resource most likely to be contested, it has rarely been taken into account explicitly".

[3]A second exception is the computational literature on spatial conflict/cooperation (e.g. Nowak et al., 1994; Ifti et al., 2004; Szabó and Szolnoki, 2009) which models the evolutionary fitness of various strategy types among many agents interacting in space (e.g. via an approach based in cellular automata). In these models, space usually plays a role in shaping which agents interact with one another and thus what selection pressures are faced by which strategies. Territory is defined, if at all, ostensively, as a region in which a single kind of agent predominates.

Our paper also contributes to the literature in political economy on the formation of states. Most definitions of the state encompass some notion of a territorial monopoly of violence (Weber, 1965; Barzel, 2002; Abramson, 2017).[4] Yet the presence of such a "monopoly" and the boundaries of such a "territory" are often taken as given. Our theory helps delineate conditions under which monopolies of violence will (and will not) emerge across space and thus provides theoretical foundations for the presence of one crucial condition for the formation of states.

This last point highlights another key contribution of our model: the size of territories and the presence (or absence) of monopolies on violence in each area are equilibrium *outcomes* rather than assumptions or simple choice variables. The idea that roving-bandits may eventually opt to become stationary and thereby take on the functions of states is broadly accepted (Olson, 2000; De La Sierra, 2018), yet it misses essential features about territory: territory is not exogenous (Agnew, 1994) and whether there are monopolistic outcomes or not depends on the entry decisions of multiple actors. To address this issue, we build on the literature on asymmetric conflict (Dari-Mattiacci et al., 2015; Olszewski and Siegel, 2016) and conflict entry (Morgan et al., 2012; Fu et al., 2015). In particular, we build on the asymmetric fixed-cost setup of Ritz (2008) by incorporating the decisions of the marginal contestant into the equilibrium calculation. In our framework, a defined territory and the number of competitors therein are equilibrium outcomes. Under some cost structures, there are territories held by a monopolist, under others, all territories are contested, and under others still, some territories are neither held nor contested by anyone.[5] By endogenizing the presence and extent of territorial monopolies on violence, our model better coheres with historical evidence suggesting that such exclusive monopolies are a special case.[6]

As noted above, the basis for our model comes from the landmark book by Boulding (1962). While this led to a few scattered articles on this topic, we are aware of only two closely related models.[7] Baker

---

[4] Abramson (2017) defines states as "organizations that maintain a quasi-monopoly of violence over a fixed territory." Weber (1965) defines the state as the "monopoly of the legitimate use of physical force within a given territory". (Barzel, 2002, p. 22) argues "The state consists of ... a territory where these individuals reside, demarcated by the reach of the enforcer's power". This is reflected even in the dictionary definition of territory as "a geographic area belonging to or under the jurisdiction of a governmental authority " https://www.merriam-webster.com/dictionary/territory.

[5] We build on a burgeoning economics literature incorporating geography into both empirical and theoretical models of political violence (Berman and Couttenier, 2015; Dow et al., 2017; Adamson, 2018). But this paper also has ties to industrial organization - in particular, to the literature on local monopoly (Maskin and Tirole, 1988). In our model, exclusive territories are *non-cooperative* equilibria leading to profit between monopolistic and 0-profit extremes.

[6] For example, the geographic extent of political territories, and number of competitors within those territories, were variable throughout European history (Branch, 2014). Parker (2012) argues "imperial domains should not be seen as bounded by static impervious borders. The margins of empires are better characterized as porous frontier zones.". A globally recurring example is the enlargement of territories after the introduction of new transport technology - e.g. the horse, ocean-going ships.

[7] Hirshleifer (1991a) noted at the end of a book chapter that "in the simplest case an equilibrium is achieved at a geographic

(2003) uses a 6 stage Stackelberg game to model how much of a territorial endowment a group would opt to protect and predicts when we might see "geographically stable territories" or "home-ranges". Similarly, Anderson and McChesney (1994) model spatial conflict over land, but without considering strategic interaction or cost variation. Our model combines the best of both these frameworks: a single stage game that endogenizes the size of territories using the framework of conflict theory (Tullock, 1974) while incorporating ideas from economic geography about regional patterns (Krugman, 1991) and boundaries (Spolaore, 2012). While the traditional approach to conflict entry emphasized the influence of attributes (e.g. the shape) of the contest-success function (Hirshleifer, 1991b; Skaperdas, 1992; Skaperdas and Jia, 2012), our cost-side approach is better suited to explain why the same contestants will fight in some regions but not others. This approach matches a historical literature that emphasizes the costs of projecting power and economies of scale in violence in political developments (Latzko, 1993; Herbst, 2000).[8] We formalize this approach to predict where regions of peace and war will exist.

Finally, our experiments provide a direct test/illustration of our model and a boundary test of the theory under conditions analogous to those faced by conflict actors outside the lab. This latter aspect of our design builds on work since Smith (1962, 1982) that examines the behavior of subjects under realistic but hard to model scenarios. Since conflict generally occurs behind a veil of radical uncertainty about its prospects, we conduct half of our sessions without giving subjects any information about the form of the contest success function faced in each conflict. Military philosophers and practitioners of all ages have expressed little sense of a contest-success function, but rather a genuine sense of Knightian uncertainty about conflict.[9] Models of Knightian uncertainty are difficult to formulate, but it is straightforward to construct experimental environments in which such uncertainty is inherent. Experiments like these can provide evidence on the extent to which people learn about and respond to underlying incentives for conflict in a world of uncertainty. Moreover, since we see that the theory successfully organizes our data, despite subjects' radical uncertainty about the environment, we can be more confident in the applicability of our model and its implication that territory and conflict should be conceived of as equilibrium outcomes of an underlying spatial game.

---

boundary". Caselli et al. (2015) created a model where "two countries play a game with two possible outcomes: war and peace" and the likelihood of war depends on the distance to a natural resource.

[8]Herbst (2000), much like Boulding, depicts pre-colonial African states as centers of power that radiate outwards. (Herbst, 2000, p .56) explains the reason for that shape being due to "the immediate fixed cost facing any leader who wished to extend authority were thus extremely high ... As a result, beyond the political core, power tended to diminish over distance."

[9]In fact, Keynes used the example of war to motivate the very idea of a non-defined probability distribution, and contests were a big part of Knight's thinking. Keynes (1937) states "The sense in which I am using the term is that in which the prospect of a European war is uncertain . . . About these matters there is no scientific basis on which to form any calculable probability whatever. We simply do not know.". Knight (1997 (1935) states "The activity which we call economic, whether of production or of consumption or of the two together, is also, if we look below the surface, to be interpreted largely by the motives of the competitive contest of game, rather than those of the mechanical utility functions to be maximized".

The experiments also speak to two other literatures in experimental economics: spatial game-theory (Kirchkamp and Nagel, 2007; Grujić et al., 2014) and the economics of conflict (Carter and Anderton, 2001; Duffy and Kim, 2005; Powell and Wilson, 2008). While experiments testing spatial game theory have explored to what extent patterns of behavior in Prisoners Dilemma experiments match the emergent distribution of agent types in simulations, our experiment focuses on the how cost structures incentivize territory formation. As for the literature on conflict experiments (see e.g. Dechenaux et al., 2015), it is vast, but the introduction of an explicit model of geography to a multi-battle contest represents an innovation within the prevailing framework.

2 Theory

A finite number of I players are located at fixed locations on a plane and can compete to obtain valuable resources at every location. Each player can put forth effort at a location to obtain a share of the resource. There are fixed costs to enter, as well as marginal costs of effort. Effort costs are higher at more distant locations, so different players will have different effort costs at each location; some will have a cost-advantage and others will have a cost dis-advantage. Each player's willingness to enter into conflict at a location is determined by the spatial gradient of costs and benefits.

Territory emerges when there is only one entrant over a set of locations. This happens when there are both asymmetric marginal costs and high entry costs. The reason is that players with higher effort costs earn lower profits, and lower profit players prefer to exit with high entry costs. While other patterns result from alternative cost structures, we focus on this territorial outcome.[10] We describe the general solution but focus most of our discussion on a two-player Tullock contest success function setting (the setup we use in our experiments) to develop intuition about when territory emerges.

2.1 Setup: Micro Motives

Consider player i based at location ℓ^i and considering conflict at location ℓ. Each location has resources Y, which could in principle vary across locations, but which we treat as fixed below. Denote $e^i(\ell)$ as the effort from i exerted in the conflict at location ℓ. The share of resources obtained by i at ℓ is $P^i(\ell)$, which is an implicit function of all efforts; $P^i = \frac{e^i}{E^i+e^i}$. Note $E^i(\ell) = \sum_{k \neq i} e^k(\ell)$ is the sum of others' conflict efforts and $n(\ell)$ is the total number players expending effort at that location. There is a constant marginal cost at each location $c^i(\ell)$, but this cost is weakly increasing with the distance from i's base $d^i(\ell, \ell^i)$.

[10] Whenever profits net of entry costs are positive for both players, both enter the conflict and exert effort equal to (8). With very high fixed costs, profits net of entry costs are always negative for both players creating a "de-militarized zone". With moderate fixed costs, there are multiple equilibria with one entrant. That case is a generalization of the case where fixed costs are low enough so that one player always has positive profit when players are best responding on the intensive margins.

There is also a fixed cost K at each location; this, too, could vary in principle, but we treat it as fixed. So i's profit at a given location is:

$$\Pi^i(\ell) = YP^i(\ell) - c^i(\ell)e^i(\ell) - K \tag{1}$$

Player i allocates effort at each location to maximize profit:

$$\max_{e^i(\ell)} \int \Pi^i(\ell) d\ell \tag{2}$$

The optimum at each location depends on $E^i(\ell)$, and the across-individual average of marginal effort costs, $\overline{c(\ell)} = \frac{1}{n(\ell)} \sum_k c^k(\ell)$. Denoting ε as the resource-share elasticity with respect to effort, which implicitly depends on all efforts, we can write the first order condition for effort as:

$$e^i(\ell) \;\; = \;\; \varepsilon^i(\ell)\frac{YP^i(\ell)}{c^i(\ell)} \tag{3}$$

For there to be regions with only one contestant (i.e. for there to be territory), one player must always choose to enter while others must not. In the presence of fixed costs of entry, conflict earnings must at least cover entry costs, or a player will prefer to exit. When entry is not a dominant strategy, some effort and entry probability will render players indifferent between entering and exiting. The $0-$profit equation for player i implies

$$e^i(\ell) = \frac{YP^i(\ell) - K}{c^i(\ell)} \tag{4}$$

Thus, we can solve for the equilibrium probability that territory emerges over a set of locations. In Appendix A.1 we show graphically how the microfoundations provided here can aggregate to model territory without specifying any functional forms, a lá Boulding. Given specific functional forms, this problem can be solved numerically with non-linear optimization techniques, but in what follows we simplify and employ the widely used Tullock contest success function. This allows us to find closed-form solutions and is the simplest setup that shows how the costs of projecting power and economies of scale in the production of violence affect territory.

2.2 Asymmetric Players with Tullock Form

First consider a Lemma pertaining to Tullock contests generally. By adding a 0 to $\Omega = \sum_k e^k$

$$\Omega \;\; = \;\; \sum_k \left(e^k + E^k\right) - \sum_k E^k = n\Omega - \sum_k E^k = \frac{1}{n-1}\sum_k E^k \tag{5}$$

Then note the first order conditions for the intensive margins at a specific location (equation 3) with

Tullock form yields

$$E^i(\ell) = \Omega(\ell)^2 \frac{c^i(\ell)}{Y} \tag{6}$$

Combining equations 5 and 6 gives

$$\Omega(\ell) \quad = \quad \frac{1}{n(\ell)-1} \sum_k \left(\Omega(\ell)^2 \frac{c^k(\ell)}{Y} \right) = \frac{1}{n(\ell)-1} \frac{\Omega(\ell)^2}{Y} n(\ell) \overline{c(\ell)} = \frac{n(\ell)-1}{n(\ell)} \frac{Y}{\overline{c(\ell)}} \tag{7}$$

Equation 8, which provides equilibrium efforts when all players are at an interior solution, is found by substituting equation 7 into 6, so that

$$E^i(\ell) = \left(\frac{n(\ell)-1}{n(\ell)} \right)^2 \frac{c^i(\ell)}{\overline{c(\ell)}^2} Y \tag{8}$$

Applying the same logic for all $i = 1, ..., n(\ell)$ creates a linear system of $n(\ell)$ equations and $n(\ell)$ unknowns, which is uniquely solved for in Appendix Section A.2. Since $\frac{c^i(\ell)}{\overline{c(\ell)}^2}$ follows a spatial gradient determined by distance from base, $d^i(\ell, \ell^i)$, spatial patterns of profit and effort result. A simple example for 3 players over 2 dimensions in which all players are at an interior solution at all locations is shown in Appendix Section A.3. The example highlights how cost asymmetries shape the spatial distribution of conflict efforts, when players enter conflict. However, territory can emerge under conditions in which not all players want to enter the conflict.

