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Essays on Game Theory and Resource Economics

DISSERTATION

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DOCTOR OF PHILOSOPHY

in Economics

by

Erick Edward Peterson

Dissertation Committee:
Professor Michael McBride, Chair
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Professor Jean-Paul Carvalho

2014

DEDICATION

To my wife Ashley, and my mother Charlotte.

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ABSTRACT OF THE DISSERTATION

Essays on Game Theory and Resource Economics

By

Erick Edward Peterson

Doctor of Philosophy in Economics

University of California, Irvine, 2014

Professor Michael McBride, Chair

The dissertation is composed of three chapters that contribute to the areas of game theory and resource economics.

Chapter one, "Waves as a Common-Pool Resource: Why Do Surfers Share Waves?", presents a game theoretic model of ocean waves, used recreationally by surfers, as a common-pool resource. In games with a finite time horizon, the surfers will compete for waves such that they deplete the value of their shared resource, leading to a tragedy of the commons. On the other hand, when the game is played with an indefinite time horizon, surfers are able to maximize the value of their resource in equilibrium assuming they are patient enough. This application of the Folk Theorem establishes that ocean waves are a common-pool resource that can be efficiently maintained in equilibrium despite a lack of clearly defined property rights.

Chapter two, "Cooperation and the 'Surfers' Dilemma': An Experimental Study", provides experimental evidence on the relationship between group size and the probability of future interactions on cooperation in common-pool resource systems. Experimental evidence suggests that increasing group size significantly reduces the level of cooperation and leads to a decreased resource value. Additional experimental evidence suggests that cooperation is positively related to the probability of future interactions.

Chapter three, “Dangerous Water: Urban Runoff and Public Health”, Utilizes a natural experiment to test the effects of coastal water pollution on public health outcomes in the South Bay Region of San Diego, California. Evidence presented in this chapter suggests that urban runoff from the Tijuana River significantly increases the number of reported cases of cellulitis, staph infection, and hepatitis A, in South Bay hospitals for white males age 18-35.

Chapter 1

Waves as a Common Pool Resource: Why Do Surfers Share Waves?

1.1 Introduction

A Common-Pool Resource (CPR) is one that no individual can be excluded from consuming while at the same time any individual's consumption diminishes the value of the resource for everyone else who may want to use it. Standard examples of CPRs include fisheries, forests, grazing pastures, and irrigation systems. One problem inherent with CPRs is the problem of overuse or over extraction which often leads to deterioration of the resource itself. Since Hardin's (1969) article in *Science* this deterioration has been known as the "tragedy of the commons." To combat this 'tragedy' it has been suggested that property rights need to be established and as a result many CPRs have fallen under state or private control. Unfortunately neither the state nor the market has been overwhelmingly successful in enabling individuals to maintain productive resource systems. Additionally, there are several cases of self-governing CPRs where communities have been able to establish their own institutions that bear little resemblance to state or private control in order to successfully maintain their local resource [Ostrom, 1990].

Ocean waves used recreationally by surfers at the beach are an understudied example of a Common-Pool Resource that is neither controlled by the market nor the state. Waves are effectively non-excludable in that anybody who is willing to paddle out into the water has access to them. They are rivalrous in consumption because the directional nature of a breaking wave ensures that only the surfer with nobody in front of him enjoys the ride. An ideal wave for surfing is one that begins to break at a known starting point called the peak and continues to break in one direction down the beach. If more than one surfer rides a wave, only the surfer 'in front' or furthest from the peak has access to the face of the wave, by definition all other surfers are behind him. Thus, the surfer in front is essentially preventing the other surfers from receiving any utility from their ride by blocking their access to the wave's face. On the other hand, a surfers utility is an increasing function of distance traveled. Thus, it is the surfer 'in back' or closest to the peak that has the greatest potential utility from riding any given wave. Clearly the presence of other surfers has the potential to deplete the value of the resource, especially if the surfers decide to locate and surf far away from the peak. When viewed in this context it is evident that ocean waves used by surfers can be classified as a common-pool resource.

Waves differ from standard CPRs in two distinct ways. First, assuming that only one surfer can enjoy any given wave means that individual waves suffer from immediate congestion. Unlike a fish or piece of timber which once taken by an individual can be divided and equally enjoyed among several individuals, only one surfer can receive positive utility from any given wave. This increases competition among surfers looking to share waves as there can only be one 'winner.'

A second distinction between waves and other CPRs is that waves are primarily shared among strangers because surfers tend to travel to many different beaches in search of the best waves. Waves at any particular beach are highly variable day to day depending on the size and direction of the swell that generated the waves, as well as wind and tidal conditions. As a result beaches tend to have a large number of outsiders or non-locals using their resource. Standard examples of CPRs such as pastures, irrigation systems, fisheries, and forests tend to be used by the same group of local individuals over and over again. Tight knit groups interacting together for an extended period of time is a characteristic common to most CPRs that successfully maintain their resource without some form of direct intervention [Ostrom, 1990]. The fact that surfers interacting in the water generally do not know each other should make cooperation more difficult to sustain.

Having observed surfers in the water for the past 25 years there is one feature common to every beach I have visited. Despite several surfers being out in lineup, typically only one surfer rides any given wave. Moreover, surfers typically begin their ride or 'take off' very close to the peak, which allows them to ride the entire distance of the wave unimpeded. This observed cooperation suggest that waves, when viewed as a CPR, do not suffer from the tragedy of the commons. When surfers take turns riding waves from the peak they are maximizing the value of their resource since utility is an increasing function of distance traveled. Thus, surfers appear to allocate waves efficiently despite the absence of property rights.

If only one surfer rides any given wave from the peak, then every other surfer is deciding to give up the utility of riding that wave hoping that he will receive the same courtesy when it is his turn. However, deciding not to ride any particular wave guarantees zero utility. If surfers can only receive utility when they ride a wave, why do surfers share waves from the peak? If surfers queue up and take off from the peak, then they are opening the door for someone else to steal the wave and the utility therein.

Figure 1.1 illustrates a location game similar to Hotelling's (1929) spatial pricing model. In this game surfers sequentially choose a location $X \in \{1, 2, \ldots, X^*\}$ where each element

Figure 1.1: Location Game Framework

$X = 1$	$X = 2$	$X = 3$	...	$X = X^* - 2$	$X = X^* - 1$	$X = X^*$

in X represents one location on a line of length X^*. This line represents the area where surfers queue to wait for approaching waves and is known as the 'lineup.' In this framework $X = 1$ corresponds to the location of the waves commonly known endpoint, while $X = X^*$ corresponds to the location of the waves commonly known starting point, a.k.a. the peak. Using this setup there are exactly X^* locations in which surfers can choose to locate. After every surfer has selected their location, they will make a binary decision to 'ride' or 'not ride' the wave.

The surfer's location decisions (and their decisions regarding whether or not to 'ride' the wave) are embedded in a repeated game setting. However, this is not a standard repeated game because the strategies available to each player will depend on the outcome of the previous round. Using a location game framework, I find that cooperation, in the form of taking turns riding from the peak, is not a sustainable equilibrium for any finite horizon game. Moreover, with finite interactions the surfers will adopt a maximin strategy in which they take turns riding waves from location 1, which represents the shortest possible ride. When the game is played with an indefinite horizon, however, surfers can justify sharing waves from the peak in equilibrium and can therefore maximize the value of their resource. This cooperative result is an application of the Folk Theorem as the surfers' cooperation is contingent on how much they value the future.

The rest of the paper is organized as follows. Section II will define the model. Section III establishes sub-optimal equilibria for any finite horizon game. Section IV establishes a socially optimal cooperative equilibrium for games with an indefinite time horizon. Section V presents a simple example. Section VI summarizes the models results and concludes the paper.

1.2 The Model

Players will be indexed by $i = 1, 2, \ldots, I$, where $i = 1$ corresponds to the first player to arrive at the beach, while $i = I$ corresponds to the last player to arrive. The order in which players sequentially choose their location in the first period is determined according to the order in which they arrive at the beach.

In each period players will have a two element choice set ($S_{i,t}$) which contains a location decision and a binary decision to 'ride' or 'not ride' the wave. The surfers' realized decisions will be denoted with lower case letters. The first element of ($S_{i,t}$) is the surfers location decision $X_{i,t} \in \{X \setminus \cup_{j<i} s_{j,t}\}$, where $x_{i,t} = 1$ corresponds to a surfer choosing the location of the waves endpoint and $x_{i,t} = X^*$ corresponds to a surfer locating at the wave's peak. Because each location is assumed to fit only one surfer, once a location has been claimed it is removed from the set of available locations until the next period begins.

The second element in $S_{i,t}$ is a binary ride decision ($R_{i,t} \in \{0, 1\}$), where $r_{i,t} = 0$ corresponds to a surfer deciding to 'not ride' the wave in period t and $r_{i,t} = 1$ corresponds to a surfer deciding to 'ride' that period's wave. This decision gives surfers the option to share waves by choosing to 'not ride' a wave when other surfers are located closer to the peak. It also gives surfers the option to steal waves by choosing to 'ride' when others are located closer to the peak. Combining the two decisions yields a formal definition of the surfers' choice set in each period.

$$S_{i,t} = [X_{i,t} \in \{X \setminus \cup_{j<i} s_{j,t}\}, R_{i,t} = \{0, 1\}] \tag{1.1}$$

A surfer will receive positive utility if and only if he has unimpeded access to the wave's face. Thus, only the surfer who decides to 'ride' ($r_i = 1$) from the lowest location-value will receive positive utility while all other surfers receive utility equal to zero. The surfers exhibit a time preference represented by a common discount factor ($\delta \in [0, 1]$). For simplicity I assume that utility increases linearly in distance traveled, however all results will hold with any strictly increasing utility function. A surfer's utility in any given period is defined as follows:

$$U_i = \begin{cases} x_{i,t} r_{i,t} & \text{if } 0 < x_{i,t} r_{i,t} < x_{j,t} r_{j,t} \ \forall \ j \neq i \\ 0 & \text{otherwise.} \end{cases} \tag{1.2}$$

The game proceeds in the following order:

1. Surfers sequentially choose a location $X \in \{1, 2, \ldots, X^*\}$ with the restriction that no two surfers can occupy the same location.
2. All surfers simultaneously decide to ride or not ride the wave.
3. The game continues; in the next period ($t = 2, 3, \ldots, T$) players repeat steps 1-3.

It is assumed that surfers cannot ride two consecutive waves. It is very difficult if not impossible for any surfer to ride two waves in a row. If a surfer decides to ride a wave he is usually still surfing when the next wave in a set begins to break. Even if the next wave is not breaking by the time he finishes his ride, it takes time to paddle back to the lineup where he can feasibly take off on another wave. If a surfer is blocked by someone else taking off in front of him, committing to 'ride' a wave often results in the blocked surfer being left out of position to catch the next wave. Therefore if a surfer chooses to 'ride' in any period

t, he must sit out in the following period *(t+1)*, and he re-enters the game in period *(t+2)*.

$$S_{i,t+1} = \{\emptyset\} \text{ if } r_{i,t} = 1, \forall i, t \tag{1.3}$$

As players sit out and re-enter the game, both the number of players and the players themselves change from period to period. Another way to look at it is that a surfers' strategy set depends on the previous period. Thus, although the game is dynamic, it is not a typical repeated game.

The previous assumption that any surfer who decides to 'ride' a wave must sit out the subsequent period imposes another condition on the model with respect to the number of players *(I)*. Specifically, the model is only interesting if there are three or more surfers participating in the game. If there were only two surfers, they could simply take turns riding waves every-other period. Once either surfer decides to 'ride' while the other decides to 'not ride' in any given period, the game becomes a one-player game for all subsequent periods. Furthermore, with only one surfer participating in each period he can surf unimpeded from any location in the lineup, and he will choose location X^*.

In principle surfers could queue up outside the bounds of a breaking wave, allowing for the number of surfers (I) to exceed the number of locations between the wave's peak and endpoint (X^*). For simplicity I assume that all players are contained in the space between the wave's peak and endpoint, which does not affect the surfer's predicted behavior but imposes the following condition on I and X^*.

$$3 \leq I \leq X^* \tag{1.4}$$

When transitioning from one period to the next there are a few further assumptions that need to be established. The primary issue that needs to be addressed is the order in which players select their location from round to round. If a surfer chooses to 'not ride' in any period t ($r_{i,t} = 0$), he remains in the lineup until the next period begins. Therefore, when the surfers select their locations in period *t+1* some will be spatially closer to vacant locations than others by virtue of their location decisions in period t. If two surfers desire the same location in period *t+1*, it is assumed that whoever was closest to that mutually desired location in period t will have priority. In essence, surfers simultaneously choose locations with ties going to whoever is closest.

The next issue is how to re-introduce a player that has been forced to sit out for one period. If a surfer chooses to 'ride' from any location in period t, he will have to paddle back to the lineup. Thus, he will not be in position to participate in period *t+1*. However, upon re-entry in period *t+2* the players who chose to 'not ride' in period *t+1* will already be queued in the lineup. These carryover players will be closer to their desired location at the end of period *t+1* while the re-entrant is still paddling back to the lineup. Thus, carryover players maintain the previous round's order of selecting a location, while re-entrants must wait for all carryover players to select their locations before choosing a location for themselves.

The last issue to consider in the multi-period game is the order in which multiple re-entrants choose their location. If there are multiple re-entrants, then more than one player decided to ride a particular wave. This means that at least one player was necessarily blocked from accessing the wave's face and those players received zero utility despite deciding to 'ride.' If more than one player rides any given wave, the player who begins their ride at the highest location-value (closest to the peak) will have priority in selecting a location upon re-entry. If two surfers ride any given wave, the blocked surfer will be able to paddle back to the lineup first because he was blocked. The surfer who blocks everyone else will be the last to paddle back to the lineup, thus, he will select his location last upon re-entry.

Given that surfers are sitting out and re-entering as the game proceeds from period to period means that although it is not technically a repeated game, the game is dynamic. Surfers must consider the consequences of their decisions on all future periods and also must use backward induction to assess their own optimal strategies for the current period. The dynamic nature of the game allows the model's predictions to vary with the surfers' time preference and the time horizon they face.

The ultimate goal is to analyze the efficiency of the surfer's predicted behavior with respect to the value of the resource (V^R), defined as the average distance surfers travel (unimpeded) per wave.

$$V^R = T^{-1} \sum_{t=1}^{T} \sum_{i=1}^{I} \delta^{1-t} u_{i,t} \tag{1.5}$$

Because $\lim_{n \to \infty} T^{-1} = 0$, V^R defines the average distance traveled per period for any game where the number of periods (T) is less than infinity. Although I analyze an infinite horizon game, the infinite horizon simply reflects the idea that surfers are uncertain about the duration of the game. When viewed through the lens of an indefinite horizon, the above definition for V^R will still capture average distance traveled in an infinite/indefinite horizon setting as long as the realized number periods is countable.

Since only one surfer receives positive utility from any given wave, the only way for surfers to maximize the value of their resource is to allow one person to ride unimpeded from the peak in every period. If the only surfer to ride a wave in any period takes off from location X^*, then he receives the maximum possible utility. Moreover, if this happens in every period then the resource provides surfers with the highest possible level of utility in each period. Alternatively, if one surfer is taking off from location 1 in each period, then the average distance traveled per wave would equal one, the shortest possible distance assuming at least one surfer rides a wave every period.