As noted above, when fixed costs are high, entry may not be a dominant strategy since a cost-disadvantaged player may earn a negative profit at the interior solution (equation 10), and would prefer to exit. However, in that case, remaining players would have incentive to reduce their efforts. But if they lower effort too much, the cost-disadvantaged player who found it in their interest to exit before would instead have a best response to enter and exert positive effort. At that point, the reduced efforts of the cost-advantaged players are not best-responses. Consider when the cost-disadvantaged player i is indifferent between entering and not. Equations 4 and 3 combine to imply the following.[11]

[11] For Tullock, it is easier to use rearrangements of equations 3 and 4. Plugging equation 3 into 4 to solve for ε^i implies that $P^i(\ell)(1-\varepsilon^i(\ell)) = K/Y$ and plugging back into equation 3 implies $e^i(\ell) = \left(\frac{\varepsilon^i(\ell)}{1-\varepsilon^i(\ell)} \right) \frac{K}{c^i(\ell)}$. Note the Tullock form implies $\varepsilon^i = \frac{E^i}{E^i+e^i}$ and $\frac{\varepsilon^i}{1-\varepsilon^i} = \frac{E^i}{e^i}$. Then plug those elasticity terms into those equations and solve.

$$
\begin{aligned}
e^i(\ell) &= \frac{\sqrt{Y}-\sqrt{K}}{\sqrt{c^i(\ell)}}\frac{\sqrt{K}}{\sqrt{c^i(\ell)}} \\
E^i(\ell) &= \left(\frac{\sqrt{Y}-\sqrt{K}}{\sqrt{c^i(\ell)}}\right)^2
\end{aligned} \tag{9}
$$

For territory to emerge, it must be the case that only one player enters with certainty. When there is a marginal player left after all higher cost players have exited, as in Hirshleifer (1995) and Ritz (2008), the decisions of the second lowest cost player are what matters for territory.[12] Thus, we further simplify by focusing on the 2 player case. This 2 player case provides intuition for how the costs of projecting power at a distance combine with economies of scale in the production of violence to affect territory, and it corresponds to the setup of our experiments.

2.3 Nash Equilibrium for Two Player Tullock

For two players, the intensive equation (8) simplifies to

$$
e^i(\ell) \quad = \quad \frac{c^{-i}(\ell)}{\overline{c(\ell)}^2}\frac{Y}{4} \tag{10}
$$

Equilibrium resource shares are $P^i(\ell) = \frac{c^{-i}(\ell)}{2\overline{c(\ell)}}$. These equations characterize equilibrium completely in the cases in which both players have a pure strategy to enter and expend effort at all locations. However, changes in either fixed costs or marginal effort costs can cause the equilibrium to switch from one in which both players have a pure-strategy to enter to one in which a cost-advantaged player has a pure strategy to enter and a cost-disadvantaged player has a mixed-strategy. The mixed strategy equilibrium occurs where the cost-disadvantaged player is indifferent between exiting and entering, but enters with a probability such that the cost advantaged player does not want to deviate.

The extensive equations (9) simplify to

$$
\begin{aligned}
e^i(\ell) &= \frac{\sqrt{Y}-\sqrt{K}}{\sqrt{c^i(\ell)}}\frac{\sqrt{K}}{\sqrt{c^i(\ell)}} \\
e^{-i}(\ell) &= \left(\frac{\sqrt{Y}-\sqrt{K}}{\sqrt{c^i(\ell)}}\right)^2
\end{aligned} \tag{11}
$$

[12]Delineating all strategic interactions for N players is cumbersome and will muddy the point we wish to make about the creation of territory. It's left for future work to explore the case of multiple cost-disadvantaged players on the extensive margins.

To compute equilibrium values, denote $e^{-i}(\ell)$ as the cost-advantaged players' effort at the indifference point for the cost-disadvantaged player. Probabilistic combinations of $e^{i}(\ell)$ and exit are a best-response to $e^{-i}(\ell)$. Denote the probability $\sigma^{i}(\ell)$, as the equilibrium probability of enter in this 2−point mixed strategy. We find $\sigma^{i}(\ell)$ when $e^{-i}(\ell)$ is a best-response to $e^{i}(\ell)$ with probability $\sigma^{i}(\ell)$. Maximizing

$$E\left[\Pi^{-i}\right] = (1-\sigma^{i}(\ell))Y + \sigma^{i}(\ell)YP^{-i}(\ell) - c^{-i}(\ell)e^{-i}(\ell) - K \tag{12}$$

has the first order conditions in equation 6 but with $\sigma^{i}(\ell)Y$ instead of Y. Specifically

$$E^{-i} = \frac{(E^{-i}+e^{-i})^2}{Y\sigma^{i}} \Rightarrow \sigma^{i} = \left(\frac{e^{-i}}{e^{i}}+1\right)\frac{c^{-i}e^{-i}}{Y}. \tag{13}$$

Substituting equations 11 into 13 and solving yields

$$\sigma^{i}(\ell) = \left(\frac{c^{-i}(\ell)}{c^{i}(\ell)}\right)\left(\frac{\sqrt{Y}-\sqrt{K}}{\sqrt{K}}\right) \tag{14}$$

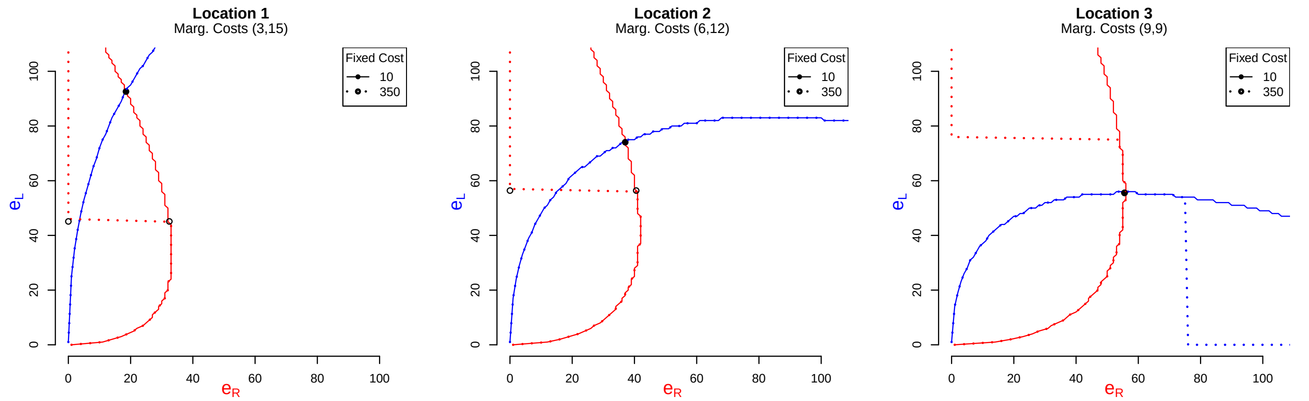
This shows the main comparative statics: as the fixed costs shrink or the other person's relative costs rise, probability of entry increases. Diminishing costs of projecting power are shown by $\frac{c^{-i}}{c^{i}(\ell)} \to 1$. Increasing economies of scale in the production of violence are shown by $\frac{\sqrt{Y}-\sqrt{K}}{\sqrt{K}} \downarrow$. What is most important for territorial outcomes is how these terms interact. Each term multiplies the other in the cumulative probability of territory in region R; $\int_R \sigma^{i}(\ell)d\ell$.

2.4 Numerical Example

A numerical example illustrates how the extensive and intensive margins change with distance from a base due to the changing cost asymmetries with high and low fixed costs. Consider two symmetric players, L and R, competing over 3 locations: Location 1 at base L, Location 3 half way between base L and base R, and Location 2 half way between location 1 and Location 3. The marginal costs of effort at each location are $(c_L, c_R) = \{(3,15),(6,12),(9,9)\}$ which changes the cost-asymmetry but not $\bar{c}$. The fixed costs are either $K = 350$ or $K = 10$. Figure 2 shows how the combination of fixed costs and marginal costs change the best responses and the equilibrium. At locations 1 and 2, we have a mixed strategy equilibrium in which L always enters the conflict and exerts effort sufficient to make R indifferent between entry and exit. The mixed strategy equilibrium in equation (14) can be visualized where the dashed red-lines intersect the solid-blue lines (although there will be small differences because P is a non-linear function which creates a difference between expected utility and utility of expected values). At location 3, both players always enter and expend effort in equilibrium. This is the simplest exposition of the non-linear and interacting effects of how the cost of projecting power and economies of scale in the production of violence affect conflict decisions at the micro level. This is the benefit and

cost structure we employ in the experiment.

Figure 2: Best Response Example



3 Experimental Design

We design a laboratory experiment to test the point and comparative static predictions of the theory directly. In our experiment two contestants are arranged along a line segment, on which there are 5 battlefields, each containing a resource worth 2000 Experimental Currency Units (ECU), at equally spaced intervals. At each battlefield, the contestants must decide whether to incur a fixed cost of entering the battle, and if so, how much costly effort to expend at that battlefield. The contestants each have a “base" at the battlefields at the ends of the line segment. We define two player types “L" and “R", with Player L being assigned a base on the leftmost battlefield and Player R being assigned to the rightmost battlefield. They can project their power out from that base by paying a fixed cost of entry (which, within a treatment is constant across battlefields) and a variable cost of conflict effort, which increases linearly with distance in our design.

Conflicts at each battlefield are realized via a Tullock contest success function. Contestants receive their *expected* conflict winnings, minus any fixed or variable costs incurred at each battlefield. Our treatments hold fixed the linear function defining the variable cost of conflict (specifically each unit of effort costs $3ECU \times (1+d)$, where d is the distance of the battlefield from the subject's base), and instead we vary the fixed costs of entry from Low $(10ECU)$ to High $(350ECU)$. In one treatment (Low), the equilibrium outcome involves conflict at all 5 battlefields, with no clearly defined territory, and in the other treatment (High), we observe more clearly defined territories, with both players always fighting at only the central battlefield in equilibrium. Table 1 displays the fixed cost parameters and the resulting equilibrium entry/effort decisions for each treatment.

Table 1: Equilibrium Predictions

Player	Value	Fixed Cost	Effort (Entry-Prob.)					Profits
			Loc1	Loc2	Loc3	Loc4	Loc5	
L	2000	10	93 (1.00)	74 (1.00)	56 (1.00)	37 (1.00)	19 (1.00)	3006
R	2000	10	19 (1.00)	37 (1.00)	56 (1.00)	74 (1.00)	93 (1.00)	3006
L	2000	350	45 (1.00)	56 (1.00)	56 (1.00)	41 (0.70)	32 (0.28)	1303
R	2000	350	32 (0.28)	41 (0.70)	56 (1.00)	56 (1.00)	45 (1.00)	1303

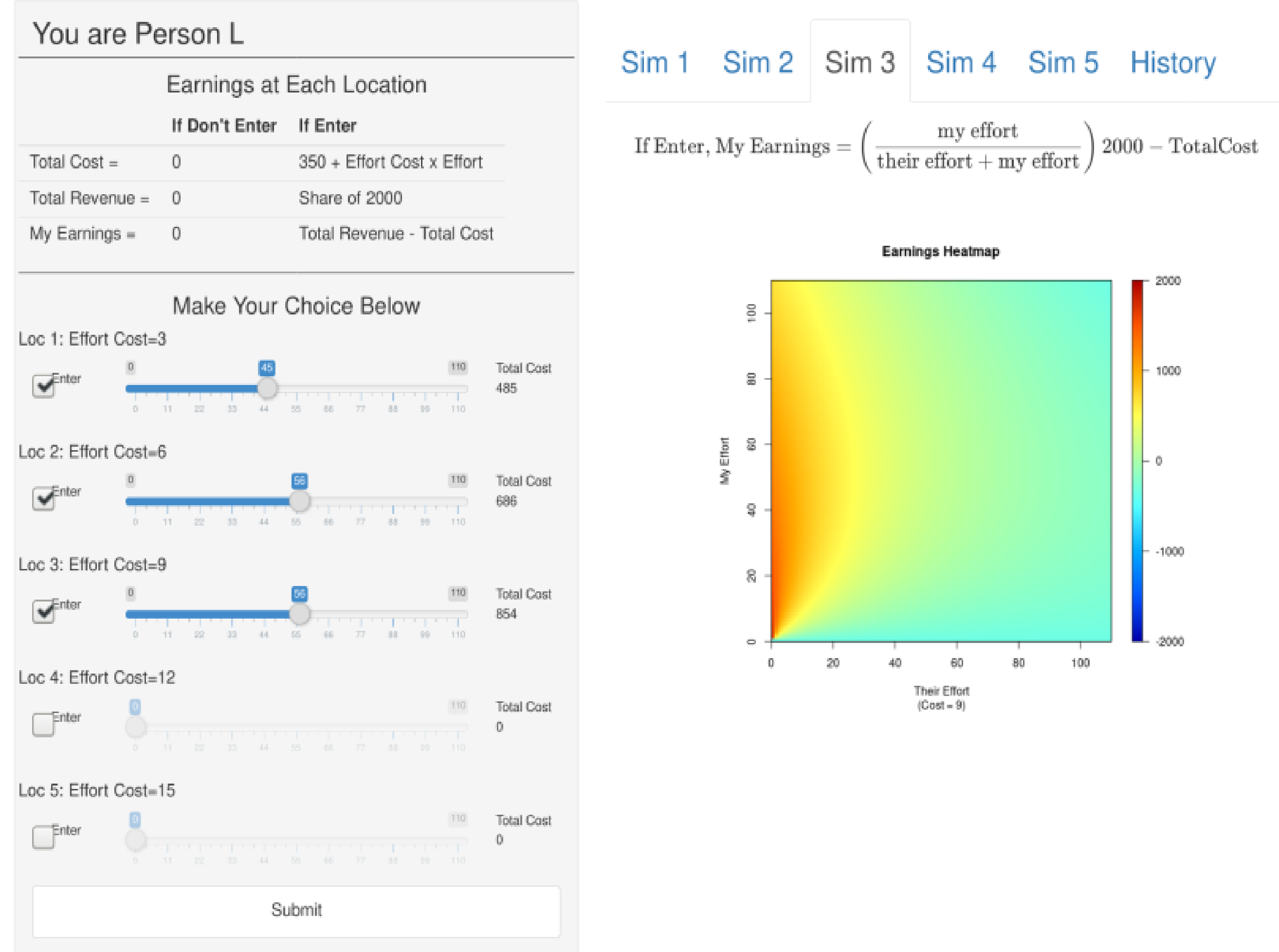
In the High treatment, the subject interface was as shown in Figure 3 (the Low treatment was presented in the same manner). The hypothetical player in the Figure is making decisions consistent with equilibrium from the perspective of Player L. Subjects first chose via a check box whether to Enter the "competition" at each "location" (aka battlefield) and then, conditional on entry, how much effort to expend. Effort costs were chosen via a slider, and the projected variable cost updated in real time as a subject moved the slider. On the right side of the screen, a heat map shows the payoff consequences associated with each combination of Player L and Player R actions; subjects could use tabs to toggle the heat map for each battlefield. At the end of each period, subjects were also provided complete information about their own and their opponent's strategy as well as the associated own payoff. This was stored as a scrollable list so that subjects could refer back to previous experience when making decisions in subsequent periods. By design, subjects had all the information required to compute the equilibrium entry and effort decisions. These treatments allow us to test whether subject behavior corresponds to the equilibrium.

3.1 Adding Realism: Uncertainty and Repeat-Interaction

To explore the boundaries of the theory, we conduct two additional treatments designed to capture important dimensions of conflict in field settings: Knightian uncertainty about conflict with non-random neighbors. Specifically, the second set of treatments differ in both the matching protocol and the information provided to subjects. First, instead of random rematching, these treatments employ partner matching since most territorial conflict arises repeatedly among neighbors. Second, the Uncertain-Low and Uncertain-High treatments introduce Knightian uncertainty, such that subjects remain *uninformed* about both the form of the contest success function and the heat map of possible payoffs. This uncertainty also reflects a fundamental feature of most conflicts.[13] Subjects are informed of the cost structure and of the fact that their share of the resource value from a conflict is increasing in their own effort and decreasing in their opponent's effort. Otherwise, they are provided no information about how conflict outcomes are generated. Like subjects in the Low and High treatments, they observe their counterpart's strategies

[13] E.g. Mao Zedongs theory on protracted war states "the peculiar nature of war makes it impossible in many cases to have full knowledge about both sides; hence the uncertainty about military conditions and operations, and hence mistakes and defeats." (Tse-Tung, 2011).

Figure 3: Subject Interface



and outcomes at each battlefield in each round, but this is their only source of information about conflict outcomes. These treatments allow us to test whether subjects learn to respond to the incentives provided by the conflict environment, despite operating under uncertainty. That is, does the equilibrium of the underlying game organize the data, even when the information conditions required for the achievement of equilibrium are not met?

3.2 Procedures

For each session, we recruited 18 subjects to the lab at random from the subject pool of the Economic Science Institute Laboratory at Chapman University. No subject had any experience in a prior contest experiment, and no subject participated in our experiment more than once. Half of the subjects were assigned the role of player L and half the role of player R, and these roles remained constant throughout a session. Subjects began the experiment in either the High or Low treatment, and we performed 16 static

repetitions of the conflict game, randomly rematching subjects between rounds. After 16 repetitions, we announced (unbeknownst to the subjects) that the fixed costs had changed and that the conflict game would continue for an additional 16 repetitions. Across sessions we randomized whether subjects first experienced the High or Low treatment, so that we can identify treatment effects using both between and within-subject treatment variation in fixed costs. The amount of information and pairing procedure was held constant within subject but varied between subjects. Each treatment block had 2 sessions beginning with Low and 2 sessions beginning with High. The entire design is summarized by Table 2.

Table 2: Experimental Design: Sessions × Individuals

	Fixed Costs	
	$350 \rightarrow 10$	$10 \rightarrow 350$
Random Matching, Full Info	2×18	2×18
Partner Matching, Knightian	2×18	2×18

Subjects received paper copies of the instructions, and these were also read aloud. At the conclusion of the instructions, we conducted a single guided practice round to familiarize subjects with the experimental interface and then subjects completed a second, self-paced practice round. The experiment began when no subjects had additional questions. After the first 16 periods, an announcement about the change in cost parameters was made orally. See Appendix B for a copy of the full instructions and the script for the practice period and oral announcements.

Subjects were paid their earnings from a single period, drawn at random at the end of the experiment. We converted ECU to dollars at a rate of 200 ECU = $1. To eliminate bankruptcy risk and ensure payoff salience, subjects' payoffs included a $10 endowment. We added the earnings from the randomly chosen period (which could be positive or negative) to the endowment and the lab-standard $7 payment for arriving on time. Subjects earned $30 for a two hour session on average, with payoffs ranging from (min= $14.75, max= $61.75).

4 Experimental Findings

4.1 Entry and Effort Under Full-Info and Random Matching

We begin with an analysis of entry decisions in the baseline treatments, High and Low, which provide subjects full information and employ random matching. Figure 4 displays conflict entry probabilities by treatment for each battlefield over the final 5 periods of each treatment condition (i.e. we focus on behavior after subjects have gained substantial experience with the environment). Since the game is

symmetric, we pool the data for the left and right players, showing entry probabilities as a function of the marginal cost of conflict effort. Recall that in the Low treatment, when entry costs are small, the model predicts always enter at all 5 battlefields by both players, and in the High treatment, when entry costs are large, the model predicts always enter only at the 3 battlefields with the lowest marginal costs of conflict. While the data clearly reject these point predictions (e.g. there is too little entry in the Low treatment, relative to theory, and both too little and too much entry, depending on the case in the High treatment), we see support for the comparative static prediction that there will be more conflict entry in the Low treatment than in the High treatment. Entry at a battlefield by only one subject reflects the creation of territory, suggesting that territory emerges more often, as predicted, when entry costs are high.

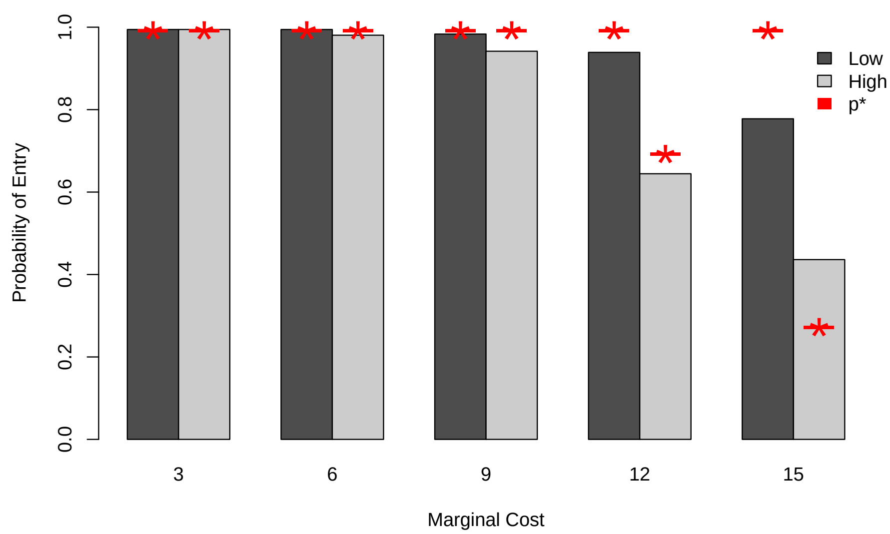


Figure 4: **Probability of conflict entry, by treatment and effort cost under full information and random matching.**

We provide statistical support for the foregoing observations via linear probability estimates with subject fixed effects and bootstrapped standard errors clustered at the subject level.[14] Thus the treatment effects are identified from within-subject variation. The dependent variable measures entry decisions. It takes a value of 1 if a subject chose to enter conflict at a given location and 0 otherwise. The independent variables include dummies for the marginal cost of conflict at the location, a High fixed cost treatment dummy, and the full set of interactions. The intercept captures the entry probability at the location with marginal cost of conflict = 3 in the Low fixed cost treatment. We use data from the final 5 periods of each treatment, so our sample consists of 72 subjects, each of whom makes 5 entry decisions (one for each location) in each of 10 periods (5 per treatment).[15] Estimates are reported in column (1) of Table 3.

[14]Results are qualitatively unchanged if we instead cluster standard errors at the session level.

[15]To see the entire effort distribution over all periods, see Appendix Section C.1. In Appendix Section C.2 we also report CDFs of subject-level average behavior.

	(1) Entry	(2) Effort
Effort Cost = 6	0.00	-10.51***
	(0.00)	(2.21)
Effort Cost = 9	-0.01	-18.38***
	(0.01)	(3.69)
Effort Cost = 12	-0.06**	-39.22***
	(0.02)	(4.11)
Effort Cost = 15	-0.22***	-52.23***
	(0.04)	(4.31)
High (Fixed Cost = 350)	0.00	-27.09***
	(0.01)	(3.67)
Effort Cost = 6 × High	-0.01	7.13**
	(0.01)	(2.17)
Effort Cost = 9 × High	-0.04	18.20***
	(0.02)	(4.39)
Effort Cost = 12 × High	-0.29***	23.19***
	(0.05)	(5.17)
Effort Cost = 15 × High	-0.34***	32.06***
	(0.05)	(5.16)
Intercept (Effort Cost = 3)	0.99***	85.39***
	(0.00)	(2.96)
Observations	3600	3127
R-sq	0.288	0.262

Clustered standard errors in parentheses.
* p<0.05, ** p <0.01, *** p < 0.001

Table 3: **Fixed effects regressions of entry and effort decisions by treatment and effort cost, under full information and random matching.**

A Wald test rejects the joint test of the null hypothesis that all observed entry probabilities are equal to their theoretical values (p-value < 0.001). As noted above, there is “too little" entry relative to the theory in the Low treatment (at locations with high effort costs) and “too much" in the High treatment. Note that the test is quite stringent, since the predicted entry rate is 100% in all but two cases (such boundary predictions are easy to reject). However, as predicted, there is less entry in the High treatment than in the Low treatment. Moreover, the data are consistent with the comparative statics of the model, as we observe negative and significant coefficients of the High cost treatment only for the two highest-effort-cost locations. Thus the data support the following finding:

Finding 1: The extent of territory depends on the fixed cost of conflict entry and effort, as predicted, with clearly defined territory emerging more often in the High treatment than in the Low.

Figure 5 displays the distribution of conflict effort, conditional on entry, at each battlefield, over the final 5 periods of each treatment. The equilibrium efforts from Table 1 are displayed as red bars dotted

with asterisks. In general, the sample median tracks the equilibrium effort at each battlefield reasonably closely, and the equilibrium effort falls within the sample interquartile range in 9 out of 10 cases.

We provide statistical support for this finding via fixed effects regression analysis of individual conflict expenditures at each battlefield, and we cluster standard errors at the subject level. The dependent variable is the subject's conflict effort at a given location, and the independent variables include dummies for the marginal cost of conflict at the location, a High fixed cost treatment dummy, and the full set of interactions. The intercept captures the conflict expenditures at the location with marginal cost of conflict = 3 in the Low fixed cost treatment. We use data from the final 5 periods of each treatment, so our sample consists of 72 subjects, each of whom makes *up to* 5 effort decisions (one for each location) in each of 10 periods (5 per treatment). Estimates are reported in column (2) of Table 3.