1.3 Finte Time Horizon

This section analyzes situations where the players know the number of periods (T) prior to entering the game. Using backward induction to identify the surfers' best responses in each period yields multiple subgame perfect equilibria (SPE). The resulting payoffs will then be summed across all surfers and periods to identify the value of the resource defined in (5). The first step in the analysis is defining the following strategy which will be crucial in establishing the SPE of any finite horizon game.

Definition 1. Strategy A consists of the following actions in any period t

a If selecting a location last and location 1 is available, select the location-value exactly one less than the lowest occupied position and 'ride' the wave;

b If not selecting a location last and location 1 is available, select location 1 and 'ride' the wave;

c If location 1 is not available and the number of remaining periods is greater than or equal to the minimum available location-value, select the minimum available location value and choose to 'not ride' the wave;

d If location 1 is not available and the number of remaining periods is less than the minimum available location-value, select any available location-value and 'ride' the wave.

1.3.1 One-Shot Interaction

I will first analyze the game in a one-shot setting omitting the time subscript and discount factor. The final period of any game with finitely repeated interaction reduces to a one-shot game. Thus, the one-shot results of this section will be used in the next section to establish the surfers' best response strategies in the final period of any finite horizon game.

Proposition 1. *In any one-shot game the value of the resource, defined as average distance traveled, equals one.*

$$V^R = 1 \text{ } if \, T = 1 \tag{1.6}$$

Proof. The proof of Proposition 1 has five steps. Step 1-Step 4 use backward induction to establish strategy A as a SPE of the one shot game. The backward induction begins with the surfers' simultaneous decisions to 'ride' or 'not ride' the wave, and then addresses the surfers' sequential location decisions. Step 5 identifies the unique equilibrium outcome with respect to the value of the resource.

1. In any one-shot game the surfer positioned in the minimum location-value has a strict best response to 'ride' the wave.

   $$r_i = 1 \text{ if } x_i < x_j, \ \forall \ j \neq i. \tag{1.7}$$

   Consider the only two options for a surfer located in the minimum location-value.

   $$\begin{aligned} (a) \quad r_i &= 1 \text{ if } x_i < x_j, \ \forall \ i \neq j \\ &\Rightarrow u_i = x_i \\ (b) \quad r_i &= 0 \text{ if } x_i < x_j, \ \forall \ i \neq j \\ &\Rightarrow u_i = 0 \end{aligned}$$

$$\therefore\ u_i(r_i = 1) > u_i(r_i = 0) \text{ if } x_i < x_j,\ \forall\ j \neq i.$$

2. If location 1 is available, the last surfer to choose his location ($surfer_I$) has a unique best response to select the location-value exactly one less than the minimum location-value already selected and 'ride' the wave.

$$s_I^* = [x_I = \min\{x_i\ \forall\ i < I\} - 1, r_I = 1] \text{ if } \min\{X_I\} = 1. \tag{1.8}$$

Given the strict best response to 'ride' the wave for any surfer located in the minimum location-value (Step 1), consider the only 4 options for $surfer_{_I}$ if $\min\{X_I\} = 1$

$$\begin{aligned}
(a)\quad s_I' &= [x_I < \min\{x_i\ \forall\ i < I\} - 1, r_I = 1] \\
&\Rightarrow u_I(s_I') = x_I < \min\{x_i\ \forall\ i < I\} - 1 \\
(b)\quad s_I'' &= [x_I > \min\{x_i\ \forall\ i < I\} - 1, r_I = 1] \\
&\Rightarrow u_I(s_I'') = 0 \\
(c)\quad s_I''' &= [x_I = \text{any } x \in X_I, r_i = 0] \\
&\Rightarrow u_I(s_I''') = 0 \\
(d)\quad s_I^* &= [x_I = \min\{x_i\ \forall\ i < I\} - 1, r_I = 1] \\
&\Rightarrow u_I(s_I^*) = \min\{x_i\ \forall\ i < I\} - 1 \\
&\therefore\ u_I(s_I^*) > u_I(s_I)\ \forall\ s_I \neq s_I^* \text{ if } \min\{X_I\} = 1
\end{aligned}$$

3. Given the best response of $surfer_{_I}$ in step 2, if location 1 is available, every other surfer ($i < I$) has a unique best response to select location 1 and 'ride' the wave.

$$s_i^* = [x_i = 1, r_i = 1] \text{ if } \min\{X_i\} = 1 \tag{1.9}$$

Consider the only three options available to $surfer_i$ if $\min\{X_i\} = 1$:

$$(a) \quad s_i' = [x_i > 1, r_i = 1]$$
$$\Rightarrow u_i(s_i') = 0$$
$$(b) \quad s_i'' = [\text{any } x \in X_i, r_i = 0]$$
$$\Rightarrow u_i(s_i'') = 0$$
$$(c) \quad s_i^* = [x_i = 1, r_i = 1]$$
$$\Rightarrow u_i(s_i^*) = 1$$
$$\therefore u_i(s_i^*) > u_i(s_i'), \ \forall \ s_i' \in S_{i<I} \text{ if } \min\{X_I\} = 1$$

4. If surfers are acting according to strategy A when location 1 is available, they can justify any strategy as a (weak) best response once location 1 has been claimed.

$$s_i^* = [\text{any } x \in X_i, \text{any } r_i \in R] \text{ if } \min\{X_i\} \neq 1 \tag{1.10}$$

The only surfer who has the opportunity to claim location 1 with certainty is the first one to select his location ($surfer_1$). By step 3 his unique best-response calls for him to claim location 1 and 'ride' the wave.

$$s_1^* = [x_1 = 1, r_1 = 1]$$
$$\Rightarrow u_1(s_1^*) = 1$$
$$\therefore u_{i>1}(s_i) = 0 \ \forall \ s_i \in S_{i>1}$$

5. If surfers use Strategy A, the value of the resource (V^R) equals one.

$$s_1^* = [x_1 = 1, r_1 = 1]$$
$$\Rightarrow u_i(s_i) = 0, \ \forall \ i > 1$$

$$\therefore V^R = \sum_{i=1}^{I} u_i = 1 \qquad \square$$

By definition of the utility function *(2)*, only the surfer who decides to 'ride' from the lowest location-value will receive positive utility. Therefore, whoever has claimed the lowest location-value has a strict best response to 'ride' the wave. All others will be guaranteed utility equal to zero regardless of their decision to 'ride' the wave or not. Thus, part d of strategy A to constitutes a weak best response for any surfer who cannot claim location 1. Changing part d of to any available strategy would represent a different SPE. However, the outcome of this different equilibrium, with respect to the value of the resource, would remain unchanged.

In the one-shot setting $surfer_1$ will optimally choose to claim location 1 and 'ride' the wave. However, choosing the location of the wave's endpoint not only guarantees him that no other surfers can block his ride; it also ensures that his ride will cover the shortest possible distance. Thus, $surfer_1$ receives the minimum (positive) value of utility.

1.3.2 Finitely Repeated Interaction

For finite horizon games with repeated interaction, the sub-optimal results of proposition 1 hold for all periods as long as the players know the number of periods (T) prior to entering the game. The final period of any game with finite interactions reduces to a one-shot game. Thus, the players' optimal strategies in period T mirror the one-shot SPE strategies listed above. There are two major differences between the one-shot case and finitely repeated interactions. The first difference is that the surfer with priority in claiming location 1 in period T is not necessarily $surfer_1$ because players will be sitting out and re-entering as the game continues from period to period. Just as in the one-shot case, the first player to select their location in period T (re-named $surfer_i$) has a unique best-response to select location

1 and 'ride' the wave, while all other surfers can justify any strategy as a best response once location 1 has been claimed.

The other difference between the one-shot case and games with finitely repeated interaction is that if a surfer is not positioned in the minimum location-value but he will have an opportunity to claim location 1 before the game ends, he can no longer justify any strategy as a best response. This is because he finds it in his best interest to 'not ride' the wave in the current period in order to mo wait for his opportunity to claim location 1 and 'ride' unimpeded in some future period.

Proposition 2. *In any game with finitely repeated interaction, the value of the resource, defined as average distance traveled, equals one.*

$$V^R = 1 \text{ } \mathit{if} \, T < \infty \tag{1.11}$$

Proof. The proof of Lemma uses backward induction to establish all SPE of the finite horizon game. The surfers' equilibrium behavior determines the realized value of the resource.

Period *T* The only strategy which guarantees positive utility in the final period is to select location 1 and 'ride' the wave. This implies that if location 1 is available individuals have a strict best-response to select location 1 and 'ride.' Thus, the first person to choose a location in the final period will select location 1 and 'ride' the wave. Once location 1 has been selected, individuals can justify any strategy as (weak) best-response, because any strategy will yield utility equal to zero.

Period (*T-1*) Knowing the strict best response of the first mover in the final period, the first person to select their location in period (*T-1*) also has a strict best response to select location 1 and 'ride' the wave. Because of surfers' time preference ($\delta < 1$), the first mover in period (*T-1*) prefers to 'ride' the wave from location 1 in the current period, rather than waiting until the final period to 'ride' the wave from location 1

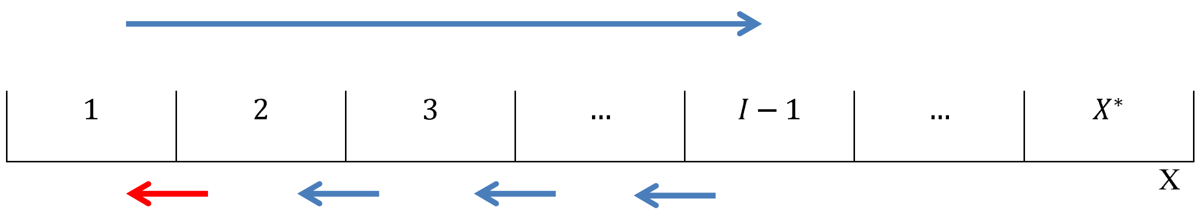
($\delta^{T-1} > \delta^{T}$). This implies that location 1 will be vacant in the final period. Thus, if location 2 is available in period (*T-1*) surfers have a strict best response to select location 2 and 'not ride' the wave. This strategy ensures that whoever selects location 2 in period (*T-1*) will be the first mover, and the only person to receive positive utility, in the final period. If the minimum available location-value is greater than 2, surfers can justify any strategy as a best response, because any combination of strategies in periods (*T-1*) or T will yield utility equal to zero.

Period (*T-2*) thru Period 1 The logic of period (*T-1*) carries all the way forward to period 1. If location 1 is available, surfers have a strict best-response to select location 1 and 'ride' the wave. If the minimum location-value for $surfer_i$ ($\min\{X_{i,t}\}$) is less than the number of remaining periods $(T - t + 1)$ but greater than 1, then $surfer_i$ has a strict best response to select the lowest available location value and 'not ride' the wave. If $\min\{X_{i,t}\} > (T - t + 1)$ then $surfer_i$ can justify any strategy as a strict best response, because he will not be able to reach location 1 before the game ends.

Result In all periods of the finite horizon game, someone has a strict best response to 'ride' the wave from location 1. Therefore, the realized value of the resource, defined as average distance traveled across all periods, equals one ($V^R = 1$). □

Figure 1.2 illustrates how surfers will behave in any finite horizon game. The short arrows below the location-values illustrate how surfers' best response strategies call for them to continue choosing the minimum available location until they reach location 1. The short arrow below location 1 illustrates that any surfer's best response will be to 'ride' the wave if he is positioned in that location. In the period immediately following any surfer's decision to 'ride' a wave he will have to sit out (Equation 3). The long arrow above the location values represents a surfer sitting out for one period as he paddles back into a position where he can re-enter the game and claim any available location. Since exactly one surfer will be sitting out in every period after the first, there will be $(I - 1)$ surfers participating in the

Figure 1.2: Non-Cooperative Equilibrium



game after period 1. After sitting out for one period surfers re-enter the game and continue to select the minimum available location value ($X = I - 1$) as long as that value is greater than or equal to the remaining number of periods ($T - t + 1$).

As has been demonstrated, any finite horizon game will have surfers taking turns choosing to 'ride' from location 1. In this equilibrium the surfers are sharing waves but they are all receiving the minimum amount of utility from their ride since they all begin their 'ride' at the location furthest from the peak. Because utility is increasing in distance traveled the surfers could be receiving higher utility per wave if they allowed one surfer to 'ride' unimpeded from a location-value greater than one. Unfortunately the surfers cannot credibly commit to this strategy and as a result the resource that surfers are sharing, a beach with directional waves, yields the minimum amount of utility to everyone using it. Similar to a centipede game, surfers end up at a sub-optimal outcome by using backward induction and identifying their opponent's best response in each subgame. If surfers were able to cooperate by allowing one another to 'ride' unimpeded from a location-value greater than one, they could increase social utility and the value of the resource they all share.

1.4 Indefinite Time Horizon

The sub-optimal results of the previous section are troubling for two reasons. First the unique equilibrium outcome of any finitely horizon game results in all surfers receiving the minimum (positive) value of utility every time they 'ride' a wave. Surfers could instead receive the maximum amount of utility across the same number of waves if they simply allowed each other to 'ride' unimpeded from the location of the peak ($X = X^*$) rather than the location of the wave's endpoint ($X = 1$). The second reason that the previous section's results are concerning is that surfers in the "real world" share waves by beginning their 'ride' close to the peak, which is in direct contrast to the model's predictions in finitely repeated settings. Is there a cooperative equilibrium in which surfers take turns riding from the wave's peak?

If the surfers face an indefinite horizon in which they believe another wave will arrive with probability $\pi \in [0, 1]$, then they will be uncertain about when the game ends. Thus, in indefinite horizon games surfers will discount future utility by the product ($\delta\pi$). Without loss of generality, these two separate discount factors, the surfers' time preference and the continuation probability, will be combined into one parameter (θ).

$$\theta = \delta\pi \in [0, 1] \tag{1.12}$$

The surfers' utility in the indefinitely repeated setting will be the same as equation (2), replacing (δ) with (θ). This section's analysis will be an application of the Folk Theorem, where surfers will be able to maintain cooperation, in the form of sharing waves from the peak rather than the endpoint, if and only if they are patient enough and they believe the game will continue with a sufficiently high probability. A trigger strategy, when played by all surfers, can sustain a cooperative equilibrium if (θ) is sufficiently high. This cooperative equilibrium result in surfers receiving the maximum amount of utility per wave, which translates into the maximum value of the resource (V^R) as defined in equation (5). In the case of an indefinite horizon, there exists a ‘defection’ equilibrium that closely mirrors the SPE of the finite horizon game. Consider the following adaptation of strategy A for the case of an indefinite time horizon.

Definition 2. Strategy A' consists of the following actions in any period t

a If location 1 is available, select location 1 and ‘ride’ the wave;

b If location 1 is not available, select the minimum available location-value and choose to ‘not ride’ the wave.

$$S_{i,t} = \begin{cases} [x_{i,t} = 1, r_{i,t} = 1] & \text{if } \min\{X_{i,t}\} = 1 \\ [x_{i,t} = \min\{X_{i,t}\}, r_{i,t} = 0] & \text{if } \min\{X_{i,t}\} \neq 1 \end{cases} \tag{1.13}$$

Strategy A' calls for players to claim the minimum available location and ‘not ride’ in every period until they reach location 1 regardless of the number of remaining periods. The above strategy is an SPE of the finite horizon game because any surfer with location 1 available has a unique best response to claim that location and ‘ride’ the wave. Choosing to ‘not ride’ from the minimum available location is a strict best-response for all surfers who will have an opportunity to claim location 1 before the game ends. Lastly, choosing to ‘not ride’ from the minimum available location-value is a weak best response for all surfers not able to claim location 1 before the game ends.