A Wald test rejects the joint test of the null hypothesis that all conflict efforts equal their theoretical point predictions (p-value < 0.001). Overall, we observe significant differences (i.e. Wald test p-values $<$ 0.05) between observed mean effort expenditures and theoretical predictions in 5 out of the 10 fixed cost $\times$ marginal cost combinations; 4 of the 5 reveal significantly higher expenditures, and 1 of the 5 reveals significantly lower expenditures than predicted. Nevertheless, the data are again broadly consistent with the comparative static predictions of the theory. For instance, effort expenditures are declining in effort costs within the Low fixed cost treatment, as expected. Similarly, effort expenditures are initially (weakly) increasing and then decreasing in effort costs in the High fixed cost treatment.

Finding 2: Conflict efforts are broadly consistent with the equilibrium comparative statics, with slight deviations from theoretical point predictions in the direction of excess conflict expenditure.

In the aggregate, the data from the Low and High treatments provide reasonably strong support for the theoretical predictions, when we observe subjects under conditions analogous to those under which the theory was derived (i.e. full information about own and other conflict capabilities and one-shot interaction, as induced via random matching).

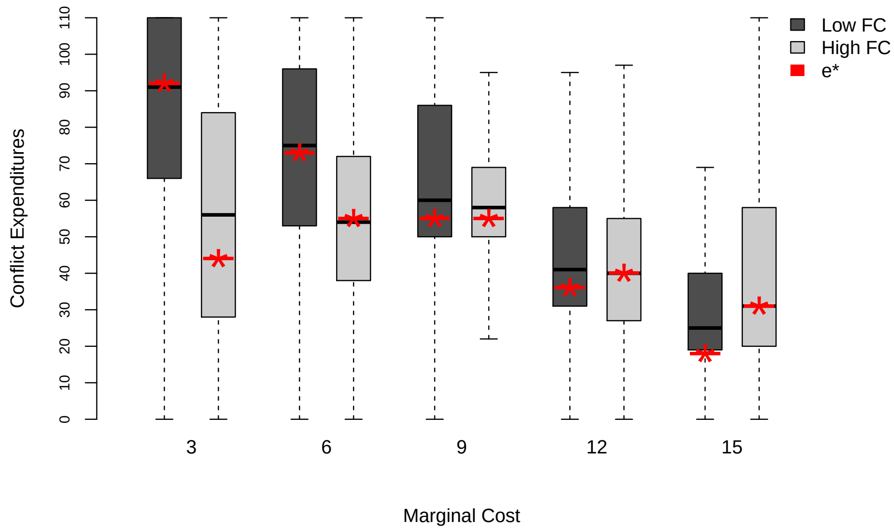


Figure 5: **Boxplots of conflict efforts, by treatment and effort cost under complete information and random matching.** Non-entry is coded as missing data. Thick black bars indicate sample medians, and the boxes bound the interquartile range.

4.2 Entry and Effort under Knightian Uncertainty and Partner Matching

Figure 6 is directly analogous to Figure 4 and displays conflict entry probabilities by treatment for each battlefield over the final 5 periods of each treatment condition. Observed entry behavior under uncertainty about the contest success function is *strikingly* similar to that observed under complete information. On the whole we see too little entry, relative to the predictions, but the data again broadly confirm the theory. Entry rates are decreasing in the marginal cost of conflict effort, and we see clear evidence that entry is less likely in the High fixed cost treatment, primarily when effort costs are also high. Note that this is true despite subjects' radical uncertainty about the contest success function, which renders computation of best responses virtually impossible, and despite the partner matching protocol, which could have facilitated widespread cooperation via repeat interaction.

We provide statistical support for the foregoing observations via linear probability estimates with subject fixed effects and bootstrapped standard errors clustered at the pair level.[16] As above the treatment effects are identified from within-subject variation. The dependent variable measures entry decisions. It takes a value of 1 if a subject chose to enter conflict at a given location and 0 otherwise. The independent variables include dummies for the marginal cost of conflict at the location, a High fixed cost treatment dummy, and the full set of interactions. The intercept captures the entry probability at the location with marginal cost of conflict = 3 in the Low fixed cost treatment. We use data from the final 5 periods of

[16]Results are qualitatively unchanged if we instead cluster standard errors at the session level and compute them via bootstrap.

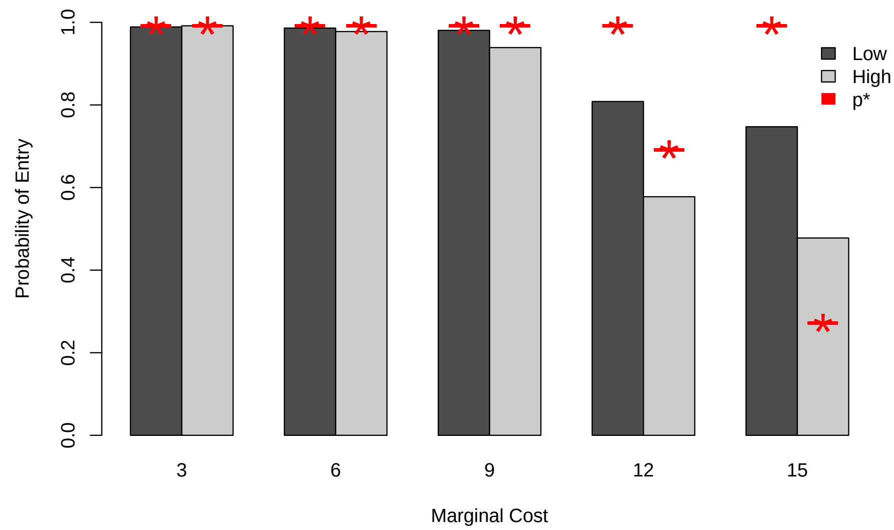


Figure 6: **Probability of conflict entry, by treatment and effort cost under Knightian uncertainty and partner matching.**

each treatment, so our sample consists of 72 subjects, each of whom makes 5 entry decisions (one for each location) in each of 10 periods (5 per treatment). Estimates are reported in column (1) of Table 4.

A Wald test rejects the joint test of the null hypothesis that all observed entry probabilities are equal to their theoretical values (p-value < 0.001), but nevertheless the treatment effect of High fixed costs is negative and both economically and statistically significant when marginal costs are high. Next we turn to subjects' effort decisions, conditional on entry.

Figure 7 displays the distribution of conflict effort, conditional on entry, at each battlefield, with non-entry coded as missing data over the final 5 periods of each treatment. As in the treatment with full information, we see that the sample median conflict expenditures are quite close to the equilibrium predictions, with the equilibrium effort always within the sample interquartile range.

As before, we report fixed effects regression analysis of individual conflict expenditures at each battlefield, and we cluster standard errors at the pair level. The dependent variable is the subject's conflict effort at a given location, and the independent variables include dummies for the marginal cost of conflict at the location, a High fixed cost treatment dummy, and the full set of interactions. The intercept captures the conflict expenditures at the location with marginal cost of conflict = 3 in the Low fixed cost treatment. We use data from the final 5 periods of each treatment, so our sample consists of 72 subjects, each of whom makes *up to* 5 effort decisions (one for each location) in each of 10 periods (5 per treatment). Estimates are reported in column (2) of Table 4.

	(1) Entry	(2) Effort
Effort Cost = 6	-0.00	-6.81**
	(0.00)	(2.36)
Effort Cost = 9	-0.01	-5.45
	(0.00)	(5.08)
Effort Cost = 12	-0.18***	-25.73***
	(0.05)	(5.43)
Effort Cost = 15	-0.24***	-35.53***
	(0.05)	(5.58)
High (Fixed Cost = 350)	0.00	-13.12*
	(0.01)	(6.41)
Effort Cost = 6 × High	-0.01	2.42
	(0.01)	(3.21)
Effort Cost = 9 × High	-0.04*	7.97
	(0.02)	(6.96)
Effort Cost = 12 × High	-0.23***	12.53
	(0.06)	(6.49)
Effort Cost = 15 × High	-0.27***	12.56*
	(0.06)	(6.11)
Intercept (Effort Cost = 3)	0.99***	68.07***
	(0.01)	(5.02)
Observations	3600	3051
R-sq	0.251	0.101

Clustered standard errors in parentheses.
* p<0.05, ** p <0.01, *** p < 0.001

Table 4: **Fixed effects regressions of entry and effort decisions by treatment and effort cost, under Knightian uncertainty and partner matching.**

A Wald test rejects the joint test of the null hypothesis that all conflict efforts equal their theoretical point predictions (p-value < 0.001). Overall, we observe significant differences (i.e. Wald test p-values $<$ 0.05) between observed mean effort expenditures and theoretical predictions in 4 out of the 10 fixed cost × marginal cost combinations; 2 of the 4 reveal significantly higher expenditures, and 2 of the 4 reveal significantly lower expenditures than predicted. Nevertheless, the data are again broadly consistent with the comparative static predictions of the theory. Effort expenditures are declining in effort costs in the Low fixed cost treatment, and expenditures are initially (weakly) increasing and then decreasing in effort costs in the High fixed cost treatment. This leads us to our third finding:

Finding 3: Entry and effort decisions under Knightian uncertainty and repeat interaction are reasonably consistent with the equilibrium of the underlying (unknown) game, suggesting that the incentive effects of entry and effort costs guide conflict decisions toward equilibrium.

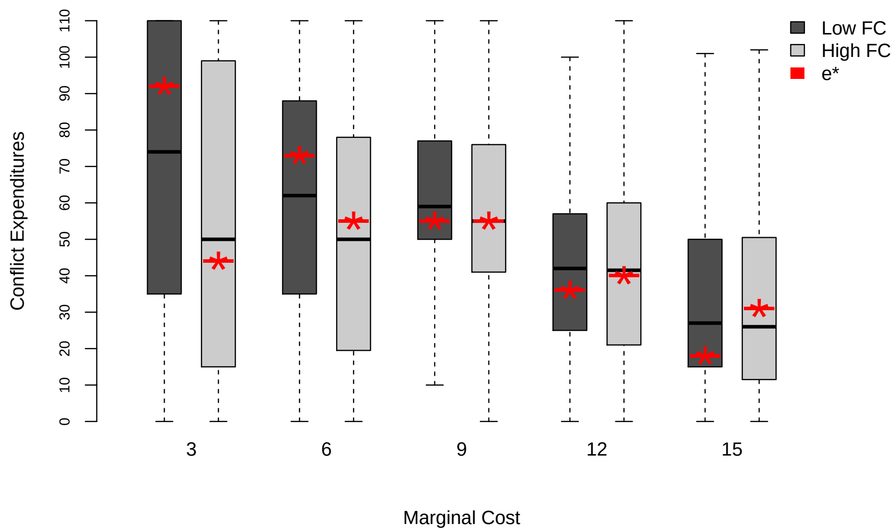


Figure 7: **Boxplots of conflict efforts, by treatment and effort cost under Knightian uncertainty and partner matching.** Non-entry is coded as missing data. Thick black bars indicate sample medians, and the boxes bound the interquartile range.

4.3 The Effect of Uncertainty and Partner Matching

Since we did not vary the presence of Knightian uncertainty or the matching protocol within-subject, our identification of the (joint) effect of these treatment variables comes from between-subject variation. We estimate two random effects regressions of entry and effort decisions at each location, including dummies for the fixed cost, marginal cost, and presence of complete information (and random matching) and the full set of interactions. We include random effects for each subject to control for repeat observation and we compute bootstrapped standard errors clustered at the session level (to account for the small number of sessions). We use data from the final 5 periods of each treatment, so our sample consists of 144 subjects, each of whom makes *up to* 5 effort decisions (one for each location) in each of 10 periods (5 per treatment). Full estimates are available upon request.

Overall, we find very little evidence for treatment differences in conflict entry or conflict expenditure between the Full-Info/Random Matching and Knightian/Partner Matching treatments. Only one of the coefficients capturing the effect of the Knightian/Partner Matching treatment is statistically significant at the 5% level in either model (out of 20 coefficients). This coheres with the visual evidence presented in the figures above and provides further support for the claim that subject behavior in our model of territory is shaped by the incentives for entry and effort induced by the cost structure. While some readers may find it surprising that repeat matching did not induce more (attempts at) cooperation, one design feature that was constant across treatments was that subjects were paid based on the outcome of a single randomly chosen period of the game. This incentive scheme likely reduces incentives to cooperate (e.g. by alternating who claims the resource in each period). The evidence from previous studies on the

impact of partner matching in conflict games is mixed. Chowdhury et al. (2013) find limited effects in repeated two-player Blotto games, but Baik et al. (2016) find evidence of reduced expenditure in repeated two-player Tullock contests. In our setting, we cannot rule out the possibility that the joint effect of introducing Knightian uncertainty and partner matching is zero, while the independent effects of either variation are equal and in opposite directions, but we view this as unlikely.

Finding 4: Subject behavior does not vary significantly with the presence of Knightian uncertainty and partner matching (i.e. under conditions that more nearly reflect conflict settings outside the lab)

5 Conclusion

We provide theory and experimental evidence that the presence and scope of territorial monopoly depends on economies of scale in the production of violence and the costs associated with the projection of violence at a distance. Our theory provides a microfoundation and extension of Boulding's "Loss of Strength Gradient" to predict the intensive and extensive margins of territorial conflict across multiple locations. A direct test of the theory in the laboratory provides evidence that conflict behavior and the consequent distribution of territory is broadly consistent with the model. Probing the boundaries of the theory with additional experiments, we then show that the theory capably predicts subjects' behavior even when they face Knightian uncertainty about the underlying game of conflict and when they interact repeatedly with the same opponents. This extension suggests that conflict behavior - hence the scope of territory - responds strongly to underlying incentives also under conditions that parallel those faced by conflict actors outside the lab.

Taken together, our theory and experiment provide a starting point for further research on the factors determining the extent and distribution of territory. Both the theoretical framework and the experimental platform can be readily extended to study the impact on territory of more complex and realistic geographies (see the Appendix for one such extension), different technologies of conflict, larger N, and so on. In addition to elaborations within the framework developed here, other extensions to the model would potentially consider dynamic processes through which territory is created and shrinks or expands over time. For instance, in the current paper, although we conceive of territory as an equilibrium outcome rather than an exogenous constraint, we still assume the home "base" for each party is fixed, when in reality the location may to some extent be a choice variable. We hope that this work inspires others to explore some of these issues.

References

ABRAMSON, S., “The Economic Origins of the Territorial State,” *International Organization* 71 (01 2017), 97–130.

ADAMS, E. S., “Approaches to the Study of Territory Size and Shape,” *Annual Review of Ecology and Systematics* 32 (2001), 277–303.

ADAMSON, J., “Political Violence and the Geographic Concentration of Countries,” , 08 2018.

AGNEW, J., “The Territorial Trap: The Geographical Assumptions of International Relations Theory,” *Review of International Political Economy* 1 (1994), 53–80.

ANDERSON, T. AND F. MCCHESNEY, “Raid or Trade? An Economic Model of Indian-White Relations,” *The Journal of Law & Economics* 37 (1994), 39–74.

BAIK, K. H., S. M. CHOWDHURY AND A. RAMALINGAM, “Group Size and Matching Protocol in Contests,” University of East Anglia Working Paper, 2016.

BAKER, M. J., “An Equilibrium Conflict Model of Land Tenure in Hunter-Gatherer Societies,” *Journal of Political Economy* 111 (2003), 124–173.

BARZEL, Y., *A Theory of the State: Economic Rights, Legal Rights, and the Scope of the State*, A Theory of the State: Economic Rights, Legal Rights, and the Scope of the State (Cambridge University Press, 2002).

BERMAN, N. AND M. COUTTENIER, “External Shocks, Internal Shots: The Geography of Civil Conflicts,” *The Review of Economics and Statistics* 97 (2015), 758–776.

BONADONNA, G., V. TORTI, V. SORRENTINO, R. M. RANDRIANARISON, M. ZACCAGNO, M. GAMBA, C. L. TAN AND C. GIACOMA, “Territory exclusivity and intergroup encounters in the indris (Mammalia: Primates: Indridae: Indri indri) upon methodological tuning,” *The European Zoological Journal* 84 (2017), 238–251.

BOULDING, K. E., *Conflict and Defense: A General Theory.* (Harper, 1962).

BRANCH, J., *The Cartographic State: Maps, Territory, and the Origins of Sovereignty*, Cambridge Studies in International Relations (Cambridge University Press, 2014).

CARTER, J. R. AND C. H. ANDERTON, “An experimental test of a predator–prey model of appropriation,” *Journal of Economic Behavior & Organization* 45 (2001), 83–97.

CASELLI, F., M. MORELLI AND D. ROHNER, “The Geography of Interstate Resource Wars,” *The Quarterly Journal of Economics* 130 (2015), 267–315.

CHOWDHURY, S. M., D. KOVENOCK AND R. M. SHEREMETA, “An experimental investigation of Colonel Blotto games,” *Economic Theory* 52 (2013), 833–861.

DARI-MATTIACCI, G., E. LANGLAIS, B. LOVAT AND F. PARISI, “Asymmetries in Rent Seeking,” in R. Congleton and A. Hillman, eds., *Companion to the Political Economy of Rent Seeking*chapter 5 (Edward Elgar Publishing Limited, 2015).

DE LA SIERRA, R. S., “On the origin of states: Stationary bandits and taxation in eastern congo,” Working paper, 2018.

DECHENAUX, E., D. KOVENOCK AND R. M. SHEREMETA, “A survey of experimental research on contests, all-pay auctions and tournaments,” *Experimental Economics* 18 (12 2015), 609–669.

DOW, G. K., L. MITCHELL AND C. G. REED, “The economics of early warfare over land,” *Journal of Development Economics* 127 (2017), 297–305.

DUFFY, J. AND M. KIM, “Anarchy in the laboratory (and the role of the state),” *Journal of Economic Behavior & Organization* 56 (2005), 297–329.

FINDLAY, R. AND M. LUNDAHL, *The Economics of the Frontier: Conquest and Settlement* (Springer, 2016).

FU, Q., Q. JIAO AND J. LU, “Contests with Endogenous Entry,” *International Journal of Game Theory* 44 (5 2015), 387–424.

GLOWACKI, L., M. L. WILSON AND R. W. WRANGHAM, “The evolutionary anthropology of war,” *Journal of Economic Behavior & Organization* (2017).

GRUJIĆ, J., C. GRACIA-LÁZARO, M. MILINSKI, D. SEMMANN, A. TRAULSEN, J. A. CUESTA, Y. MORENO AND A. SÁNCHEZ, “A Comparative Analysis of Spatial Prisoner’s Dilemma Experiments: Conditional Cooperation and Payoff Irrelevance,” *Scientific Reports* 4 (2014).

HERBST, J., *States and power in Africa: Comparative lessons in authority and control*, Princeton Studies in International History and Politics (Princeton University Press, 2000).

HIRSHLEIFER, J., “Conflict and settlement,” in *The World of Economics* (Springer, 1991a), 117–125.

———, “The Technology of Conflict as an Economic Activity,” *The American Economic Review* 81 (1991b), 130–134.

———, “Anarchy and its Breakdown,” *Journal of Political Economy* 103 (02 1995), 26–52.

HOTELLING, H., “Stability in Competition,” *The Economic Journal* 39 (1929), 41–57.

IFTI, M., T. KILLINGBACK AND M. DOEBELI, “Effects of neighbourhood size and connectivity on the spatial continuous prisoner’s dilemma,” *Journal of theoretical biology* 231 (2004), 97–106.

JOHNSON, D. D. AND M. D. TOFT, “Grounds for War: The Evolution of Territorial Conflict,” *International Security* 38 (2014), 7–38.

KEYNES, J. M., “The General Theory of Employment,” *The Quarterly Journal of Economics* 51 (1937), 209–223.

KIMBROUGH, E. O., K. LAUGHREN AND R. SHEREMETA, “War and conflict in economics: Theories, applications, and recent trends,” *Journal of Economic Behavior & Organization* (2017).

KIRCHKAMP, O. AND R. NAGEL, “Naive learning and cooperation in network experiments,” *Games and Economic Behavior* 58 (2007), 269–292.

KNIGHT, F., *The Ethics of Competition*, Classics in Economics Series (A.M. Kelley, 1997 (1935)).

KOVENOCK, D. AND B. ROBERSON, “Contests with Multiple Battlefields,” in M. Garfinkel and S. Skaperdas, eds., *The Oxford Handbook of the Economics of Peace and Conflict*Oxford Handbooks in Economics, chapter 21 (Oxford University Press, USA, 2012), 503–531.

KRUGMAN, P., “Increasing Returns and Economic Geography,” *Journal of Political Economy* 99 (1991), 483–499.

LATZKO, D. A., “The Concept of "Military Economies of Scale",” *Explorations in Economic History* 30 (1993), 470–484.

MASKIN, E. AND J. TIROLE, “A Theory of Dynamic Oligopoly, I: Overview and Quantity Competition with Large Fixed Costs,” *Econometrica* 56 (1988), 549–569.

MITANI, J. C., D. P. WATTS AND S. J. AMSLER, “Lethal intergroup aggression leads to territorial expansion in wild chimpanzees,” *Current Biology* 20 (2010), R507 – R508.

MORGAN, J., H. ORZEN AND M. SEFTON, “Endogenous entry in contests,” *Economic Theory* 51 (10 2012), 435–463.

NOWAK, M. A., S. BONHOEFFER AND R. M. MAY, “Spatial games and the maintenance of cooperation,” *Proceedings of the National Academy of Sciences* 91 (1994), 4877–4881.

OLSON, M., *Power and Prosperity: Outgrowing Communist and Capitalist Dictatorships* (Basic Books, 2000).

OLSZEWSKI, W. AND R. SIEGEL, “Large Contests,” *Econometrica* 84 (2016), 835–854.

PARKER, B. J., "8 Geographies of Power: Territoriality and Empire during the Mesopotamian Iron Age," *Archeological Papers of the American Anthropological Association* 22 (2012), 126–144.

POWELL, B. AND B. WILSON, "An Experimental Investigation of Hobbesian Jungles," *Journal of Economic Behavior & Organization* 66 (2008), 669–686.

RITZ, R. A., "Influencing Rent-Seeking Contests.," *Public Choice* (2008), 291.

RUSCH, H. AND S. GAVRILETS, "The logic of animal intergroup conflict: A review," *Journal of Economic Behavior & Organization* (2017).

SKAPERDAS, S., "Cooperation, Conflict, and Power in the Absence of Property Rights," *The American Economic Review* 82 (09 1992), 720–739.

SKAPERDAS, S. AND H. JIA, "Technologies of conflict," in M. Garfinkel and S. Skaperdas, eds., *The Oxford Handbook of the Economics of Peace and Conflict*chapter 19 (Oxford: Oxford University Press, 2012), 449.

SMITH, J. M. AND G. R. PRICE, "The logic of animal conflict," *Nature* 246 (1973), 15–18.

SMITH, V., "Microeconomic systems as an experimental science," *The American Economic Review* 72 (1982), 923–955.

SMITH, V. L., "An Experimental Study of Competitive Market Behavior," *Journal of political economy* 70 (1962), 111–137.

SPOLAORE, E., "The Economics of Political Borders," Working paper, CESifo, 2012, 3854.

SZABÓ, G. AND A. SZOLNOKI, "Cooperation in spatial prisoner's dilemma with two types of players for increasing number of neighbors," *Physical Review E: Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics* 79 (01 2009), 016106.

TOFT, M. D., "Territory and war," *Journal of Peace Research* 51 (03 2014), 185–198.

TSE-TUNG, M., *Selected Military Writings of Mao Tse-Tung* (Praetorian Press LLC, 2011).

TULLOCK, G., *The Social Dilemma: The Economics of War and Revolution (A Public Choice Monograph)*, Public Choice Society book and monograph series (University Publications, 1974).

———, "Territorial Boundaries: An Economic View," *The American Naturalist* 121 (1983), 440–442.

VANVALKENBURGH, P. AND J. F. OSBORNE, "Home Turf: Archaeology, Territoriality, and Politics," *Archeological Papers of the American Anthropological Association* 22 (2012), 1–27.

VASQUEZ, J., *What Do We Know about War?* (Rowman & Littlefield, 2012).

WEBER, *Politics as a Vocation* (Fortress Press, 1965).