In order to see if the negative equilibrium outcome of Proposition 2 can be avoided consider the following trigger strategy in which players take turns riding unimpeded from location X^* if and only if this was the outcome of all previous periods, otherwise they revert to the sub-optimal strategy A' of equation (13).

Definition 3. Strategy B consists of the following actions in any period t:

a If the only surfer to ride in the previous period travels a distance of X^*, claim the maximum available location-value in every period and ride the wave once location X^* has been reached;

b If any surfer in the previous period travels a distance less than X^*, act according to strategy A'.

$$S_{i,t} = \begin{cases} \begin{cases} [x_{i,t} = X^*, r_{i,t} = 1] & \text{if } \max\{X_{i,t}\} = X^* \\ [x_{i,t} = \max\{X_{i,t}\}, r_{i,t} = 0] & \text{if } \max\{X_{i,t}\} \neq X^* \end{cases} & \text{if } \sum_{i=1}^{I} u_{i,t-1} = \theta^{t-2} X^* \\ \begin{cases} [x_{i,t} = 1, r_{i,t} = 1] & \text{if } \min\{X_{i,t}\} = 1 \\ [x_{i,t} = \min\{X_{i,t}\}, r_{i,t} = 0] & \text{if } \min\{X_{i,t}\} \neq 1 \end{cases} & \text{otherwise} \end{cases} \tag{1.14}$$

Cooperation, defined as surfers waiting their turn to 'ride' a wave from location X^*, results in one surfer traveling the maximum possible distance in each period. Thus, a cooperative equilibrium would be an efficient allocation with respect to the value of the resource (V^R). Of course the surfers' time preference combined with uncertainty that the game will continue implies that waiting may not be an optimal strategy.

If surfers are acting cooperatively under strategy B (denoted $s^C_{i,t}$), then any $surfer_i$ will have to wait $(i-1)$ periods to claim location X^* for the first time. This is because every surfer always claims the maximum available location-value. For example, $surfer_1$ will be able to claim location X^* and 'ride' in the first period. The second surfer to arrive ($surfer_2$) will locate at $(X^* - 1)$ and 'not ride' in period 1, which allows him to claim location X^* and 'ride' in period 2 with probability (π). Continuing this logic, $surfer_3$ claims location $(X^* - 2)$ in period 1, location $(X^* - 1)$ in period 2, and he will 'ride' the wave (unimpeded) from location X^* in period 3 with probability (π^2).

The continuation probability (π) combined with the surfers' time preference (δ) captures the surfers' distaste for waiting ($\theta \in [0,1]$). Therefore, in the cooperative equilibrium $surfer_i$ will find the expected utility from his first wave ridden equals X^* discounted by the number of periods it takes him reach the peak $(i-1)$.

$$E[u_{i,t}(S_{i,t}^C)] = (\theta^{i-1}X^*) \text{ if } t = i, \ \forall \ i,t \tag{1.15}$$

After $surfer_i's$ first ride he will have wait (I) periods in between opportunities to claim location X^* again. Thus, the surfer's payoff stream from all periods of the game is as follows;

$$\begin{aligned} E[\sum_{t=1}^{T} u_{i,t}(S_{i,t}^C)] &= X^*(\theta^{i-1} + \theta^{I+i-1} + \theta^{2I+i-1} + \theta^{3I+i-1} + \dots) \\ &= \frac{(\theta^{i-1}X^*)}{1-\theta^I}, \quad \forall i \end{aligned} \tag{1.16}$$

Of course, surfers can only receive the above payoff sequence from the cooperative equilibrium if the expected utility from 'defecting' is less than (16). Defection occurs in the first period when any surfer selecting the maximum available location chooses to 'ride' the wave from a location-value less than X^*. Because whoever claims location X^* in the first period ($surfer_1$) is in a position to receive the maximum value of utility, he cannot possibly defect.

$$s_{i,1}^D = [x_{i,1} = \max\{X_{i,1}\}, r_{i,1} = 1] \text{ if } \max\{X_{i,1}\} \neq X^*, \ \forall i > 1 \tag{1.17}$$

This implies $surfer_i's$ one-time defection payoff will be equal to the location value he selects in period 1. Since equation (17) states the defector must select the maximum available location-value, he will necessarily be occupying location$[(X^* - i) + 1]$, which also equals his utility earned by defecting in the first-period.

$$u_{i,1}(s_{i,1}^D) = [(X^* - i) + 1], \ \forall i > 1. \tag{1.18}$$

If $surfer_i$ 'defects,' he will have to wait (I) periods before he can claim location 1 and 'ride' the wave unimpeded a second time (assuming the game continues long enough). Similarly he will have to wait (I) periods before he will have the opportunity to claim location 1 each time thereafter. Thus, after period 1 where $surfer_i$ receives his one-time defection payoff, he will 'ride' from location 1 every (I) periods until the game ends.

$$E[\sum_{t=1}^{T} u_{i,t}(S_{i,t}^D)] = [(X^* - i) + 1] + \frac{\theta^I}{(1 - \theta^I)}, \ \forall i > 1. \tag{1.19}$$

Equation (19) represents the expected utility for any $surfer_i$ who chooses to defect in period 1. In order for surfers to maintain the cooperative portion of the trigger strategy in equilibrium the expected utility in (16) must be greater than or equal to the expected utility in (19) for all surfers.

$$\frac{(\theta^{i-1} X^*)}{1 - \theta^I} \geq [(X^* - i) + 1] + \frac{\theta^I}{(1 - \theta^I)} \tag{1.20}$$

Proposition 3. *In an indefinite horizon game, there exists a cooperative equilibrium in* *which the value of the resource, defined as the average distance traveled, equals X^* if surfers are patient enough and expect the game will continue with sufficiently high probability.*

$$\exists \quad \{\theta \in [0,1] : V^R = X^*\}. \tag{1.21}$$

Proof. The proof of proposition 3 consists of two steps. Step 1 establishes existence of the cooperative equilibrium. Step 2 derives the value of the resource under cooperation.

1. There exists $\theta \in (0,1)$ such that (20) holds

$$\begin{aligned} \frac{(\theta^{i-1}X^*)}{1-\theta^I} &\geq [(X^*-i)+1] + \frac{\theta^I}{(1-\theta^I)} \\ \Rightarrow \qquad \theta^{i-1}X^* &\geq (1-\theta^I)[(X^*-i)+1] + \theta^I \\ \Rightarrow \quad \theta^{i-1}X^* + \theta^I(X^*+i) &\geq [(X^*-i)+1] \end{aligned} \tag{1.22}$$

   Existence is established using the intermediate value theorem

$$\begin{aligned} \theta = 0 \quad \Rightarrow \quad [\theta^{i-1}X^* + \theta^I(X^*+i)] &= 0 \\ &< [(X^*-i)+1] \quad \forall\ X^*, i > 0, \\ \theta = 1 \quad \Rightarrow \quad [\theta^{i-1}X^* + \theta^I(X^*+i)] &= 2X^* + i \\ &> [(X^*-i)+1] \quad \forall\ X^*, i > 0. \end{aligned}$$

$$\therefore \qquad \exists \quad \{\theta \in (0,1) : \frac{(\theta^{i-1}X^*)}{1-\theta^I} \geq [(X^*-i)+1] + \frac{\theta^I}{1-\theta^I},\ \forall i\}.$$

2. Show the value of the resource V^R equals X^* if surfers adhere to the cooperative trigger strategy $(s^C_{i,t})$ defined in equation (14).

$$\text{Assume} \quad \{\theta \in (0,1) : \frac{(\theta^{i-1}X^*)}{1-\theta^I} \geq [(X^*-i)+1] + \frac{\theta^I}{1-\theta^I},\ \forall i\}$$

$$\Rightarrow \qquad E[\sum_{t=1}^{T} u_{i,t}(s_{i,t}^{*})] > E[\sum_{t=1}^{T} u_{i,t}(s_{i,t}^{\prime})], \ \forall i$$

$$\Rightarrow \qquad \sum_{i=1}^{I} u_{i,t}(s_{i,t}^{*}) = X^{*}(\theta^{1-t}), \ \forall t$$

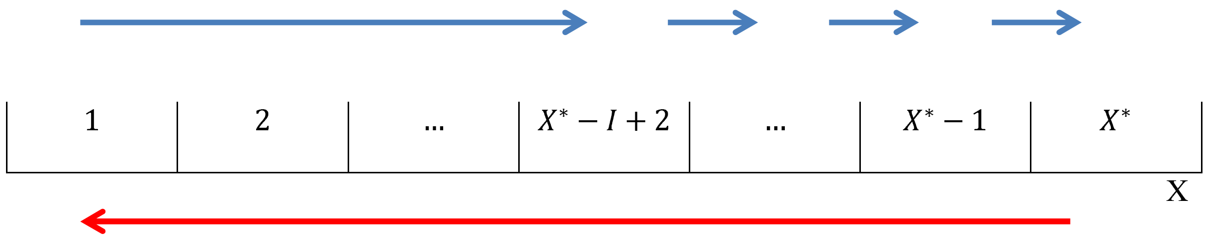
$$\therefore \qquad V^{R} = T^{-1} \sum_{t=1}^{T} \sum_{i=1}^{I} \ = \ X^{*} \qquad \square$$

In infinite/indefinite horizon games, the cooperative strategy represents a SPE as long as the surfers are patient enough (δ is high) and they believe another wave will arrive with high enough probability (π is high). This is similar to the "Folk Theorem" because players can sustain cooperation in a game with infinite/indefinite interactions provided they have a sufficiently high valuation of future utility (θ). In this situation the surfers are maximizing the value of their resource (V^R) as defined in equation (5) because in every period of the game one surfer is riding the wave unimpeded from the maximum possible location-value (X^*).

Figure 1.3 illustrates how the game will proceed in the cooperative equilibrium. The long arrow below the location-values represents a surfers unimpeded 'ride' from the wave's peak. The long arrow above the location-values represents a surfer sitting out for one period while he paddles back to the lineup following his ride. There are (I) surfers in the game but after the first period one surfer will be sitting out in each period. Therefore, there will only be ($I - 1$) surfers participating in any period after the first. This implies that after the first period, the maximum location-value available to the re-entrant will always be location ($X^* - I + 2$). The short arrows above the location-values represent surfers waiting their turn to 'ride' the wave by selecting the maximum available location-value every period and deciding to 'not ride.' This happens until surfers reach location X^* when they ride the wave and repeat the process all over again.

If surfers are able to maintain the cooperative strategy in equilibrium, they will be maxi-

Figure 1.3: Cooperative Equilibrium



mizing the value of their shared resource, and the waves will be providing the largest social benefit in terms of the utility any single wave provides society. Moreover they will be achieving the highest value of social utility without any clearly defined property rights. In this situation, which is commonly observed in real world settings, the surfers avoid the tragedy of the commons.

1.5 A Simple Example

This section will demonstrate the difference in social utility earned by the surfers when they choose the cooperative equilibrium of the previous section versus choosing the finitely repeated SPE strategies of section III. Consider a game where three surfers ($I = 3$) are deciding where to locate in a lineup with six locations ($X^* = 6$). The first case to be considered will be a finite horizon game where the surfers know the game will only last 3 periods ($T = 3$). The second case will be a game with an indefinite horizon that will also last for three periods but in the second case the surfers do not know the game will end in period 3.

Table 1.1 presents the surfers' SPE strategies for both cases. The first column indicates the time period. The finitely repeated SPE strategies according to Proposition 2 are presented in column 2, while the cooperative trigger strategies of the infinitely repeated interactions

Table 1.1: Cooperative vs. Non-Cooperative Strategies

Period	Finite SPE Strategies	Cooperative SPE Strategies
1	$s_{1,1} = [x_{1,1} = 1, r_{1,1} = 1]$ $s_{2,1} = [x_{2,1} = 2, r_{2,1} = 0]$ $s_{3,1} = [x_{3,1} = 3, r_{3,1} = 0]$	$s_{1,1} = [x_{1,1} = 6, r_{1,1} = 1]$ $s_{2,1} = [x_{2,1} = 5, r_{2,1} = 0]$ $s_{3,1} = [x_{3,1} = 4, r_{3,1} = 0]$
2	$s_{1,2} = \{\emptyset\}$ $s_{2,2} = [x_{2,2} = 1, r_{2,2} = 1]$ $s_{3,2} = [x_{3,2} = 2, r_{3,2} = 0]$	$s_{1,2} = \{\emptyset\}$ $s_{2,2} = [x_{2,2} = 6, r_{2,2} = 1]$ $s_{3,2} = [x_{3,2} = 5, r_{3,2} = 0]$
3	$s_{1,3} = [\text{any } x \in X_{1,3}, \text{any } r \in R]$ $s_{2,3} = \{\emptyset\}$ $s_{3,3} = [x_{3,3} = 1, r_{3,3} = 1]$	$s_{1,3} = [x_{1,3} = 5, r_{1,3} = 0]$ $s_{2,3} = \{\emptyset\}$ $s_{3,3} = [x_{3,3} = 6, r_{3,3} = 1]$

(14) are presented in column 3.

An interesting feature of both cases (finite and indefinite horizon) is that the number of players changes from period 1 to period 2. Moreover, since one person rides the wave in each period, implying he must sit out in the subsequent period, the surfers themselves are different from period to period. This differentiates the model from most games with repeated interaction where the players remain constant across periods.

In accordance with Proposition 2, the SPE of column 2 yields the minimum value of the resource (V^R) since one surfer decides to 'ride' from location 1 in each period. In this case $surfer_1$ can justify any strategy as a best response in period 3 since he knows he will not have another opportunity to claim location 1. Therefore there are multiple SPE for the finite horizon game. However, there can be only one outcome with respect to the value of the resource.

If the surfers with an indefinite horizon choose the cooperative equilibrium, their strategies will yield the maximum value of social utility. Column 3 of Table A shows that if the surfers adhere to the cooperative strategies in equation (14) then one surfer will 'ride' (unimpeded) from location 6 in each period. Unlike games with finite interactions, in the cooperative equilibrium $surfer_1$ cannot justify any strategy as a best response in period 3 because he believes the game will continue for another period with sufficiently high probability. Therefore $surfer_1$ must position himself in the maximum available location in period 3 anticipating the game will continue to period 4.

Of course, the surfers will only adhere to the cooperative equilibrium if they are patient enough. Plugging in $(i = 2, 3), (I = 3)$and$(X^* = 6)$ into inequality (20) yields $(\theta \geq 0.6501)$ for $surfer_2$ and $(\theta \geq 0.7024)$ for $surfer_3$. Therefore, as long as $(\theta \geq 0.7024)$ the surfers will find it in their best interest to cooperate by taking turns riding from location X^*. If the continuation probability was lower than this threshold $(\theta \geq 0.7024)$, the surfers know someone will 'defect' in the first period and prefer to play the game according to the non-cooperative SPE of the finite horizon game.

1.6 Conclusion

The model predicts that in any finite horizon game surfers will optimally choose to locate in the minimum available location-value and 'not ride' the wave until they claim the location of the wave's endpoint at which point they 'ride' the wave. This happens because locating at the wave's endpoint is the only way a surfer can assure himself positive utility as that is the only location where no other surfer can block his ride. Unfortunately this equilibrium results in the minimum value of utility for surfers on every wave since utility is increasing in distance traveled and they are starting from the point that yields the shortest possible ride. Furthermore, this does not match the cooperative behavior typically observed by surfers [Nazer, 2004].

In contrast to the finite horizon case, when players face an indefinite time horizon the model predicts that surfers can optimally choose a cooperative equilibrium where they take turns riding from location X^*, if they are sufficiently patient (Folk Theorem). This cooperative equilibrium results in surfers receiving the maximum value of utility from each wave because everybody gets to ride the maximum distance (peak to endpoint). If the players are not patient enough or do not believe another wave will arrive with sufficiently high probability, they will revert to the finite horizon SPE (Strategy A).

If surfers share waves by taking turns choosing to 'ride' from the peak then they will be maximizing the value of their resource, defined as average distance traveled. Unfortunately, if the surfers are not patient enough or believe that the game will soon end, their equilibrium strategies call for them take turns riding waves from location 1. This non-cooperative equilibrium which diminishes the value of the resource, defined as average distance traveled, is akin to a "tragedy of the commons."

If surfers in the "real world" shared waves by taking off very close to the peak, then they must perceive the game to be one with an infinite/indefinite horizon. If surfers believed they were engaged in a finite horizon game or if they were impatient, then the only SPE calls for them to share waves from the location of the wave's endpoint. Repeated personal observation of surfers acting cooperatively in the field implies that surfers not only believe they are playing a game with an indefinite time horizon, they are also patient enough to maintain a cooperative equilibrium. Despite a lack of clearly defined property rights, surfers are able to maintain open-access resource systems that generate near maximum levels of social utility. Hence it appears that surfers have avoided the tragedy of the commons, and I provide an analysis of how they may have done so in this paper.

Chapter 2

Cooperation and the 'Surfers' Dilemma': An Experimental Study

2.1 Introduction

Recently nations with large surf-tourism industries have been proposing policies that either limit or completely open access to some of the worlds most popular surf breaks. Those nations proposing limited access are doing so in response to overcrowding and the potential to capture monopoly rents from those willing to pay a premium for the right to surf a world class wave with relatively little competition from other surfers. On the other hand in 2010 Fiji unilaterally opened access to all of their surf breaks, including two of the world's most famous waves which had previously been open only to guests of the Tavarua Island Resort. These policies will necessarily affect the number of surfers sharing particular surf breaks. Those breaks protected by limited access will see fewer surfers competing for waves while Fijian surf breaks should see their numbers increase substantially.

Ocean waves used by surfers are an understudied class of open access or common-pool resources. A common-pool resource (CPR) is a natural or manmade resource that is costly (but not impossible) to exclude individuals from receiving the benefits of appropriation. Surf breaks, areas where waves are particularly conducive for surfing, represent a CPR in the sense that nobody can be easily excluded from accessing them. However, from the perspective of surfers, individual waves are a private good in that only one surfer can enjoy the full benefit from any given wave. This interaction between public goods (the ocean/coastline) and private goods (waves) creates rivalries in consumption that can theoretically lead to a tragedy of the commons. In the case of surf breaks the tragedy of the commons refers to a degradation of the resources value, defined as the average distance traveled per wave for all surfers. The CPR problem of surfing is very similar to fisheries where the body of water and the associated stock of fish represent a CPR, but once extracted the fish themselves are a private good.

This paper uses an experimental design to investigate the relationship between group size and cooperation among surfers. The level of cooperation directly affects the value of surfers' shared resource. Peterson (2011) develops a model that captures the strategic tensions surfers face when deciding where to locate in the water and whether or not to 'ride' a given wave. In this model the surfers' equilibrium decisions directly affect the value of the resource (in this case a surf break). Applying the model in a laboratory setting I find that increasing group size from 4 to 7 significantly decreases the value of the resource. Surfers in groups of four are able to enjoy 'rides' above the minimum length 15% of the time. That number drops to 4% when the group size is increased to seven. This evidence suggests that nations limiting access to specific surf breaks should see the value of those breaks increase, at least for those surfers lucky enough to have access. If privatization displaces surfers resulting in larger numbers at surf breaks that remain open, then those open-access surf breaks should see their value decrease.

The rest of the paper is organized as follows. Section II investigates the nature of the CPR problem of surfing and includes a literature review of the impacts of group size on collective action. Section III formally introduces the model. Section IV explains the experiment design. Section V offers theoretical predictions for the experiment outcomes. Section VI presents experiment results and Section VII concludes and offers extensions for future research.

2.2 Background

A surfer's utility is derived from distance traveled on the shear face of a breaking wave. Thus, waves that break over longer distances are more attractive to surfers. There is of course a tradeoff as those beaches that offer long rides are hence more densely crowded and because only a finite number of waves arrive in an hour, larger crowds entail (on average) fewer total rides per surfer. As a response to overcrowding a large surf-tourism industry has emerged wherein surfers travel all over the globe in search of waves that offer long rides with relatively little competition from other surfers. Over time the number of surfers has steadily increased while the number of newly discovered beaches has declined [Nazer, 2004].

Today even the most remote locations are being overcrowded by surfing tourists looking for the perfect wave. The first line of a field report on the Mentawai Islands, prepared by the Center for Surf Research at San Diego State University, states "Indonesias Mentawai Islands have reached surf-tourism saturation" [Ponting, 2012]. The problems with overcrowding at this once remote surf destination have also been noticed by eleven time world surfing champion Kelly Slater who posted the following comment on twitter in July 2012, "If there was any question as to whether weve ruined the Mentawais the sobering reality of 16 boats at 1 average break tonight confirmed it."[1]

While demand increases, nations endowed with desirable waves must choose how to manage access to their resource. Limiting access to particularly desirable surf breaks allows the

[1]https://twitter.com/kellyslater, posted on July 8, 2012

owners of exclusive access rights to charge tourists monopoly rents in exchange for the promise of relatively empty lineups. On the other hand maintaining an open-access policy allows a higher volume of tourists to enjoy the resource. A higher volume of tourists implies higher revenues for other local firms that cater to tourists (hotels, restaurants, charter boats, etc.). A higher volume of tourists also means that surfers will have to wait longer between rides and as a result they will not be willing to pay excessive rents for their experience. Moreover, if a larger group size negatively effects surfers' cooperation then the resource value will be diminished and surfers will be willing to pay even less for their experience. In the worst case scenario non-cooperative behavior resulting from overcrowding could devalue a surf break to the point where few are willing to pay the travel costs to ride that wave.

There is limited research on the economics of surf-breaks. Rider's (1997) theoretical paper treats waves as a common pool resource and introduced the term "surfer's dilemma" to describe the problem of more than one surfer riding a given wave. Kaffine [2009] empirically finds a positive relationship between quality of Californias surf breaks and the level of informal property rights imposed by locals.

Although several scholars have investigated the effect of group size on collective action in CPRs, there is little consensus on the direction of the relationship. Mancur Olson (1965) first identified a potentially negative impact of large groups on cooperation in the commons. "Indeed, unless the number of individuals in a group is quite small, or unless there is coercion or some other special device to make individuals act in their common interest, rational self-interested individuals will not act to achieve their common or group interests" (pg. 2). There is a vast literature testing Olson's hypothesis with little consensus on the direction of the relationship between group size and collective action. Baland and Platteau (1999) agree with Olson's hypothesis "Probably the most salient conclusion which emerges from these works, including the works of economic theorists, concerns the crucial role of group size: the smaller the group the stronger its ability to perform collectively" (p.773). Tang [1992] also finds evidence that smaller groups perform better than large groups in managing irrigation systems. Agrawal and Goyal [2001] find that the costs of monitoring increase more than proportionately as group size increases.

Despite the research that supports Olson's hypothesis there are several studies that suggest group size has a negligible or even positive effect on collective action. Wade [1988] investigates irrigation groups in South India and finds that small group size is not necessary to facilitate successful collective action. Using an experimental study on voluntary provision of public goods, Isaac and Walker [1988] conclude that there is no pure group size effect. Marwell and Oliver [1993] published a series of articles on 'Critical Mass Theory,' a theory of public goods provision in groups. They argue, based on a significant body of empirical evidence, "the size of a group is positively related to its level of collective action" (p.38).

To combat potentially negative outcomes associated with large groups sharing a resource, some nations actively limit access to their best waves cultivating a high-rent, low-volume surf tourism industry. In 2011 the Republic of Maldives leased the previously uninhabited island of Thanburudhoo, home of the nation's two most popular surf breaks, Honkeys and Sultans, to developers for 50 years [Mull, 2010, Connoly, 2012]. Developers plan to build a boutique surf resort where guests will have exclusive access to these surf breaks displacing tourists from competing resorts and a small number of local surfers.

In September 2012 the Indonesian government issued an extensive regulation and management revision proposal that would establish different levels of accessibility for different surf breaks around the Mentawai Islands off the west coast of Sumatra [Baker, 2012, Ponting, 2012]. The Mentawai's are an extremely popular surf destination where extensive overcrowding has led some local villages to impose access restrictions on some of the most popular breaks. The new management revision proposal includes limits on the number of charter boats operating in the area and a code of conduct for surfer's behavior in the water.

Fiji used to employ a similar exclusive access policy on Tavarua Island home to their most famous waves, Cloudbreak and Restaurants, but reversed the policy in 2010 when they issued an open-access decree for all Fijian surf breaks. This policy shift was in response to a sagging economy and subsequent push by local businesses to open the waters and increase the number of surfers visiting the islands [Carroll, 2010, Holmes, 2010].

The idea behind limiting access to high-demand waves is that smaller groups will find it easier to cooperate. As it pertains to surfing, cooperation implies that only one surfer rides any given wave. Because the resource value is defined as average distance traveled per wave, in order for surfers to maximize the value of their shared resource each wave should have one surfer beginning their ride from a position that maximizes distance traveled.

2.3 Baseline Theory

2.3.1 The Model

Figure 2.1 illustrates a location game similar to Hotelling's (1929) spatial pricing model. In this game surfers sequentially choose a location $X \in \{1, 2, , X^*\}$ where each element in X represents one location on a line of length X^*. This line represents the area where surfers queue to wait for approaching waves and is known as the 'lineup.' In this framework $X = 1$ corresponds to the location of the wave's commonly known endpoint, while $X = X^*$ corresponds to the location of the wave's commonly known starting point, a.k.a. 'the peak.' Using this setup there are exactly X^* locations in which surfers can choose to locate. After every surfer has selected their location, they will make a binary decision to 'ride' or 'not ride' the wave.

The model used in this paper and the resulting predictions were first developed in chapter 1

Figure 2.1: Location Game Framework

$X = 1$	$X = 2$	$X = 3$	...	$X = X^* - 2$	$X = X^* - 1$	$X = X^*$

where the surfer's location decisions (and their decisions regarding whether or not to 'ride' the wave) are embedded in a dynamic setting. In games with finite interaction the surfers will adopt a maximin strategy in which they take turns riding waves from location 1, which represents the shortest possible ride. When the game is played with indefinite interaction, however, surfers can justify sharing waves from the peak in equilibrium and can therefore maximize the value of their resource. This cooperative result is an application of the Folk Theorem as the surfers' cooperation is contingent on their preferences for future utility.

Players will be indexed by $i = \{1, 2, , I\}$, where $i = 1$ corresponds to the first player to arrive at the beach, while $i = I$ corresponds to the last player to arrive. The order in which players sequentially choose their location in the first period is determined according to the order in which they arrive at the beach.

In each period, players will have a two-dimensional choice set ($S_{i,t}$) which contains a location decision and a binary decision to 'ride' or 'not ride' the wave. The surfers' realized decisions will be denoted with lower case letters. The first element of ($S_{i,t}$) is the surfers location decision ($X_{i,t} \in \{X \setminus \cup_{j<i} s_{j,t}\}$), where $x_{i,t} = 1$ corresponds to a surfer choosing the location of the wave's endpoint and $x_{i,t} = X^*$ corresponds to a surfer locating at the wave's peak. Because each location is defined as fitting only one surfer, once a location has been claimed it is removed from the set of available locations until the next period begins.

The second element in ($S_{i,t}$) is a binary ride decision ($R_{i,t} \in \{0, 1\}$), where $r_{i,t} = 0$ corresponds to a surfer deciding to 'not ride' the wave in period t and $r_{i,t} = 1$ corresponds to a surfer deciding to 'ride' that period's wave. Because waves break directionally starting at the peak, the decision to ride the wave or not is made sequentially with the surfer who chooses the largest location-value making their decision first while the surfer who selected the lowest location-value makes their decision last. This decision gives surfers the option to share waves by choosing to 'not ride' a wave when other surfers are located closer to the peak. It also gives surfers the option to steal waves by choosing to 'ride' when others are located closer to the peak. Combining the two decisions yields a formal definition of the surfers' choice set in each period.

$$S_{i,t} = [X_{i,t} \in \{X \setminus \cup_{j<i} s_{j,t}\}, R_{i,t} = \{0,1\}] \tag{2.1}$$

I assume that a surfer will receive positive utility if and only if he has unimpeded access to the wave's face. Thus, only the surfer who decides to 'ride' ($r_{i,t} = 1$) from the lowest location-value will receive positive utility while all other surfers receive utility equal to zero. The surfers exhibit a time preference represented by a common discount factor ($\delta \in [0,1]$). For simplicity I assume that utility increases linearly in distance traveled, however all results will hold with any strictly increasing utility function. A surfer's utility in any given period is defined as follows:

$$U_i = \begin{cases} x_{i,t} r_{i,t} & \text{if } 0 < x_{i,t} r_{i,t} < x_{j,t} r_{j,t} \ \ \forall \ j \neq i \\ 0 & \text{otherwise.} \end{cases} \tag{2.2}$$

It is assumed that surfers cannot ride two consecutive waves. Therefore if a surfer chooses to 'ride' in any period t, he must sit out in the following period *(t+1)*, and he re-enters the game in period $t+2$.

$$S_{i,t+1} = \{\emptyset\} \text{ if } r_{i,t} = 1, \forall i, t \tag{2.3}$$

The game proceeds in the following order:

1. Surfers sequentially choose a location $X \in \{1, 2, \ldots, X^*\}$ with the restriction that no two surfers can occupy the same location.
2. All surfers simultaneously decide to 'ride' or 'not ride' the wave.
3. The game continues to the next period ($t = 2, 3, \ldots, T$) where players repeat steps 1-3.

As players sit out and re-enter the game, both the number of players and the players themselves changes from period to period. Another way to look at it is that a surfers' strategy set depends on the previous period. Thus, although the game is dynamic, it is not a typical repeated game. Surfers must consider the consequences of their decisions on all future periods and also must use backward induction to assess their own optimal strategies for the current period. The dynamic nature of the game allows the model's predictions to vary with the surfers' time preference and the time horizon they face.