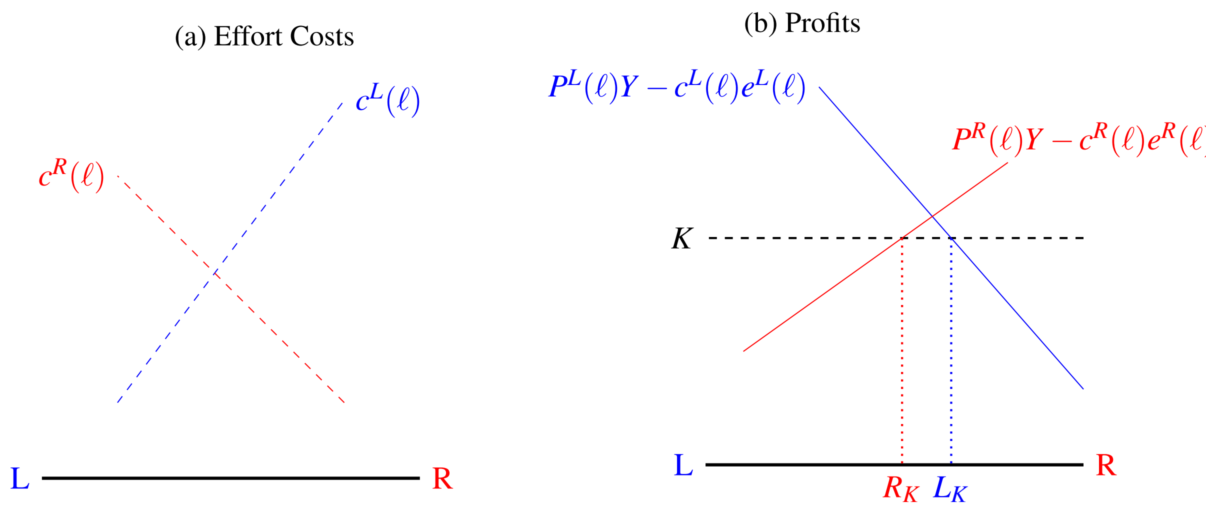
Appendices to Adamson and Kimbrough (2018)

A Additional Theoretical Results

A.1 Macro Behavior

Combining the microeconomics of conflict with geographic variation in costs leads to some powerful predictions about territory at the macro level. Figure 8 depicts two players competing at each location along a continuum. Cost curves, $c^i(\ell), K$, are drawn as dashed lines and the variable returns, $P^i(\ell)Y - c^i(\ell)e^i(\ell)$, are drawn as solid lines for interior Nash equilibrium. When there is exit, the profit lines have more of an $S-$shape as the cost-advantaged player earns more when the other exits. The region $L_K R_K$ is the region where both players have a pure strategy to enter and expend effort. We call this the *critical boundary*, and its size depends on the costs of entry as well as the spatial gradient of effort costs of both players.[17]

Figure 8: Territories for 2 Players



This macro picture is useful because it provides intuitive statics even when the contest success functions aren't explicitly specified. So while Tullock contests have equilibrium variable returns that decrease with distance, this is a plausibly general claim.[18] This macro picture lets us consider one important extension

[17] This answers calls by (Boulding, 1962, p.265) that "we need to develop a concept of a *critical boundary*, which may be the same as the legal boundary but which may lie either inside it or outside it".

[18] Any monotone decreasing profit functions (in Nash EQ) will create the same qualitative picture. Holding all efforts at a single value, the variable returns decrease with distance simply because the unit costs are increasing with distance. In partial equilibrium, efforts will be adjusted so that less effort will be expended to the higher cost locations, and this will amplify the downward slope. However, non-monotonicities in costs can create multiple regions of conflict. Likewise, neither common and constant fixed costs nor common and constant prize values are requisite, but adding heterogeneity to these variables will change the equilibrium region of conflict.

that is nearly intractable at the micro level: the case in which the resource can be destroyed by conflict. Empirical observation suggests border violence is more likely with natural resources close by (Caselli et al., 2015). This is a special case when Y does not depend on e. But if the resource can be destroyed by fighting, then there is an additional cost when both players enter and expend effort. When the resource is elastic, the mutual conflict line $P^iY - c^ie^i$ shifts downwards when there are two entrants. This acts as an extra entry deterrent for cost-disadvantaged players. As a consequence, the area of conflict shrinks. In a world of natural resources, an increasing value of land (or declining costs) leads to larger political territories and larger regions of conflict. But in a world where the value of land is increasingly produced, the political territories grow larger and more exclusive. This matches the time series of maps in many historical epochs: going from small separated entities to regional empires with border wars to exclusive territories (Branch, 2014).

A.2 Uniqueness

Note that the system of equations described by 8 implies that for a given location

$$\begin{bmatrix} 0 & 1 & 1 & \dots & 1 \\ 1 & 0 & 1 & \dots & 1 \\ \vdots & & & & 1 \\ 1 & 1 & 1 & \dots & 0 \end{bmatrix} \begin{bmatrix} e^1 \\ e^2 \\ \vdots \\ e^n \end{bmatrix} = \begin{bmatrix} c^1 \\ c^2 \\ \vdots \\ c^n \end{bmatrix} \left(\frac{n-1}{n}\right)^2 \frac{Y}{\bar{c}^2}$$

Then for the identity matrix I_n and vector $\mathbf{1}_n$, the Sherwin-Morrison Formula yields

$$(-I_n + \mathbf{1}_n\mathbf{1}_n^T)^{-1} = -I_n - \frac{-I_n\mathbf{1}_n\mathbf{1}_n^T I_n}{1 - \mathbf{1}_n^T I_n \mathbf{1}_n} \tag{15}$$

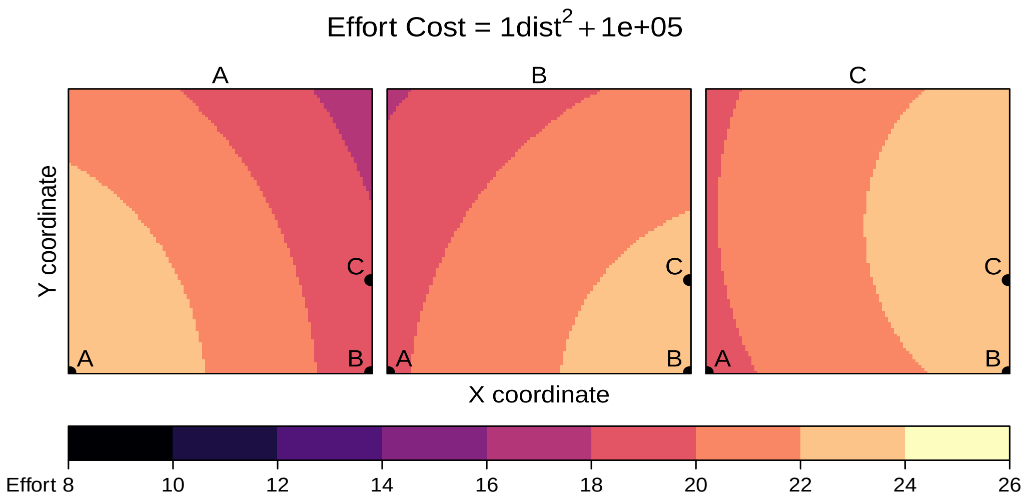
which implies the unique equilibrium solution

$$\mathbf{e} = \frac{n-1}{n^2}\frac{Y}{\bar{c}^2} \begin{bmatrix} -n+2 & 1 & 1 & \dots & 1 \\ 1 & -n+2 & 1 & \dots & 1 \\ \vdots & & & & 1 \\ 1 & 1 & 1 & \dots & -n+2 \end{bmatrix} \mathbf{c} \tag{16}$$

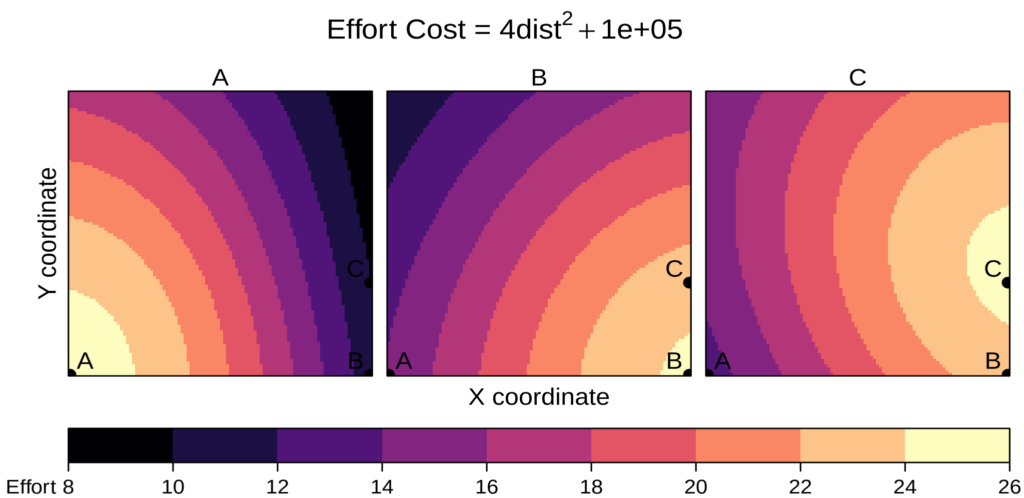
A.3 Effort Example for 3 Players on 2 Dimensions

Consider a numerical example that shows the effect of a change in the spatial gradient of costs on the effort surface. Let $Y = 1E7$ and there be no fixed costs. Figure A1 shows the distribution of efforts for each player on a 100×100 grid.

Figure A1



Effort Cost = $1\text{dist}^2 + 1\text{e+}05$
A
B
C
Y coordinate
C
A
B
X coordinate
Effort 8
10
12
14
16
18
20
22
24
26



Effort Cost = $4\text{dist}^2 + 1\text{e+}05$
A
B
C
Y coordinate
C
A
B
X coordinate
Effort 8
10
12
14
16
18
20
22
24
26

B Experiment Instructions

B.1 Instructions for the High treatment

Introduction

This is an experiment on economic decision-making. If you read the instructions carefully and make good decisions, you can earn a considerable amount of money, which will be paid to you in CASH at the end of the experiment.

During the experiment you are not allowed to communicate with any other participant. If you have any questions, raise your hand, and the experimenter(s) will answer them privately. You must also put away all materials unrelated to the experiment, including cell-phones, tablets, and pen-and-paper.

If you do not follow these instructions you will be excluded from the experiment and paid only the show-up payment of $7.

Experimental decisions will involve Experimental Currency Units (ECU). At the end of the experiment, ECU will be converted to dollars at a rate of 200 ECU = $1.

Your Task

You have been assigned a role as either a "Person L" or a "Person R". In each period of this experiment, you will be randomly paired with another person of the opposite role. You will each decide whether to compete for valuable resources at five different locations {1, 2, 3, 4, 5}. Person L is based at location 1, and Person R is based at location 5.

At each location, there is a resource worth 2000 ECU. For each location, you will choose whether to pay a cost to **enter** a competition for the resource at that location, and if you **enter**, you will choose how much costly **effort** to expend in the competition. Depending on your entry/effort decision at a given location and the entry/effort decision of the other person, you will each receive some, all, or none of the resource. Note that you and the other person will make your decisions simultaneously so that you will not know the other person's decision when making your own.

The cost of competing at a location has two components.

(1) The first component is the "**Entry Cost**". This is the cost of entering the competition for the resource at a given location. You pay this cost if you choose to **enter** at that location at all. In this experiment the **Entry Cost** is 350 ECU at each location.

(2) The second component is the "**Effort Cost**". This is the cost (in ECU) per unit of effort you expend in the competition. The table below shows the costs for each person's effort at each location. Notice that the cost is not the same in all locations, and in particular the cost per unit of effort is higher for locations that are further away from the location at which a person is based. For example, for Person L, the **Effort Cost** is 3 ECU per unit at location 1 (where Person L is based) and rises up to 15 ECU per unit at location 5 (the furthest location from where Person L is based). You may input up to 110 units of effort at each location.

In the experiment, you will always be either person L or person R. Your task is to decide at which locations you want to compete, and how much effort you want to expend at each location.

Location	**Effort Cost Person L** (ECU)	**Effort Cost Person R** (ECU)
1 (Person L)	3	15
2	6	12
3	9	9
4	12	6
5 (Person R)	15	3

The Rules of Competition

There are a total of 5 competitions, one at each location, and the outcome of each competition is independent of the outcome of the other competitions. Each Person will receive some, all or none of the 2000 ECU resource at each location. Your payoff in a period is the sum of your payoffs from all 5 locations.

There are three possible scenarios for the competition at each location, and these scenarios depend on the entry and effort decisions of both people.

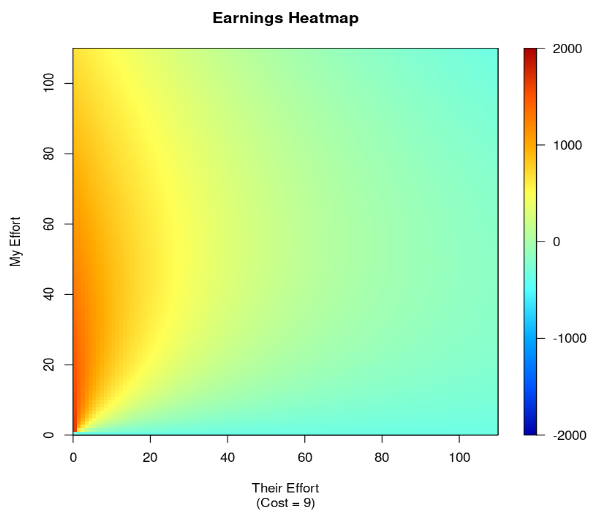
(1) If no one enters the competition at a location, no one receives the resource at that location, and no one pays any costs. Both people earn $0 at that location.
(2) If only one person enters the competition at a location, the person who enters receives the entire resource (worth 2000 ECU) and pays both the Entry Cost and the Effort Cost. The other person earns 0 ECU at that location.
(3) If both people enter the competition at a location, payoffs are determined as follows. Each unit of effort by Person L increases the share of the resource that Person L receives in the competition. Each unit of effort by Person R increases the share that Person R receives in the competition. Specifically, your **share** of the resource is equal to: $\frac{My\ Effort}{Their\ Effort + My\ Effort}$. Note that **both Person L and Person R** must pay their Entry and Effort Costs, and note that if your costs are higher than the value of the resource you receive, your payoff from that location will be negative. Note, if both people enter the competition and both choose an effort of 0, the resource will be divided equally, with both people paying only the Entry Cost.

    To help you make informed decisions, the experiment interface allows you to simulate the payoffs you would receive for various choices of your effort and the other person's effort at each location. The screenshot below shows the simulator interface. The colored panel (called a heatmap) uses color to show the payoff that would result from various choices by you and the other person. Red colors indicate combinations of actions that would lead to high payoffs, and

blue colors indicate combinations of actions that would lead to low (negative) payoffs (see the scale on the right).

Sim 1 Sim 2 Sim 3 Sim 4 Sim 5 History

$$\text{If Enter, My Earnings} = \left(\frac{\text{my effort}}{\text{their effort} + \text{my effort}}\right) 2000 - \text{TotalCost}$$



Example

To clarify, we provide a hypothetical example of the outcome of competition at all 5 locations.

(1) Suppose *only* Person L enters the competition at location 1 and spends 0 units of effort. Person L will pay the **Entry Cost** (350 ECU), but will not have to pay any **Effort** Cost. Person L will then receive the resource (worth 2000 ECU), and so will earn 1650 ECU. Person R will receive 0 ECU.

(2) Suppose *only* Person L enters the competition at location 2 and spends 10 units of effort. Person L will pay the **Entry Cost** (350 ECU), and will also pay the **Effort Cost** (6 x 10 = 60 ECU). Person L will then receive the resource worth (2000 ECU) and so will earn 1590 ECU. Person R will receive 0 ECU.

(3) Suppose neither Person L nor Person R enters the competition at location 3. Both people will receive 0 ECU, and no one will receive the resource.

(4) Suppose both Person L and Person R enter the competition at location 4, and suppose Person L puts in 30 units of effort and Person R puts in 10 units of effort.
The total cost paid by Person L at location 4 is equal to the **Entry Cost** (350 ECU) plus the **Effort Cost** (12 x 30 Units = 360 ECU).

3

The total cost paid by Person R at location 4 is equal to the **Entry Cost** (350 ECU) plus the **Effort Cost** (6 x 10 Units = 60 ECU).
Person L would get 30/(30+10) = ¾ of the resource (or 1500 ECU). Subtracting the costs of entry and effort, Person L would then receive 1500 - 350 - 360 = 790 ECU.
Person R would get 10/(10+30) = ¼ of the resource (or 500 ECU). Subtracting the costs of entry and effort, Person R would then receive 500 - 350 - 60 = 90 ECU.

(5) Suppose *both* Person L and Person R enter the competition at location 5 and both spend 0 units of effort. Both Person L and Person R will pay the **Entry Cost** (350 ECU each), and both will pay zero additional **Effort Cost.** They will each receive half of the resource value (1000 ECU), which after subtracting the costs leave each with a total of 650 ECU.

Both peoples' total earnings for the period are the sum of their earnings from all five locations:

Location	**Earnings Person L**	**Earnings Person R**
1	1650	0
2	1590	0
3	0	0
4	790	90
5	650	650
Total = 1+2+3+4+5	4680 ECU	740 ECU

Additional Information

In this experiment, we will repeat this task for 32 repetitions, called periods. Each period lasts a total of 2 minutes and 30 seconds. Note that a timer is displayed on the top right corner of your screen and will update every 10 seconds. At the start of each period, you will be matched with a randomly chosen person of the other type. You will then have 2 minutes and 20 seconds to make your choices. If you haven't submitted your choice by that time, then your current values will be recorded. The period will then end and display the choices and earnings of you and your competitor at each location. This will repeat for 16 periods, at which point the experiment will pause and you will receive further instruction. At the end of the experiment, we will randomly choose one period as your experiment earnings.

All participants in the experiment receive an initial endowment of 2000 ECU. Your experiment earnings will consist of this endowment, plus or minus your earnings from the randomly chosen period. We will convert these ECU to dollars at a rate of 200 ECU = $1. We will add this to your showup payment of $7.

Before beginning the experiment, we will do two practice periods. For the first practice period, we will guide you through your decisions to show you how the interface works. The second period will be a live practice round where you can explore the interface on your own. Note that these two periods cannot be chosen for payment. When the two periods are finished, please wait for instructions. Are there any questions?

B.2 Script for the High treatment

1 Tutorial

Before you make any decisions, we will walk you through the interface and ensure that you understand how to make choices in this experiment.

Please click the "Initialize" button to begin the tutorial.

At the top left of your screen, you will see a statement indicating whether you are Person L or Person R.

Below that information is a table showing how your payoff is determined at each location, depending on whether you choose to enter the competition or not. No matter what, if you choose not to enter, your payoff is 0. If you Enter, your payoff depends on your effort decision and the entry/effort decision of your counterpart.

Below this table is where you will make your choices. For each location, you can see the effort cost at that location. Location 1 is displayed at the top, and location 5 is displayed at the bottom.

Slider Example

Please check the Enter box under Loc 1. Notice that your Total Cost (shown to the right) jumps to 350 ECU. This is the cost you would incur if you Enter at location 1. By adjusting the slider, you can choose how much effort cost to incur. Your total cost will also adjust in real time as you move the slider. For example, move the slider to 54. Your cost is then $350 + 54 \times$Your Effort Cost at Loc 1 (which is 3 if you are a Person L and 15 if you are a Person R).

Simulator Tabs

The Simulator tabs on the right allow you to see how your payoff at each location would vary depending on the choices made by you and your counterpart. For now, look at the payoff heatmap for Loc 1. Suppose your counterpart chose an effort of 40, you can find your payoff for various efforts by finding the 40 on the x-axis and tracing upward on the screen. Warmer colors (red, orange, yellow) are associated with higher payoffs.

Please take 2 minutes to look at this information for each location. When you are finished looking, please make entry and effort decisions for all 5 locations. Click "Submit" when you are finished. Remember this is a practice period and will not be chosen for payment. If you have any questions please raise your hand and a monitor will assist you.

Period Summary

Now that everyone has hit submit, the "Last Period Summary" screen has appeared. This shows you the outcome of your decisions at each location, including your effort and your counterpart's effort and both people's earnings. If a person chose not to enter, their Effort will be listed as N/A. After 10 seconds, this will disappear and the next period will begin.

History Tabs

A record of all your previous decisions and outcomes, as well as your counterparts, will be shown on the "History" tab.

2 Practice Round

This is the beginning of your practice period. Please make your choices on your own. Note that the Seconds Remaining in the period is shown on the top-right and will be updated every 10 seconds.

3 Begin Game

This is the beginning of the Periods for which you may be paid.

4 Switchover Instructions

Please remove your hands from the computer mice and keyboards. We have now completed 16 periods and will take a short break before continuing.

After the break, we will now restart the experiment for 16 more periods with the same rules as before. The only change is that the Entry Cost has changed from 350 ECU to 10 ECU. We will choose only one of these 32 periods for payment at the end. During the break, take a minute to think about how well your strategy worked and how you will continue.

[wait 2 mins]

We will continue the game shortly. Before everyone makes their choices, I want to talk you through the new simulators. Please click the "Continue Game" button on your browser.
Everyone click "Sim 3", these are your new payoffs at that location.
Everyone click the Simulator Tab for their base location to see your new payoff schedule there.
Everyone click the Simulator Tab for the location furthest from their base.

The experiment has begun again and you may now make your choices.

5 Game Completion

The game is now complete. Please fill out this short-survey.

Once everyone has completed the survey, a monitor will direct you to submit your surveys and will then call you for payment.

B.3 Instructions for the Uncertain-High treatment

Introduction

This is an experiment on economic decision-making. If you read the instructions carefully and make good decisions, you can earn a considerable amount of money, which will be paid to you in CASH at the end of the experiment.

During the experiment you are not allowed to communicate with any other participant. If you have any questions, raise your hand, and the experimenter(s) will answer them privately. You must also put away all materials unrelated to the experiment, including cell-phones, tablets, and pen-and-paper.

If you do not follow these instructions you will be excluded from the experiment and paid only the show-up payment of $7.

Experimental decisions will involve Experimental Currency Units (ECU). At the end of the experiment, ECU will be converted to dollars at a rate of 200 ECU = $1.

Your Task

You have been assigned a role as either a “Person L” or a “Person R”. In each period of this experiment, you will be randomly paired with another person of the opposite role. You will each decide whether to compete for valuable resources at five different locations {1, 2, 3, 4, 5}. Person L is based at location 1, and Person R is based at location 5.

At each location, there is a resource worth 2000 ECU. For each location, you will choose whether to pay a cost to **enter** a competition for the resource at that location, and if you **enter**, you will choose how much costly **effort** to expend in the competition. Depending on your entry/effort decision at a given location and the entry/effort decision of the other person, you will each receive some, all, or none of the resource. Note that you and the other person will make your decisions simultaneously so that you will not know the other person’s decision when making your own.

The cost of competing at a location has two components.

(1) The first component is the “**Entry Cost**”. This is the cost of entering the competition for the resource at a given location. You pay this cost if you choose to **enter** at that location at all.
(2) The second component is the “**Effort Cost**”. This is the cost (in ECU) per unit of effort you expend in the competition. The table below shows the costs for each person’s effort at each location. Notice that the cost is not the same in all locations, and in particular the cost per unit of effort is higher for locations that are further away from the location at which a person is based. You may input up to 110 units of effort at each location.

In the experiment, you will always be either person L or person R. Your task is to decide at which locations you want to compete, and how much effort you want to expend at each location.

The Rules of Competition

There are a total of 5 competitions, one at each location, and the outcome of each competition is independent of the outcome of the other competitions. Each Person will receive some, all or none of the 2000 ECU resource at each location. Your payoff in a period is the sum of your payoffs from all 5 locations.

There are three possible scenarios for the competition at each location, and these scenarios depend on the entry and effort decisions of both people.

(1) If no one enters the competition at a location, no one receives the resource at that location, and no one pays any costs. Both people earn 0 at that location.
(2) If only one person enters the competition at a location, the person who enters receives the entire resource (worth 2000 ECU) and pays both the Entry Cost and the Effort Cost. The other person earns 0 ECU at that location.
(3) If both people enter the competition at a location, payoffs are determined as follows. Each unit of effort by Person L increases the share of the resource that Person L receives in the competition. Each unit of effort by Person R increases the share that Person R receives in the competition. Note that **both Person L and Person R** must pay their Entry and Effort Costs, and note that if your costs are higher than the value of the resource you receive, your payoff from that location will be negative.

Example

To clarify, we provide a hypothetical example of the outcome of competition at all 5 locations.

(1) Suppose *only* Person L enters the competition at location 1 and spends 0 units of effort. Person L will pay the **Entry Cost**, but will not have to pay any **Effort** Cost. Person L will then receive the resource (worth 2000 ECU). So
    Person L will earn 2000-EntryCost_L
    Person R will receive 0 ECU.
(2) Suppose *only* Person L enters the competition at location 2 and spends 10 units of effort. Person L will pay the **Entry Cost**, and will also pay the **Effort Cost**. Person L will then receive the resource worth (2000 ECU). So
    Person L will earn 2000-EntryCost_L-EffortCost_L .
    Person R will receive 0 ECU.
(3) Suppose neither Person L nor Person R enters the competition at location 3. Both people will receive 0 ECU, and no one will receive the resource.
(4) Suppose both Person L and Person R enter the competition at location 4, and suppose Person L puts in 30 units of effort and Person R puts in 10 units of effort. Since both Person L and Person R chose to enter the competition, each receives a share of the resource.
    Person L will earn 2000*Share_L – EntryCost_L-EffortCost_L
    Person R will earn 2000*Share_R - EntryCost_R-EffortCost_R
(5) Suppose *both* Person L and Person R enter the competition at location 5 and both spend 0 units of effort. Both Person L and Person R will pay only the **Entry Cost.** They will each receive a share of the resource.
    Person L will earn 2000*Share_L – EntryCost_L
    Person R will earn 2000*Share_R - EntryCost_R

Both peoples' total earnings for the period are the sum of their earnings from all five locations.

Additional Information

In this experiment, we will repeat this task for 32 repetitions, called periods. Each period lasts a total of 2 minutes and 30 seconds. Note that a timer is displayed on the top right corner of your screen and will update every 10 seconds. At the start of each period, you will be matched with a randomly chosen person of the other type. You will then have 2 minutes and 20 seconds to make your choices. If you haven't submitted your choice by that time, then your current values will be recorded. The period will then end and display the choices and earnings of you and your competitor at each location. This will repeat for 16 periods, at which point the experiment will pause and you will receive further instruction. At the end of the experiment, we will randomly choose one period as your experiment earnings.