The ultimate goal is to analyze the efficiency of the surfer's predicted behavior with respect to the value of the resource (V^R), defined as the average distance surfers travel (unimpeded) per wave.

$$V^R = T^{-1} \sum_{t=1}^{T} \sum_{i=1}^{I} \delta^{1-t} u_{i,t} \tag{2.4}$$

Because $\lim_{n\to\infty} T^{-1} = 0$, V^R defines the average distance traveled per period for any game where the number of periods (T) is less than infinity. When viewed through the lens of an indefinite horizon, the above definition for V^R will capture average distance traveled as long as the realized number of periods is countable. When faced with an indefinite time horizon, expected utility depends not only on the common discount factor ($\delta \in [0, 1]$) but also on the probability, $\pi \in [0, 1)$, that the game will continue for another round (another wave will arrive). Combining the two terms yields the surfers overall time preference:

$$\theta = \delta\pi \in [0, 1). \tag{2.5}$$

Since only one surfer receives positive utility from any given wave, the only way for surfers to maximize the value of their resource is to allow one person to 'ride' unimpeded from the peak in every period. If the only surfer to 'ride' a wave in any period takes off from location X^*, then he receives the maximum possible utility. Moreover, if this happens in every period then the resource provides surfers with the highest possible level utility in each period. Alternatively, if one surfer takes off from location 1 in each period, then the average distance traveled per wave would equal one, the shortest possible distance assuming at least one surfer rides a wave every period.

2.3.2 Equilibrium Predictions

In this subsection I will summarize the equilibrium predictions presented in chapter 1, "Waves as a Common Pool Resource: Why Do Surfers Share Waves," adding one additional proposition. I focus my analysis on games with indefinitely repeated interaction and only briefly touch on predicted equilibrium behavior in games with finitely repeated interaction.

Proposition 1. *In any game with finitely repeated interaction the value of the resource, defined as average distance traveled, equals one.*

$$V^R = 1 \; if \, T < \infty \tag{2.6}$$

Proof. See chapter 1, proposition 2.

Proposition 1 states that in any game with finitely repeated interaction, surfers cannot achieve cooperative outcomes. The following definition characterizes a non-cooperative SPE in games with finite interaction. There are multiple SPE in these finite interaction games however all SPE require the first mover in any round to select location 1 and 'ride' the wave.

Definition 1. Strategy A consists of the following actions in any period t:

a If location 1 is available, select the location 1 and 'ride' the wave;

b If location 1 is not available, select the minimum available location-value and choose to 'not ride' the wave;

$$s_{i,t} = \begin{cases} [x_{i,t} = 1, r_{i,t} = 1] & \text{if } \min\{X_{i,t}\} = 1 \\ [x_{i,t} = \min\{X_{i,t}\}, r_{i,t} = 0] & \text{if } \min\{X_{i,t}\} \neq 1 \end{cases} \quad \forall \; i, t \tag{2.7}$$

In order to see if the negative equilibrium outcome with finitely repeated interaction can be avoided in an indefinitely repeated setting consider the following trigger strategy in which players take turns riding unimpeded from location X^* if and only if this was the outcome of all previous periods, otherwise they revert to the sub-optimal strategy A of equation (7).

Definition 2. Strategy B consists of the following actions in any period t:

a If the only surfer to 'ride' in the previous period travels a distance of X^*, claim the maximum available location-value in every period and 'ride' the wave once location X^* has been reached;

b If any surfer in the previous period travels a distance less than X^*, act according to strategy A.

$$S_{i,t} = \begin{cases} \begin{cases} [x_{i,t} = X^*, r_{i,t} = 1] & \text{if } \max\{X_{i,t}\} = X^* \\ [x_{i,t} = \max\{X_{i,t}\}, r_{i,t} = 0] & \text{if } \max\{X_{i,t}\} \neq X^* \end{cases} & \text{if } \sum_{i=1}^{I} u_{i,t-1} = \theta^{t-2} X^* \\ \begin{cases} [x_{i,t} = 1, r_{i,t} = 1] & \text{if } \min\{X_{i,t}\} = 1 \\ [x_{i,t} = \min\{X_{i,t}\}, r_{i,t} = 0] & \text{if } \min\{X_{i,t}\} \neq 1 \end{cases} & \text{otherwise} \end{cases} \tag{2.8}$$

Cooperation, defined as surfers waiting their turn to 'ride' a wave from location X^*, results in one surfer traveling the maximum possible distance in each period. Thus, a cooperative equilibrium would be an efficient allocation with respect to the value of the resource (V^R). Of course the surfers' time preference combined with uncertainty that the game will continue implies that waiting may not be a best response.

It is shown in chapter 1 that surfers can maintain the cooperative portion of strategy B in equilibrium, if and only if the expected utility from cooperation is greater than or equal to the expected utility from defecting, for all surfers:

$$\frac{(\theta^{i-1} X^*)}{1 - \theta^I} \geq [(X^* - i) + 1] + \frac{\theta^I}{(1 - \theta^I)} \tag{2.9}$$

Proposition 2. *In an indefinite horizon game, there exists a cooperative equilibrium in* *which the value of the resource, defined as the average distance traveled, equals X^* if surfers are patient enough and expect the game will continue with sufficiently high probability.*

$$\exists \quad \{\theta \in [0,1] : V^R = X^*\}. \tag{2.10}$$

Proof. See chapter 1, proposition 3.

In indefinite horizon games, the cooperative strategy represents a SPE as long as the surfers are patient enough (δ is high) and they believe another wave will arrive with high enough probability (π is high). This is similar to the Folk Theorem because players can sustain cooperation in a game with infinite/indefinite interactions provided they have a sufficiently high overall time preference (θ). In the cooperative equilibrium surfers are maximizing the value of their resource (V^R) as defined in equation (4) because in every period of the game one surfer is riding the wave unimpeded from the maximum possible location-value (X^*).

According to equation 9, the decision to cooperate depends on the surfer (i), the size of the group (I), the surfers' time preference (θ), and the potential value of the resource (X^*). Thus, holding group size and potential resource value fixed, the value of a single surfer's overall time preference ($\bar{\theta}_i$), above which he prefers strategy B, is different for all surfers. Therefore, surfers will only cooperate if their overall time preference is greater than the largest value of $\bar{\theta}_i$ for all i. Let $\hat{\theta}$ represent this critical value,

$$\hat{\theta} = \max_{i \in I}\{\bar{\theta}_i \forall i \in I\}. \tag{2.11}$$

Proposition 3. *For X^* sufficiently large, the critical value for surfers' overall time preference ($\bar{\theta}_i$), above which they prefer strategy B in equilibrium, is a globally increasing function of the number of players (I).*

$$\frac{\partial \hat{\theta}(I)}{\partial I} > 0 \tag{2.12}$$

Proof. Let Ω represent the expression that solves equation 9 for equality,

$$\Omega = \bar{\theta}_i^I (X^* - i) + \bar{\theta}_i^{i-1} X^* - X^* + i - 1 = 0 \tag{2.13}$$

Notice that $\frac{\partial \Omega}{\partial \bar{\theta}} > 0$, and for X sufficiently large $\frac{\partial \Omega}{\partial i} < 0$. This implies that

$$\frac{\partial \bar{\theta}}{\partial i} = -\frac{\frac{\partial \Omega}{\partial i}}{\frac{\partial \Omega}{\partial \bar{\theta}}} > 0$$

Thus, for X^* sufficiently large, the largest critical value of $\bar{\theta}_i$ is increasing in i. Thus, $\hat{\theta}$ represents the critical value of $\bar{\theta}_i$ for the last person to select their location in period 1 $(i = I)$,

$$\hat{\theta} = (\bar{\theta}_i = I).$$

Substituting $\bar{\theta}$ for $\hat{\theta}$ yields the following modified expression for Ω

$$\hat{\Omega} = (\hat{\theta}^I - \hat{\theta}^{I-1}) X^* - \hat{\theta}^I I - X^* + I - 1 = 0$$

Note: $\frac{\partial \hat{\Omega}}{\partial \hat{\theta}} > 0$ because $X^* > I$, and for X^* sufficiently large $\frac{\partial \hat{\Omega}}{\partial I} < 0$. Therefore,

$$\frac{\partial \hat{\theta}}{\partial I} = -\frac{\frac{\partial \hat{\Omega}}{\partial I}}{\frac{\partial \hat{\Omega}}{\partial \hat{\theta}}} > 0$$ □

To summarize the predicted behavior from the baseline model: Surfers will not cooperate if they know the duration of the game, that is cooperation is not sustainable in any finite horizon game. Surfers can maintain a cooperative equilibrium in games with indefinitely repeated interaction if and only if they are patient enough (Folk Theorem). Lastly, cooperative equilibria become more difficult to achieve as group size increases.

2.4 Experiment Design

2.4.1 Basic Design

In order to test the equilibrium predictions of the previous section, I designed a laboratory experiment which allowed me to control the probability of future interaction and the size of the group across experimental sessions. In all treatments subjects were randomly assigned into groups of either four or seven. In the first round of each potentially multiple round interaction subjects sequentially selected a number between 1 and 10, with the restriction that no two subjects could select the same number. Once all subjects selected their number, they were asked to either 'Claim' or 'Not Claim' the number they selected. Within each group the subject who decided to 'Claim' the lowest number received points equal to the number he selected, while all other subjects receive zero points. At the end of each round the computer chooses a random number from a uniform distribution over [0,1]. If the random draw was less than the commonly known continuation probability, then the game continued for another round. If the random draw was greater than the continuation probability, the game ended and subjects were randomly re-assigned into new groups of either four or seven, depending on the session.

I conducted six experimental sessions with a total of 214 subjects. Treatment variables include the continuation probability and the number of subjects in a group. Using a between subjects design, all variables were held constant throughout each session. In each session, subjects participated in a series of (potentially) multiple-round interactions with an indefinite time horizon. The total number of interactions in each session ranged from 1 to 10. The number of rounds per interaction ranged from 1 to 16. Each session had between 28 and 40 subjects who were randomly sorted into groups of either four or seven at the beginning of each interaction.

Table 2.1: Responses to Experiment Questionnaire

					Major*						
Session	Number of Subjects	Number of Groups	Percent Male*	Percent with 1+ Statistics Courses	Percent Business or Economics	Percent Psychology or Cognitive Science	Percent Other Social Science, Sociology, or Criminology	Percent Physical Science or Engineering	Percent Life Science, Biology, or Public Health	Percent Humanities, Language, or Undecided	Average Take Home Earnings**
All	214	46	39%	57%	19%	7%	16%	27%	25%	6%	$15.48
4_30	40	10	35%	69%	23%	5%	23%	25%	23%	3%	$12.58
4_60	40	10	52%	67%	15%	5%	17%	33%	25%	5%	$15.70
4_90 (1)	28	7	29%	54%	14%	18%	14%	25%	18%	11%	$15.39
4_90 (2)	36	9	56%	67%	12%	18%	16%	25%	16%	13%	$14.86
7_90 (1)	35	5	40%	65%	26%	6%	9%	26%	28%	6%	$16.74
7_90 (2)	35	5	34%	37%	14%	6%	17%	26%	31%	6%	$17.37

Note: * Information obtained from the questionairre; ** Includes show-up payment

The sessions took place in a computer laboratory at a large public university. The experiment was programmed and conducted using z-Tree experimental software [Fischbacher, 2007]. Subjects were students who had registered to be in the laboratory subject pool and were recruited by email solicitation. Subjects were not allowed to participate in more than one session. The instructions shown to subjects are listed in appendix A.1 and screenshots of the experiment are shown in appendix A.2. At the end of the session subjects answered a short questionnaire asking a variety of demographic questions (i.e. age, gender, academic status, courses completed, and major). This demographic information is summarized in Table 2.1.

In the first session, denoted 4_30, the subjects were randomly assigned into groups of four at the beginning of each interaction. After the first round of each interaction, the game continued for another round with probability 0.3. The subjects participated in 10 interactions covering 16 total rounds for an average of 1.6 rounds per interaction. In the second session, denoted 4_60, the continuation probability was increased to 0.6 while subjects were still placed into groups of four at the beginning of each interaction. In session 4_60 subjects played 7 total games covering 21 total rounds for an average of 3 rounds per interaction. The third and fourth sessions, denoted 4_90(1) and 4_90(2) respectively, also randomly assigned subjects into groups of four at the beginning of each new interaction but the continuation probability in these sessions increased to 0.9. The subjects in session 4_90(1) participated in 4 interactions covering 22 total rounds for an average of 5.5 rounds per interaction. The subjects in session 4_90(2) had only one interaction which lasted for 16 rounds.

The fifth and sixth sessions, denoted 7_90(1) and 7_90(2) respectively, increased group size at the beginning of each new interaction from four to seven. In these sessions the interaction continued for another round with probability 0.9. In session 7_90(1) the subjects participated in one interaction which lasted 11 rounds. Session 7_90(2) also had one interaction which lasted for 14 rounds.

The unit of observation is a group-round. For each round completed at most one subject per group earns points. The points earned per group-round measures the level of utility provided by the group's shared resource. Across all sessions the number of group-rounds ranged from 55 to 200, with 748 group-rounds in total.

Subjects earned $1.00 for each point earned during the session. Because each round in sessions 7_90(1) and 7_90(2) took longer to complete due to increased group size, the subjects received a $15 show-up payment for those two sessions, while subjects in sessions with group size equal to four (4_30, 4_60, 4_90(1), and 4_90(2)) received a show-up payment of $7. The average take-home earnings across all sessions was approximately $16 for 90 minutes of participation.

2.4.2 Individual Interactions

The subjects were randomly assigned into groups of four or seven at the beginning of each new interaction (depending on the session). At the beginning of each new interaction subjects were shown a welcome screen (informing them that they had been randomly re-assigned to a new group of four (or seven) and that they would remain in the same group until the next multiple-round interaction begins. Once each subject indicates that they are ready by clicking 'OK,' they proceed to the first round of play. After each round is complete the computer draws a random number between 0 and 1. If the random number drawn is smaller than the continuation probability (0.3, 0.6, or 0.9), then that interaction continues for one more round. Otherwise subjects are informed that the current interaction has ended. They are returned to the welcome screen where they wait to begin a new multiple-round interaction within new randomly assigned groups.

2.4.3 Individual Rounds

In each round of every (potentially) multiple-round interaction participants must make two decisions. The first stage is the sequential 'location decision' for which participants select a number between 1 and 10 with the restriction that no two participants may select the same number in any round. Once the first mover selects a number between 1 and 10, the second mover is informed of the first mover's decision and must select one of the remaining 9 numbers. The third mover is then informed of the first two movers' decisions and must select one of the remaining 8 numbers. This continues until all participants have selected a number. Subjects are randomly assigned a ranking that determines the order in which they will make this decision in the first round. After the first round the order is determined by the subjects' decisions in the preceding round.

The second stage in each round replicates the binary ride decision for which participants must decide to 'Claim' or 'Not Claim' their number. This decision is made sequentially such that the participant who selected the largest number in the first stage decides to 'Claim' or 'Not Claim' their number first, while the participant who selected the smallest number makes this decision last. Prior to entering the second stage, all participants are made aware what numbers were selected in the first stage and the order in which they will make decisions in the second stage.

In order to have a chance at earning points in any round, participants must decide to 'Claim' their number. However, any participant that decides to 'Claim' their number must sit out for one round regardless of their points earned. Any participant that decides to 'Not Claim' their number will earn zero points for that round but they will be allowed to participate in the next round. The participant that decides to 'Claim' the lowest number will earn points equal to that number they selected, while all other participants earn zero points.

The order in which subjects select their number is determined randomly in the first round only. After the first round the decision order is preserved for those who decide to 'Not Claim' their number. Thus, if a subject selects their number first in any round (t) and they decide to 'Not Claim' their number, then they will still have the opportunity to select their number first in the next round ($t+1$). If a subject decides to 'Claim' their number in any round (t) then they will not participate in the next round ($t+1$) and they will re-enter the interaction in the following round ($t+2$). If there is only one subject re-entering the interaction, he will select his number last. If there are multiple re-entrants, the order in which they select their number is determined by the number selected prior to sitting out. The person who selected the lowest number among the re-entrants will select their number last, while the person who decided to 'Claim' the largest number will select their number first among the re-entrants. All re-entrants must wait for carryover players, those who decided to 'Not Claim' their number in the previous round, to select their numbers before they will have an opportunity to select a number for themselves.

To illustrate how the order is determined and how points are earned, consider the following example: Suppose that in round 1 the first mover selects number 1, the second mover selects number 2, the third mover selects number 3, and the fourth mover selects number 4. If the two players who selected number 1 and number 2 decide to 'Not Claim' their number while the players who selected numbers 3 and 4 decide to 'Claim' their number, then the third mover would be the player to 'Claim' the lowest number and he would receive 3 points for round 1. All other players receive zero points for round 1.

In round 2, the first and second mover from the first round will be the only participants because they decided to 'Not Claim' their numbers in round 1. Because the order is preserved for those players who decide to 'Not Claim' their number the first mover in the first round will also be the first mover in round 2. Similarly, the second mover from the first round will remain the second mover in round 2, The third and fourth movers from the first round will not be participating because they decided to 'Claim' their numbers in round 1.

Suppose the first mover in round 2 selects number 1 and decides to ‘Claim’ that number while the second mover selects number 2 and decides to ’Not Claim’ that number. In this case the first mover will receive one point while the second mover will receive zero points. The first mover must sit out round 3, while the second mover will participate in round 3 and will have the opportunity to select a number first.

In round 3 the two players who decided to ‘Claim’ their number in round 1 will re-enter the game and join the one player who decided to ‘Not Claim’ their number in round 2. The one player who decided to ‘Not Claim’ his number in round 2 will select his number first in round 3. The player who decided to ‘Claim’ number 4 in round 1 will be the second mover in round 3 and the player who decided to ’Claim’ number 3 in round 1 will be the third and final mover in round 3.

Once every participant has decided to ‘Claim’ or ‘Not Claim’ their number, all subjects are shown a profit screen that summarizes all decisions made by each participant and the resulting points earned by each participant for that round. In the final round of every game the profit screen informs the subjects that the current game is over and includes one additional piece of information relative to the standard profit screen, their total points earned for the entire game.

2.4.4 Continuation Probability

Proposition 2 suggests that if surfers are sufficiently patient, a cooperative equilibrium can emerge. Plugging in parameter values for group size ($I = \{4, 7\}$), subject ($i = \{1, 2, \ldots, I\}$), and largest available number ($X^* = 10$) into inequality 10, the minimum theoretical time preference ($\theta \in (0, 1)$) required for a cooperative equilibrium can be backed out. For sessions with group size equal to 4, setting both sides of inequality 14 equal for the fourth mover ($i = 4$) yields a minimum required value of $\theta = 0.78$. For the session with group size equal to 7, solving inequality 14 for the sixth mover ($i = 6$) yields the minimum value of $\theta = 0.83$.

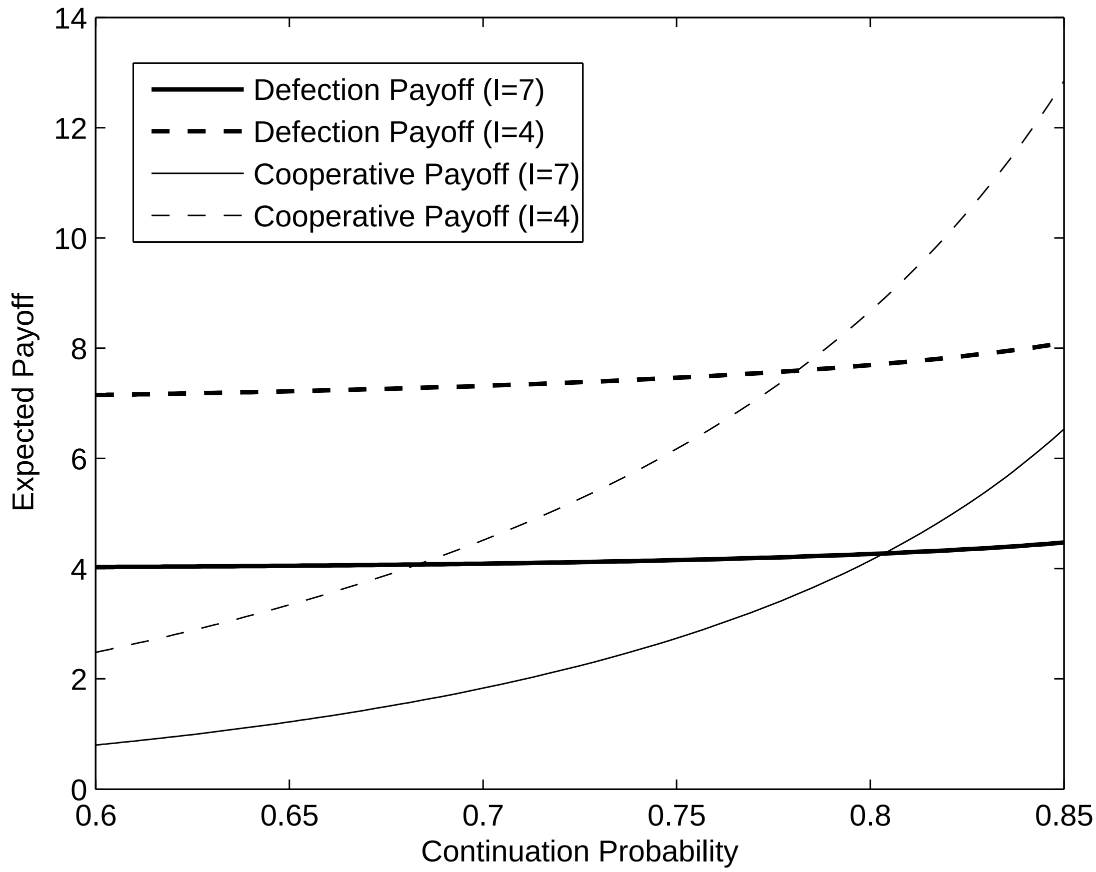
To test proposition 2, an application of the Folk Theorem, I increased the continuation probability while holding the group size of four constant. The continuation probability (π) is the only component of the subjects' overall time preference (θ) that I can control in the lab. Their discount factor (δ), which is independent of π, is likely close to one in this setting given the small time interval between individual rounds and the fact that they receive cash payments in one lump sum at the end of the session. Thus, the continuation probability is more likely to affect the subjects overall time preference relative to their discount factor. In the first session (4_30) the continuation probability was set at 0.3, well below the theoretical cutoff value of 0.78. For the second session (4_60) the continuation probability was increased to 0.6. In the third and fourth sessions (4_90(1) and 4_90(2)) the continuation probability was increased to 0.9, above the theoretical threshold.

2.4.5 Group Size

Proposition 3 states that increasing the group size will have a negative effect on cooperation. To test the effects of group size on cooperation, I increased the group size from 4 to 7 while holding the continuation probability constant at 0.9. In sessions 4_90(1) and 4_90(2) the group size was set at four while the group size for sessions 7_90(1) and 7_90(2) was set to seven. Because anyone who decides to 'Claim' their number must sit out for one round, the number of participants in any round after the first will often be at least one less than the size of the group. Thus, if only one participant decides to 'Claim' their number in each round, as theory predicts in both cooperative and non-cooperative equilibria, the number of participants after the first round will be effectively doubled between the 4_90 and 7_90 sessions.

Figure 2 maps the expected payoffs for cooperation and defection for a range of continua-

Figure 2.2: Cooperative vs. Non-Cooperative Payoffs



tion probabilities. The slopes of the expected payoffs in the non-cooperative equilibria are relatively flat compared to expected payoffs under cooperation due to the fact that continuation payoffs are so much smaller in the non-cooperative case (1 vs. 10). Also, the expected payoffs under both cooperative and non-cooperative equilibria are higher when the group size equals four. This is due to the fact that subjects in smaller groups have to wait fewer rounds between opportunities to claim a number, regardless if that number is 1 or 10.

2.4.6 Hypotheses

In order to test for cooperation in the surfers dilemma game the primary variable of interest is points earned per round. Because each individual round represents one wave, in order to measure the value of the resource as defined in equation (4) I simply substitute points earned for distance traveled.

Hypothesis 1. Holding group size fixed, the points earned per round will be larger in the sessions with a higher continuation probability.

This hypothesis supports the claim of Proposition 1 and represents a Folk Theorem result applied to the 'surfer's dilemma' game. Because the continuation probabilities in the first two sessions (4_30 and 4_60) are below the theoretical cutoff value of 0.78 I expect subjects in these two sessions to converge to the non-cooperative equilibrium. Sessions 4_90(1) and 4_90(2) set the continuation probability at 0.9, above the theoretical cutoff value. Subjects in these two sessions can rationally converge to a cooperative equilibrium. I expect the points earned per round will be larger in sessions 4_90(1) and 4_90(2) relative to sessions 4_30 and 4_60.

Hypothesis 2. Holding the continuation probability fixed, the points earned per round will be larger in sessions with a smaller group size.

This hypothesis supports the claim of Proposition 2. Because the group size in sessions 4_90(1) and 4_90(2) are smaller than group size in sessions 7_90(1) and 7_90(2) I expect the average points earned per round across all groups in the sessions with four subjects per group to be larger than sessions where group size is set to seven.

2.5 Results

Table 2.2 contains a summary of the experiment results obtained for all six sessions. The table includes the number of games played by each group, the total number of rounds completed, and the total number of observations for each session. The average number of players per round and the average points earned per round for all six sessions are also included. The last three columns of Table 2.2 are expressed in percentage terms. The first of these entries is the percentage of rounds in which subjects earned the minimum of one point. The next to last column displays the percentage of rounds in which the first mover selected the number one and the last column of shows the percentage of rounds in which the first mover was the winner. According to the SPE strategy of Definition 1, if subjects are engaged in a non-cooperative equilibrium it is a strict best response for the first mover to select the number one and 'Claim' that number. The evidence in Table 2.2 suggests that subjects conformed to this strategy a majority of the time.

For each round where at least one subject decided to 'Claim' a number, I record their points earned. There are some cases where all participants in a group decided to 'Claim' their numbers. When this happens the entire group skips a round. As a result the number of observations per session does not necessarily equal the number of groups times the number of rounds. Across all sessions with group size equal to four there are 11 group-rounds where the number of players equals one. When there is only one participant in a given round, no other participants can 'Claim' a number. Thus, the lone participant can essentially 'Claim' any number without any competition from other group members. As a result in all 11 cases where the number of participants equals one, the players earned the maximum 10 points. These 11 group-rounds are not included in the analysis.

Table 2.2: Experiment Results

Session	Number of Subjects	Number of Groups	Number of Games	Total Number of Rounds	Number of Observations*	Number of Players per Round	Average Points Earned per Round	Percent Points Earned Equals One	Percent First Mover Selected Number One	Percent First Mover Earned Points
All	214	46	24	100	773	3.66	1.43	86.2%	69.5%	69.5%
4_30	40	10	10	16	157	3.44	1.37	84.1%	66.8%	67.5%
4_60	40	10	7	21	200	3.17	1.50	85%	63.5%	64%
4_90 (1)	28	7	4	22	149	2.96	1.44	85.2%	77.8%	77.2%
4_90 (2)	36	9	1	16	146	2.77	1.80	67.1%	54.1%	58.2%
4_90 (both)	64	16	5	38	295	2.85	1.62	76.2%	66.1%	67.8%
7_90 (1)	35	5	1	11	55	5.47	1.11	96.4%	74.5%	74.5%
7_90 (2)	35	5	1	14	66	5.34	1.26	89.4%	71.2%	69.7%
7_90 (both)	70	10	2	25	121	5.40	1.19	92.6%	72.7%	71.9%

Note: * number of observations is defined as total number of rounds with profit greater than zero and the number of players greater than one

2.5.1 Hypothesis 1

In sessions 4_30 and 4_60 the continuation probability was set below the theoretical cutoff for cooperation. The average points earned per round in these two sessions were 1.37 and 1.50 respectively. Using a two-sample (one-sided) t-test I cannot reject the null hypothesis that the mean points per round are equal across the two treatments (p-value 0.15).

In sessions 4_90(1) and 4_90(2) the continuation probability was set at 0.9, above the theoretical cutoff. The average points earned per round in these two sessions were 1.44 and 1.80 respectively. Using a two sided t-test for equality I reject the null hypothesis that the two means are equal (p-value 0.026). In session 4_90(1) there were 4 interactions over 22 rounds while the session 4_90(2) had only a single interaction which lasted for 16 rounds. In the session with multiple interactions the average points per round decreased in each successive interaction. It is possible that being in the same group for an entire session (which is also the case in both sessions with group size equal to seven) creates an added incentive to cooperate relative to sessions where there are multiple interactions taking place within different groups.

Combining the results from both sessions with a continuation probability of 0.9, the subjects' average points per round was 1.62. Comparing this to the mean of session 4_30 using a one sided t-test I reject the null hypothesis that the two means are equal, in favor of the alternative that the average points earned per round was greater in the two sessions with the higher continuation probability of 0.9 (p-value 0.013).

I also compared the combined results of sessions 4_90(1) and 4_90(2) to the average profits of session 4_60. Using a one sided t-test I cannot reject the null hypothesis that the two means are equal (p-value 0.19). Despite no statistical distinction between results when the continuation probability is increased from 0.3 to 0.6 or from 0.6 to 0.9, there is evidence of increased cooperation when the continuation probability jumps from 0.3 to 0.9.