All participants in the experiment receive an initial endowment of 2000 ECU. Your experiment earnings will consist of this endowment, plus or minus your earnings from the randomly chosen period. We will convert these ECU to dollars at a rate of 200 ECU = $1. We will add this to your showup payment of $7.

Before beginning the experiment, we will do two practice periods. For the first practice period, we will guide you through your decisions to show you how the interface works. The second period will be a live practice round where you can explore the interface on your own. Note that these two periods cannot be chosen for payment. When the two periods are finished, please wait for instructions. Are there any questions?

B.4 Script for the Uncertain-High treatment

1 Tutorial

Before you make any decisions, we will walk you through the interface and ensure that you understand how to make choices in this experiment.

Please click the "Initialize" button to begin the tutorial.

At the top left of your screen, you will see a statement indicating whether you are Person *L* or Person *R*.

Below that information is a table showing how your payoff is determined at each location, depending on whether you choose to enter the competition or not. No matter what, if you choose not to enter, your payoff is 0. If you Enter, your payoff depends on your effort decision and the entry/effort decision of your counterpart.

Below this table is where you will make your choices. For each location, you can see the effort cost at that location. Location 1 is displayed at the top, and location 5 is displayed at the bottom.

Slider Example

Please check the Enter box under Loc 1. Notice that your Total Cost (shown to the right) jumps. This is the cost you would incur if you Enter at location 1. By adjusting the slider, you can choose how much effort cost to incur. Your total cost will also adjust in real time as you move the slider. For example, move the slider to 54. Your cost is then your EntryCost $+54\times$ EffortCost at Loc 1.

Please take 2 minutes to look at this information for each location. When you are finished looking, please make entry and effort decisions for all 5 locations. Click "Submit" when you are finished. Remember this is a practice period and will not be chosen for payment. If you have any questions please raise your hand and a monitor will assist you.

Period Summary

Now that everyone has hit submit, the "Last Period Summary" screen has appeared. This shows you the outcome of your decisions at each location, including your effort and your counterpart's effort and both people's earnings. If a person chose not to enter, their Effort will be listed as N/A. After 10 seconds, this will disappear and the next period will begin.

History Tabs

A record of all your previous decisions and outcomes, as well as your counterparts, will be shown on the "History" tab.

2 Practice Round

This is the beginning of your practice period. Please make your choices on your own. Note that the Seconds Remaining in the period is shown on the top-right and will be updated every 10 seconds.

3 Begin Game

This is the beginning of the Periods for which you may be paid.

4 Switchover Instructions

Please remove your hands from the computer mice and keyboards. We have now completed 16 periods and will take a short break before continuing.

After the break, we will now restart the experiment for 16 more periods with the same rules as before. The only change is that the Entry Cost has changed. We will choose only one of these 32 periods for payment at the end. During the break, take a minute to think about how well your strategy worked and how you will continue.

[wait 2 mins]

Please click the "Continue Game" button on your browser.
The experiment has begun again and you may now make your choices.

5 Game Completion

The game is now complete. Please fill out this short-survey.

Once everyone has completed the survey, a monitor will direct you to submit your surveys and will then call you for payment.

C Additional Data Analysis and Figures

C.1 Effort Distribution over all Periods

Empirical conflict scholarship has emphasized the importance at looking at more than just the mean, in particular thinking about war and peace as tail events. While modern statesmen are concerned about the onset of war and worst-case scenerios, even Livy stated “the outcome corresponds less to expectations in war than in any other case whatsoever”. The boxplots shown in Figures 4 and 5 summarize efforts, but further insights can be gleaned from analyzing the entire distribution. Figure C1 shows a histogram of efforts with unit length bins for each treatment at each location. The left-most bar, plotted in red indicates the proportion of subjects that chose not to enter the conflict. While there is much heterogeneity, with some observations at nearly every effort level in every location, there are noticeable cost-effects. For locations that are close to the base (effort costs 3 or 6), the biggest effect of high fixed costs are to pull expenditures away from the maximum allowed. For locations that are close to the base (effort costs 12 or 15), the biggest effect of high fixed costs is to cause exit. In summary, the combination of fixed & marginal costs have big effects on the maximum and the minimum effort in addition to big effects on mean effort.

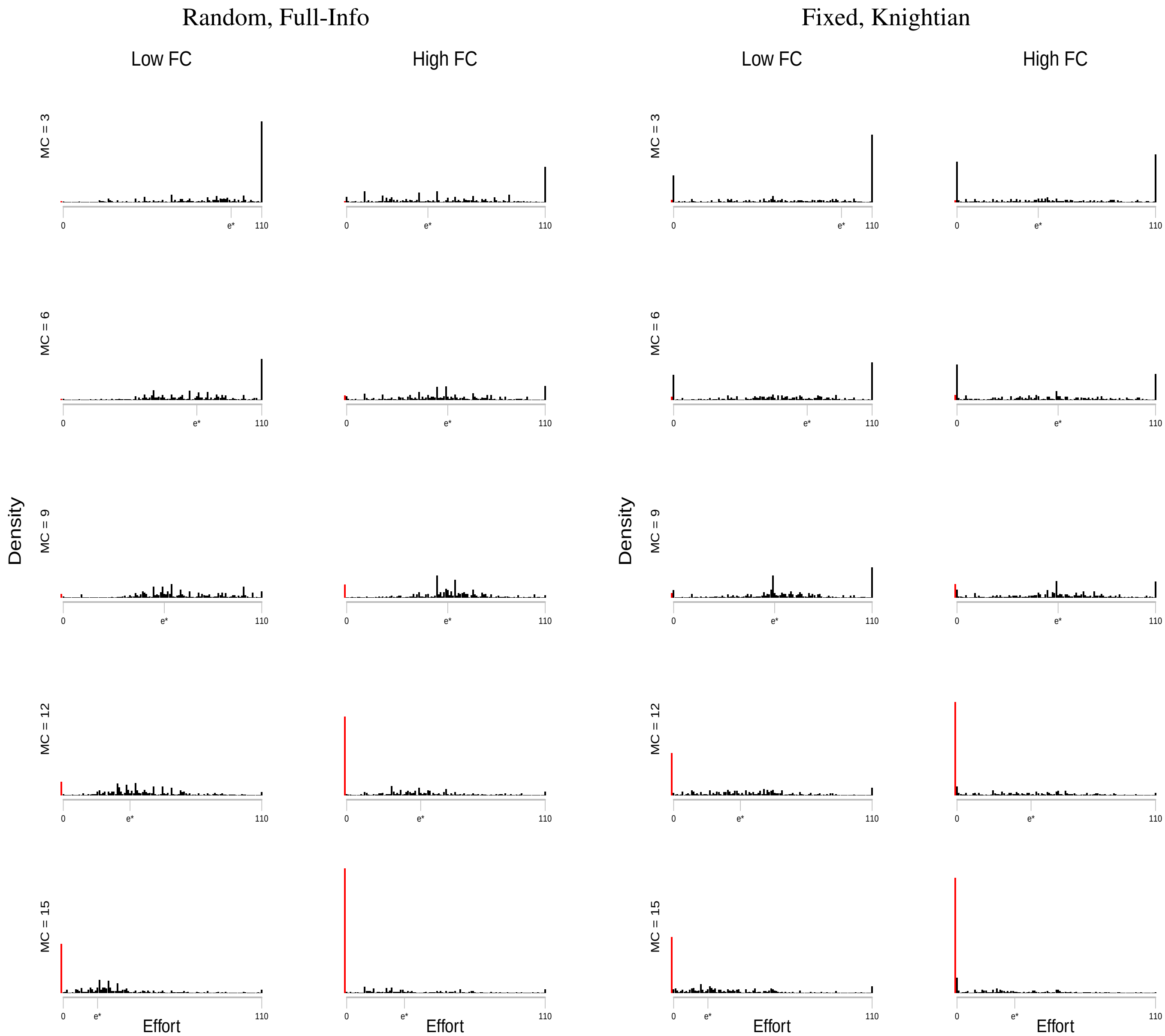


Figure C1: **Effort Histograms, by block, by treatment and effort cost.** The red bar indicates the proportion of decisions that involved choosing not to enter the conflict.

C.2 Individual Level Analysis

In practice, the aggregate observations reported in the body of the paper mask considerable heterogeneity across subjects. To capture this heterogeneity, we compute subject level means of entry probability and effort expenditure, conditional on entry for each marginal cost of effort under Low and High fixed costs. Figure C2 displays empirical CDFs of these subject level means.

In terms of entry decisions, we see that most subjects always enter conflict when the marginal cost of

effort is 9 or less. However, when the marginal cost is high, we observe striking variation in subject-level entry rates. In terms of average effort, conditional on entry, there is striking heterogeneity regardless of the marginal cost of conflict. Explanations for the fact that the average of the subject-level averages tracks the theory reasonably closely, despite the rarity of individual subjects behaving consistently with the theory are beyond the scope of this paper, but perhaps this is a fruitful direction for future research which might seek to understand individual variation in the degree of “territoriality".

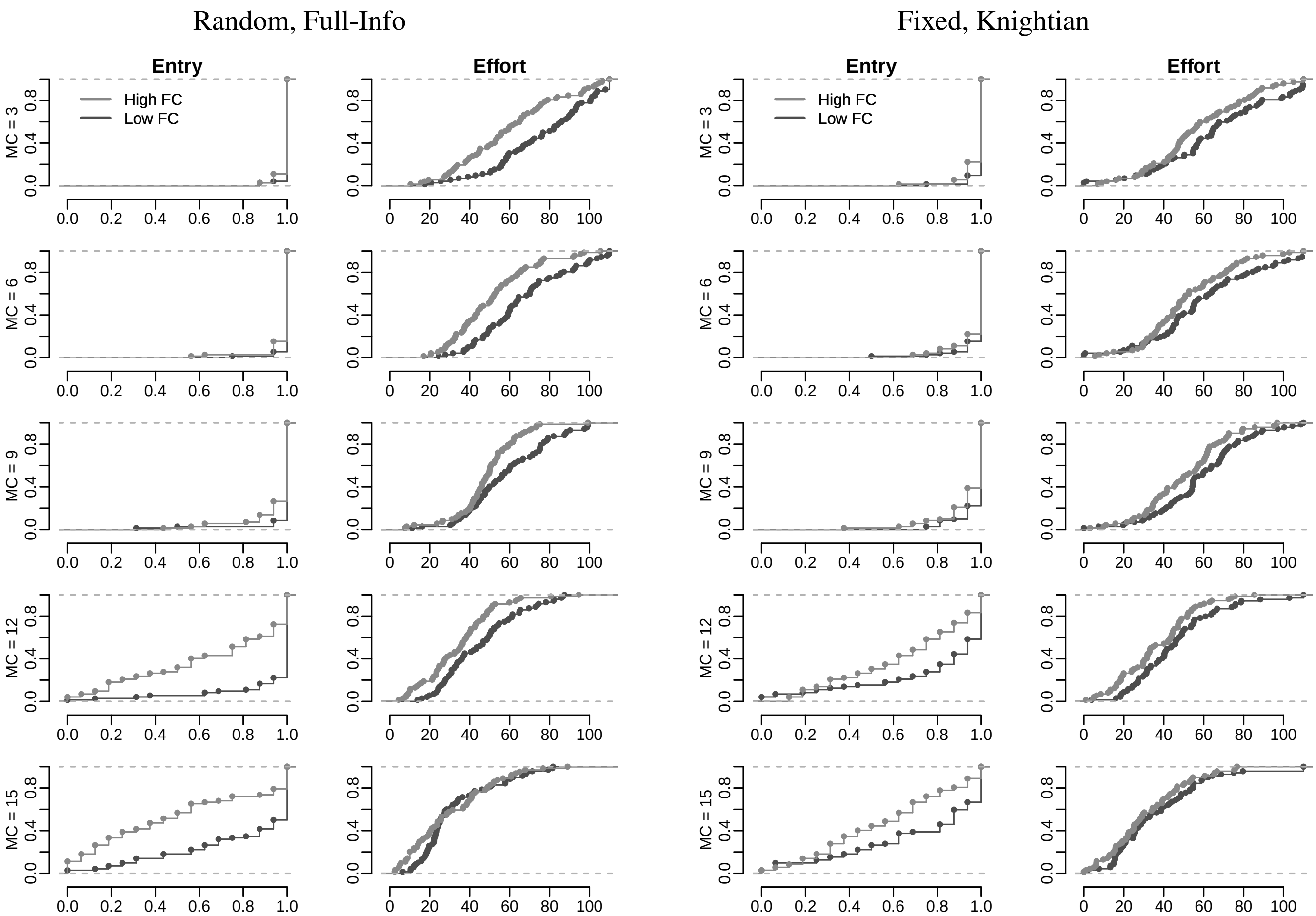


Figure C2: **Empirical CDFs of mean entry probability and effort expenditure, by subject, treatment and the marginal cost of effort at the location.** Non-entry is coded as missing data in computing effort means.