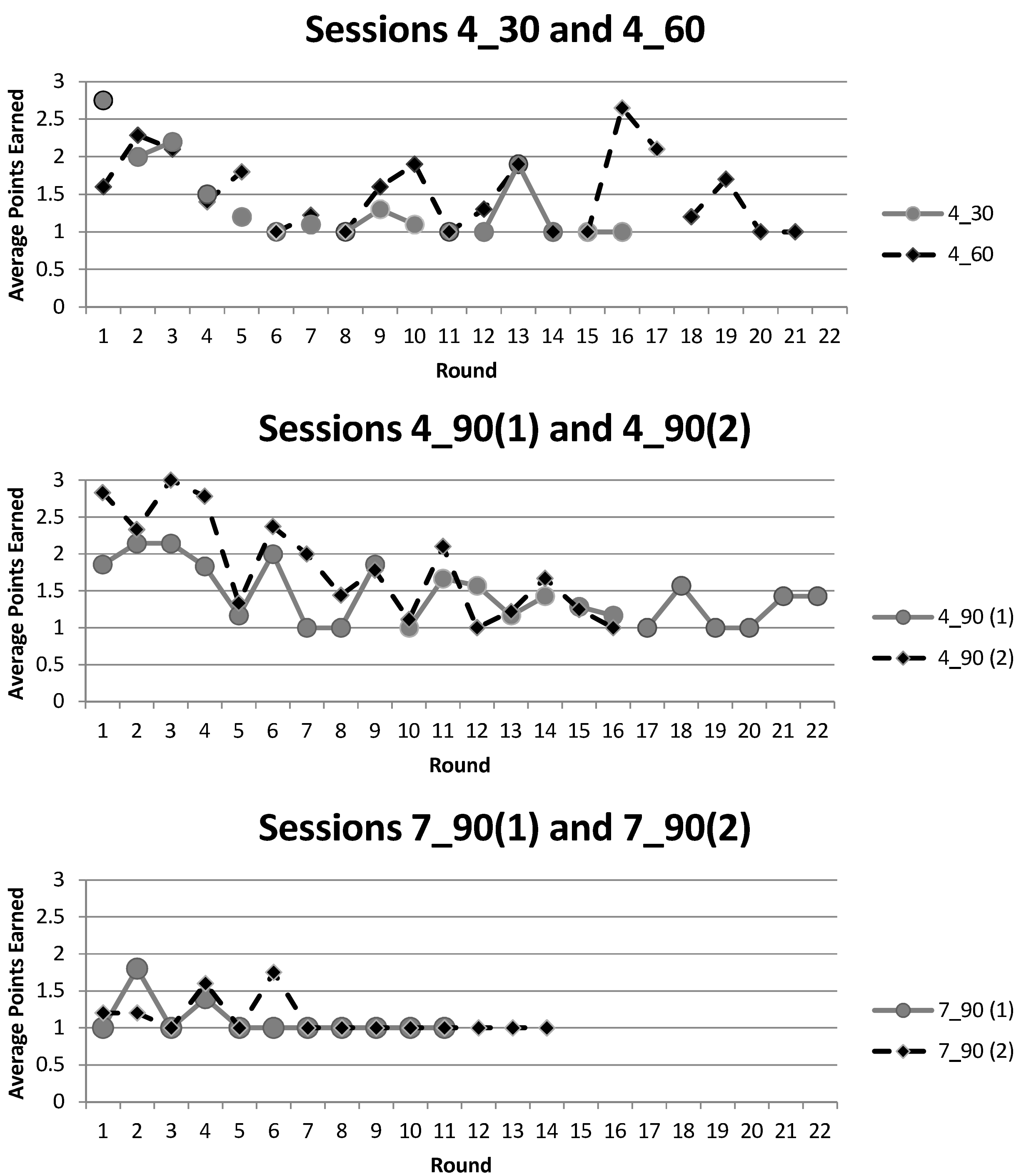
It is entirely possible that the 0.9 continuation probability is not sufficiently high to induce cooperation among the subjects. Although the theoretical cutoff value for the required continuation probability is 0.78, obtaining this number required complex calculations that the subjects are unable to perform in the lab. Although the subjects were much closer to the non-cooperative equilibrium (1 point per round) relative to the cooperative outcome (10 points per round), their mean points per round were significantly greater than 1 (p-value equals 0.00 for all sessions).

2.5.2 Hypothesis 2

To test my second hypothesis I varied only the group size while holding the continuation probability constant. In sessions 4_90(1) and 4_90(2) there were four subjects in each group while that number increased to seven for sessions 7_90(1) and 7_90(2)between sessions 4_90(1) and 4_90(2) session 3 (7_90). Both sessions with group size equal to seven produced only one interaction with 11 and 14 rounds respectively. With group size equal to seven the interactions took significantly longer relative to the sessions with group size equal to four. The average number of participants per round (with at least one player) in the two sessions with group size equal to four was 2.87 while the average number of participants per round in sessions with group size equal to seven was 5.40.

Subjects in session 7_90(1) averaged 1.11 points per round, while subjects in session 7_90(2) averaged 1.25 points per round. Comparing the two means using a two sided t-test I cannot reject the null hypothesis that the two means are equal (p-value 0.31). Combining the two sessions with group size equal to seven produces an average points per round equal to 1.19. Sessions 4_90(1) and 4_90(2) yielded a combined average points per round of 1.62. Comparing the combined results (4_90(both) and 7_90(both)) using a one sided t-test I reject the null hypothesis that the two means are equal (p value 0.00). Thus, the subjects' points earned

Figure 2.3: Average Payoff by Session



per round decreased when the group size was augmented from four to seven confirming the predictions of hypothesis 2.

Subjects in the two sessions with group size equal to four earned the minimum one point in 76.2% of rounds while that number jumps to 92.6% for the two sessions with group size equal to seven. Clearly when the group size was increased from four to seven the subjects' behavior was much closer to the non-cooperative SPE of definition 1. This evidence supports Proposition 3 and suggests that cooperation in the 'surfer's dilemma' game less likely when group size increases.

To check for learning effects and convergence of behavior over time Figure 3 plots the average earnings per round across all groups. In the four sessions with group size equal to four behavior did not converge to the non-cooperative equilibrium. In these sessions average earnings oscillates between 1 and 3 points per round. In the two sessions with group size equal to seven there was only one interaction with eleven and fourteen rounds respectively. In session 7_90(1) there were only two group-rounds in which subjects earned above the minimum one point, and no groups earned above the minimum after the fourth round. In session 7_90(2) there were seven group-rounds in which subjects earned above the minimum one point and no groups earned above the minimum after round six. Thus, it appears subjects' behavior in sessions 7_90(1) and 7_90(2) converged to a non-cooperative equilibrium closely mirroring the SPE of Definition 1.

2.6 Conclusion

The primary finding in this study is that increasing group size severely limits the level of cooperation in the 'surfers' dilemma' game. It is clear that increasing the group size from four to seven significantly reduces the average earnings per round (wave). Moreover behavior in both sessions with group size equal to seven converged to the non-cooperative equilibrium, which yields the minimum points per round. The findings of this study cast doubt on the ability of large groups to sustain cooperation when sharing waves at a single surf break. This result supports Olson's hypothesis that collective action is negatively related to group size. Similar to other case studies found in Ostrom [1990], surf breaks are a unique example of self-governing CPRs where individuals have been able to establish their own institutions, bearing little resemblance to state or private control, in order to successfully maintain their shared resource.

Theory and evidence also support the notion that cooperation is positively related to the probability of future interactions. Thus, the realized value of the resource will be larger when surfers feel that there is a high probability of future interactions, which means either there is a high probability that another wave will arrive before he exits the water or there is a high probability that the other surfers in the lineup will remain in the water. This result supports the existing literature studying the shadow of the future and its impact on cooperation in indefinitely repeated games.

Cooperative equilibria are commonly observed among surfers in real world settings even when the groups are relatively large [Nazer, 2004, Stebbins, 2013]. This suggests that other factors limiting surfers' ability to act in their own self-interest may be contributing to the favorable collective outcomes commonly observed. These factors include social norms, unwritten rules, and external punishments for non-cooperative behavior. Indeed there have been many documented cases of verbal and physical confrontation that occur in the water when individuals behave non-cooperatively [Young, 2000, Kaffine, 2009]. Possible extensions of this study that may better capture real world settings could include establishing a social norm of cooperation, introducing long-term and short-term players (locals and non-locals), or imposing punishments for defectors. Punishments here are additional actions outside of the original game, not simply not-cooperating in future interactions.

While the model is specific to surfers interacting in a surf break, the location game developed in this paper can be applied to other common pool resource systems. For example, many migratory fish species reproduce close to shore before migrating out to sea. These fish are much larger as adults and each fish would be worth much more if allowed to mature. Thus, locations further along the migratory path would be worth more if fisherman in locations closer to the breeding grounds refrained from catching fish. Natural irrigation systems represent another common pool resource system that could be analyzed within this framework.

Chapter 3

Dangerous Waters: Urban Runoff and Public Health

3.1 Introduction

There is a large body of epidemiological research showing a relationship between exposure to polluted recreational waters and several types of illness including gastroenteritis (GI), acute respiratory disease (ARD), and infections of the eye, ear, and skin [Pruss, 1998]. Dwight et al. [2005] estimate a cost of illnesses associated with coastal water pollution at two southern California beaches to be $3.3 million per year. Most of these studies utilize survey data gathered from beach attendees to estimate the effects of pollution. One notable exception is Fleisher et al. (1996, 1998) who utilized a randomized controlled trial to uncover variable health effects for different sources of pollution.

While there is ample research that suggests a positive relationship between coastal water pollution and minor illnesses, there is currently no research that expands the analysis to include severe illnesses which require hospitalization such as cellulitis, staph infection, and hepatitis A. Using data on hospitalizations from the California Office of Statewide Health, Planning, and Development (OSHPD), data on water quality and beach closures from the San Diego department of environmental health (DEH), and data on surf conditions from surfline.com, this paper utilizes a natural experiment to capture the effects of coastal water pollution on hospitalizations for white males age 18-35.

Imperial Beach, a beach community located in San Diego's South Bay, presents a unique case study for the effects of water pollution on public health. Imperial beach is the southern most beach community in California and its beaches stretch all the way south to the international border between the United States and Mexico. During significant rain events the Tijuana river flows directly into the Pacific ocean 2 miles north of the U.S. international border, just south of Imperial beach proper. Due to geography and ocean surface currents the effects of pollution from the Tijuana river are concentrated in Imperial Beach and are rarely detected north of San Diego's South Bay [Kim et al., 2009, Terrill et al., 2009].

Although the area is highly impacted by the Tijuana river, the river only flows during significant rain events and does not openly flow into the ocean when dry weather prevails. According to Jay Novak, founder of the Tijuana River Valley Citizen's Council, "Any day during or after a rain you can see the water coming out. It's not a pleasant sight. The water is usually brown and sudsy and it's usually littered with lots of plastics and debris" [Dacong, 2010]. Because the river only flows into the ocean during times of significant precipitation in the watershed, the variation in the presence and levels of coastal water pollution off Imperial Beach is essentially random.

Another feature that makes Imperial Beach a unique case study is that it is very popular beach for surfers. "The California Coastline from Imperial Beach to the international border is home to San Diego County's best surf spots, but it's also where the Tijuana River empties a dangerous amount of sewage, chemicals, and other pollutants into Imperial Beach waters when it rains" [Gill, 2009]. The popularity of these beaches and their proximity to the Tijuana River necessitates frequent monitoring of ocean water quality by the DEH. Whenever concentrations of fecal indicator bacteria (FIB) exceeds California health standards (Assembly Bill 411, Statutes of 1997, chapter 765) the DEH will post warning/closure signs indicating that the water is not safe for swimming. Despite the warning signs surfers frequently ignore the closures and enter the water, especially when the surfing conditions are particularly good (large waves) [Thomas, 2009, Gill, 2009]. Surfing conditions vary randomly because they are determined by the magnitude and direction of ocean swells generated by weather systems often thousands of miles away. The offshore storm systems that generate ocean swells are unrelated to local storm systems that generate precipitation in the area.

Combining data on water quality from the DEH with data on surf conditions from surfline.com allows me to identify 'risky' days in which the water was contaminated and the surf was better than average. Comparing these 'risky' days to days when the water was clean and/or the surfing conditions were average or worse, provides a natural experiment to test the effects of exposure to water pollution on public health.

This paper contributes to the existing literature in the following ways. First, to my knowledge this is the first paper to utilize a quasi-experimental design to analyze the health effects of coastal water pollution. Other papers studying the health effects of water pollution have utilized either survey data or controlled experiments. Second, relative to other California beaches Imperial Beach has higher concentrations of FIB and exceeds California health standards more frequently, increasing the range and severity of associated illnesses. Third, this paper provides the first analysis of the relationship between exposure and hospitalizations for conditions including cellulitis, staph infections, sinus problems, and hepatitis A. Lastly, the nature of the natural experiment allows for analysis of public health effects caused by contaminated coastal water for surfers or other individuals who prefer to enter the water when surfing conditions are good. Other studies have posited the potential effects for surfers but none have specifically targeted surfers for their analysis.

The rest of the paper is organized as follows. Section II provides background information on the health effects of costal water pollution and the sources of water pollution in Imperial Beach. Section III describes the data used for the estimation. Section IV reviews the estimation methodology. Section V presents estimation results, section VI discusses the results, and section VII concludes.

3.2 Background

There have been several epidemiological studies on health effects associated with coastal water pollution. Dwight et al. [2004] finds larger health effects in urban coastal communities of Orange County, CA relative to rural costal communities near Santa Cruz, CA. Fleisher et al. [1996] preformed a random assignment experiment at four distinct U.K. beaches with different sources and concentrations of contaminants. In this study subjects were randomly assigned as bathers or non-bathers and health outcomes were compared across the two cohorts. The authors found a relationship between bathing in water contaminated with domestic sewage and four types of illnesses (GI, ARD, eye and ear infections). Dwight et al. [2005] combines estimates of health effects for Orange County, California with the results from the randomized trial performed by Fleisher et al., to estimate a cost of illness associated with bathing in contaminated water of $3.3 million for Huntington Beach and Newport Beach, California. Pruss [1998] provides a thorough review of epidemiological studies on health effects from exposure to recreational waters.

Beyond the epidemiological studies listed above, there is an abundance of anecdotal evidence that suggests bathing in contaminated waters in Imperial Beach can cause major health impacts. Chris Schumacher, a surfer who frequents Imperial Beach, contracted orbital cellulitis after surfing Imperial Beach when the beaches were closed due to excessive contamination [Plopper, 2013]. Jeff Knox, who has been surfing near the Tijuana River for five decades said

"Just about everyone who surfs Imperial Beach becomes ill" [Rodgers, 2006]. Other illnesses reported by respondents to a beach user survey in Imperial Beach include sinus problems, ear infections, sore throats, skin infections, and pink eye [Gill, 2009]

Recent studies have also detected the presence of viruses including staphylococcus aureus, MRSA, and hepatitis A in the coastal waters throughout Southern California. Goodwin et al. (2012) found staphylococcus aureus in 59% of seawater samples taken from three different beaches in Southern California. The same study detected staphylococcus aureus in beach sand for 53% of the samples taken. Additionally, the authors found MRSA was present in 1.6% of seawater samples and 2.7% of sand samples.

Gersberg et al. (2006) took 20 samples of coastal water during the wet and dry weather seasons. All of the samples taken during the wet season (late October through April) were collected after a rain event, which is defined as precipitation of 0.5 cm or more in a 72-hour period. The study found hepatitis A present in 100% of wet weather samples collected 0.2 miles north of the Tijuana River mouth, and 71% of wet weather samples collected at the Imperial Beach pier. Concentrations of hepatitis A were below the limit of detection for all dry weather samples. All dry weather samples were collected at the Imperial Beach pier during the dry season (May through early October). In response to these findings Gersberg and fellow researchers at San Diego State University's Graduate School of Public Health, the non-profit environmental organization Wildcoast, and the local Imperial Beach health clinic created a program called 'sick from the Surf' to provide 1200 free hepatitis A vaccinations to uninsured surfers [Gill, 2009, Thomas, 2009].

The Surfrider Foundation, arguably the most active and recognized non-profit dedicated to preserving coastal ecosystems, has created the no border sewage (No BS) campaign in order to bring awareness to the problems associated with runoff from the Tijuana River [Foundation, 2011]. They sponsor regular clean-ups of the Tijuana River and surrounding tributaries where trash collections measure in the tons.

The Tijuana River outflows just north of the border and drains precipitation from a watershed of 4,480 square kilometers (km^2), two-thirds of which is in Mexico. The river outfall is the primary source of contamination in the area. Since the passing of NAFTA the population of Tijuana has exploded leading to massive problems of overpopulation. Tijuana is now one of the largest manufacturing cities in the world attracting workers from all over Mexico and Central America. Overpopulation has lead to several communities being built with little or no waste management infrastructure. In the Tijuana region 25% to 35% of homes and businesses are not connected to a sewer system, and roughly 40% of the city has no trash collection service [Rodgers, 2006]. Because citizens have nowhere to put their trash or fecal waste the dry river beds become open landfills. Recall that the river beds and tributaries typically only flow during rain events. Thus, after significant rainfall in the watershed the waste gets flushed out of the makeshift landfills and into the Tijuana River, eventually finding its way to the ocean. Because of the large numbers of manufacturers with little environmental regulation and large population centers without proper waste management infrastructure, the volume of contamination in the Tijuana River watershed is shocking. Because the Tijuana River is the primary source for contamination in Imperial Beach, surfers there face a larger risk of exposure relative to surfers in other locations further north [Kim et al., 2009, Terrill et al., 2009, Gersberg et al., 2006, Rodgers, 2006].

Beyond the Tijuana river, there are three other sources of pollution that can potentially impact the water quality in Imperial Beach. The first is the South Bay International Water Treatment Plant Ocean Outfall (SBIWTP), a 25 million gallon per day advanced primary treatment plant located in San Diego County, California, about 2 miles west of the San Ysidro Port of Entry. The physical - chemical plant treats sewage originating in Tijuana, Mexico, and discharges it to the Pacific Ocean through the South Bay Ocean Outfall, a four and one-half mile long 11 foot diameter pipe completed in January 1999. The City of Tijuana also discharges pre-treated waters from the Punta Bandera treatment plant (PBD), which discharges pre-treated waters directly onto the beach sand at San Antonio de los Buenos, 6 miles south of the border [Kim et al., 2009, Terrill et al., 2009]. Another potential source of pollution is local runoff from Imperial Beach occurring after rain events.

Ocean currents in the area dictate that the primary source of contamination is the Tijuana River outflow and occasionally the SBIWTP outfall. Contamination from the PBD treatment plant rarely reaches north of the international border [Kim et al., 2009, Terrill et al., 2009]. Moreover the geography of San Diego's south bay combined with the primary ocean currents ensures that most of the pollution from the aforementioned sources rarely travels north of Coronado, which borders Imperial Beach to the north and is the northernmost city before the entrance to San Diego Bay.

Surfers prefer to surf when the waves are big. The size of waves is determined by the magnitude and direction of ocean swells generated by weather systems hundreds or even thousands of miles away. Thus, variation in the quality (size) of the waves is random and does not follow a predictable pattern. Because most major storms typically form in the winter, swells typically originate from the northwest in the (northern hemisphere's) winter and from the southwest in the summer. Imperial Beach faces west-southwest so ocean swells originating anywhere from the south to the northwest will generate waves in Imperial Beach. Coronado faces more south relative to Imperial Beach and is also shielded to the west by Point Loma. Therefore Coronado only gets (big) waves from swells originating anywhere from the south to west-southwest. Compared to Coronado, Imperial Beach is more popular among surfers because it gets waves from a wider range of swell directions, creating favorable surf conditions (large waves) on a more consistent basis. Moreover, waves in Coronado tend to breaks rapidly or 'close out,' which is not an ideal wave for surfing. Waves at Imperial beach on the other hand break directionally over longer distances. Surfers derive utility from distance traveled on the shear face of a breaking wave. Thus, most South Bay surfers prefer Imperial Beach over Coronado.

The natural and random variation in both rain events which cause the Tijuana river to discharge into the ocean and surfing conditions generated by ocean swells creates an ideal environment for a natural experiment testing the health effects of coastal water pollution on public health. If the number of surfers who enter the water is positively correlated with the quality (size) of the surfing conditions then I can identify days when surfers were more willing to go surf by using archived data on surf conditions. Moreover, if I also know when the water was contaminated I can identify 'risky' days in which the water was contaminated and the surfing conditions were above average, creating increased incentive to enter the water. Comparing health outcomes during these 'risky' days to those on days when the water was clean and/or the surfing conditions were average can potentially identify health effects associated with surfers being exposed to polluted coastal waters.

3.3 Data

The main source of data for this study comes from the California office of statewide health, planning, and development (OSHPD), who maintain a database of medical records for inpatient discharges and emergency room visits for hospitals in the state of California. I have data by admission date from their patient discharge database (PDD) for years 2001-2012. The data set includes 10 San Diego hospitals and seven specific conditions. Of the 10 hospitals in the data set, four are located in the South Bay: Scripps Mercy Hospital - Chula Vista (130 beds), Sharp Chula Vista Medical Center (343 beds), Sharp Coronado Hospital (181 beds), and Paradise Valley Hospital (301 beds). The remaining six hospitals are located north of the South Bay closer to downtown: Scripps Mercy Hospital - San Diego (420 beds), Sharp Memorial Hospital (368 beds), UCSD Medical Center (530 beds), UCSD La Jolla/Sally Thornton Hospital (119 beds), Alvarado Hospital (115 beds), and Kaiser Foundation Hospital (458 beds).

The 4 conditions analyzed are: Cellulitis (ICD-9 681.0-680.1, 682.0-682.7, 682.9, and 376.01), Staphylococcus Infection (ICD-9 41.10-41.12 and 41.19), Hepatitis A (ICD-9 70.0-70.1), and Acute Sinusitis (ICD-9 461.0-461.3 and 461.8-461.9). In addition to the above four conditions I included three placebo conditions in the analysis. The three placebo conditions are Appendicitis (ICD-9, 540.0-540.1 and 540.9), Fracture of Radius/Ulna (ICD-9 813.0-813.5, and 813.8-813.9), and Fracture of Tibia/Fibula (ICD-9 823.0-823.4, and 823.8-823.9). These three placebo conditions should be unrelated to an individual coming in contact with or swimming in contaminated water. Because I am trying to identify health effects on specific 'risky' days, it is also important that the placebo conditions are urgent or acute conditions rather that chronic ailments.

The data on surf conditions comes from the data archives at surfline.com, a long standing and highly reputable surf forecast website whose forecasts and real-time views of beaches reach 1.5 million surfers a week [Dixon, 2011, Miller, 2011]. The data was obtained from surfline's surf hindcast website that contains archived data on reported surf conditions from 1997-present. The data is recorded daily at either 3 or 6 hour intervals (3 hour intervals from 1997-2010 and 6 hour intervals from 2011-2012). Because surfline's website updates surf reports twice a day (once at sunrise and again in the early afternoon) surfers who rely on surfline's website usually see reports that are posted online just after sunrise. Moreover, a majority of surfers leave for the beach before 9:00 a.m. [Nelsen, 2007]. Thus, I only use data from the 6:00 a.m. reading on any given day. The data contain minimum and maximum wave heights, the size and direction of the swell, and the speed and direction of the wind. For the purposes of this study, I consider surf to be above average if the minimum reported wave height at 6:00 a.m. was greater than 3 feet. For the years 2001-2012 the minimum wave height exceeded 3 feet on 11.25% of sample days.

Data on water quality is provided by the San Diego Department of Environmental Health (DEH). The data set contains results of all water quality sampling in the county, the sites and dates where the samples were taken, and indicators for whether or not the samples exceeded standards set by the state of California. The DEH also provided a data set containing the dates and locations of all beach closures and the source of the contamination leading to the closure from 2001-2012.

Data on the Tijuana River flow rate and local precipitation was provided by the Southern California Coastal Ocean Observing System (SCCOOS). The SCCOOS monitors the flow rate and height of the Tijuana river and also contains a measure of cumulative precipitation for the year. The data were updated daily from 2000-2003 and every 15 minutes from 2004-2012. SCCOOS also tracks surface ocean currents near the mouth of the Tijuana River by releasing particles into the water and electronically tracking their movement for three days after being released. The SCCOOS website is essential for Imperial Beach surfers wanting to know whether or not the water is being impacted by the Tijuana River.

After a series of interviews with Keith Kezer, the program lead at the DEH Beach and Bay monitoring program I learned that the DEH has limited funding for water quality sampling during the winter months so they rely heavily on the SCCOOS website to determine the presence of pollution emanating from the Tijuana river. They also informed me that they typically only test the water in the winter time after closures to ensure that the water is safe prior to removing a closure signs. Closure signs are almost never posted in response to negative water quality samples in the winter months (November 1 - March 31). Instead, in order to determine if closure signs should be posted in the winter months, the DEH relies on information from the SCCOOS website, local precipitation, as well as visual inspection of the water's color, clarity, or smell.

Because the DEH utilizes the SCCOOS website, local weather conditions, and sensory feedback, to determine when the beaches will be closed, I use DEH posted beach closures to proxy for the presence of contamination. This simplifies the analysis and incorporates all relevant information regarding coastal water quality into one variable. From 2001-2012 the DEH posted closure signs at least as far north as the Imperial Beach Pier for 16% of sample

Table 3.1: Monthly Averages of Coastal Conditions

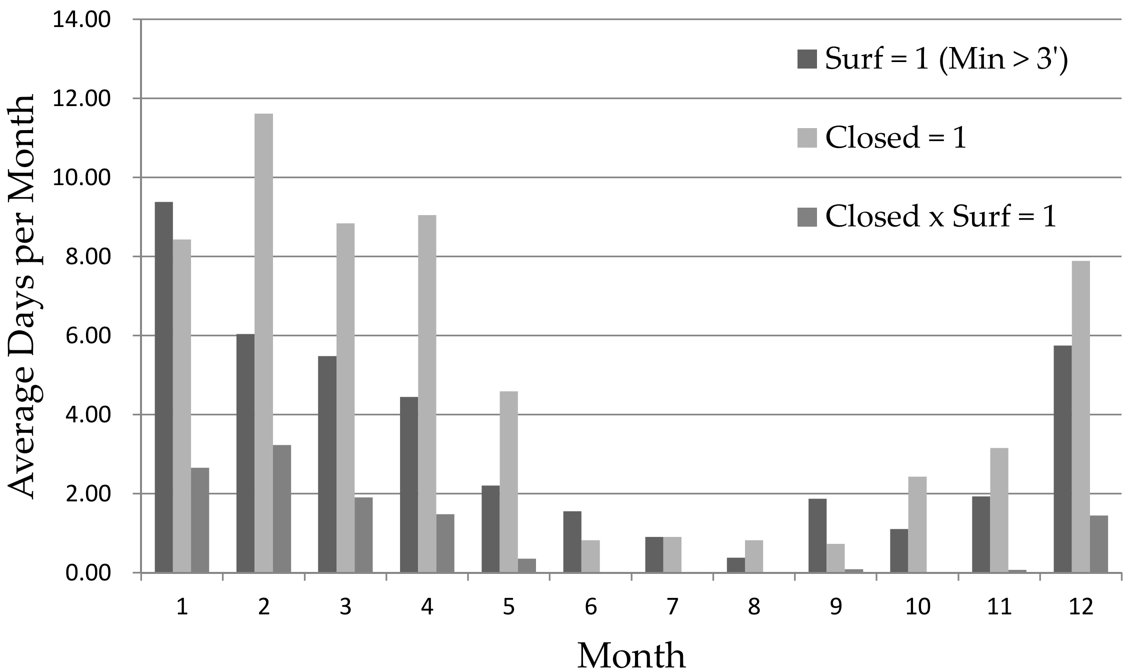
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wave Min	2.99	2.67	2.45	2.47	2.16	2.18	1.91	1.90	2.07	1.98	1.88	2.57
	(1.73)	(1.29)	(1.24)	(1.19)	(0.99)	(0.86)	(0.82)	(0.75)	(0.94)	(0.84)	(1.05)	(1.46)
Wave Max	6.48	5.78	5.44	5.42	4.84	4.86	4.33	4.32	4.68	4.44	4.28	5.62
	(3.41)	(2.59)	(2.43)	(2.32)	(1.95)	(1.67)	(1.56)	(1.39)	(1.78)	(1.62)	(1.99)	(2.92)
Surf =1 (Min > 3')	9.38	6.04	5.48	4.45	2.21	1.56	0.91	0.38	1.87	1.11	1.93	5.75
	(4.31)	(3.67)	(3.59)	(3.52)	(2.05)	(2.08)	(1.71)	(0.73)	(1.54)	(1.36)	(2.19)	(4.03)
Closed = 1	8.43	11.62	8.84	9.05	4.59	0.82	0.91	0.82	0.73	2.43	3.16	7.89
	(10.19)	(6.71)	(5.79)	(6.66)	(4.03)	(1.40)	(1.62)	(1.49)	(1.54)	(5.14)	(5.62)	(6.48)
Closed x Surf = 1	2.66	3.23	1.91	1.48	0.36	0.00	0.00	0.00	0.09	0.00	0.07	1.45
	(3.06)	(2.59)	(1.57)	(1.76)	(0.71)	(0.00)	(0.00)	(0.00)	(0.29)	(0.00)	(0.25)	(1.80)

Note: Closed = 1 if closure signs were posted at beaches located in Imperial Beach by the San Diego Dept. of Environmental Health.

days. 'Risky' days, defined as days when the beaches were posted closed and the minimum reported wave height exceeded 3 feet, represent 3% of total sample days from 2001-2012.

Table 3.1 presents monthly averages of coastal conditions, including surf conditions and water quality, from 2001-2012. Daily surf forecasts on surfline.com take the form of minimum-maximum wave height (ie; 2-4 feet). 'Wave Min' represents the average reported minimum surf height from surfline.com's hindcast website for each month. 'Wave Max' represents the average reported maximum wave height from the same website. For the purposes of this study, days in which the minimum reported wave height exceeds 3 feet are considered above average surfing conditions. In Table 3.1, $surf = 1$ represents the average number of days that the minimum reported wave height was greater than 3 feet for each month. I consider the water to contaminated whenever the San Diego Department of Environmental Health posted closure at least as far north as Imperial Beach pier. '$Closed = 1$' represents the average number of day closure signs were posted each month. '$Closed \cdot Surf = 1$' repre-

Figure 3.1: Coastal Conditions by Month



sents the average number of 'risky' days, defined as days in which the water was polluted and the surfing conditions were above average. Figure 3.3 graphs the monthly averages for $Closed = 1$, $Surf = 1$, and $Closed \cdot Surf = 1$.

3.4 Estimation Methodology

The estimation structure takes two different forms depending on the population sample being analyzed. In the full sample case, including hospitals located in both the north and the south, I use a difference in difference in differences (DDD) approach to isolate the effects of coastal water pollution on those individuals seeking medical attention in South Bay hospitals. I also utilize a split sample approach where I analyze data from hospitals in the north and south separately using a standard difference in differences (DD) estimation. The full sample DDD analysis is estimated using the following specification:

$$\begin{aligned}\text{outcome}_{i,t} = \beta_0 + \beta_1\text{closed}_{i,t} + \beta_2\text{surf}_{i,t} + \beta_3\text{south} + \beta_4(\text{closed}_{i,t}\cdot\text{surf}_{i,t})\\ + \beta_5(\text{closed}_{i,t}\cdot\text{south}_{i,t}) + \beta_6(\text{surf}_{i,t}\cdot\text{south}_{i,t}) + \delta(\text{closed}_{i,t}\cdot\text{surf}_{i,t}\cdot\text{south}_{i,t})\\ + \beta_7\text{beds}_i + \beta_8\text{year}_t + \beta_9\text{month}_t + \epsilon_{i,t}\end{aligned} \tag{3.1}$$

Where $outcome_{i,t}$ represents the total number of incidences of a given illness in hospital i on day t. $\text{closed}_{i,t}$ is an indicator variable equal to one if the DEH posted closure signs at least as far north as the Imperial Beach pier. $surf_{i,t}$ is an indicator variable equal to one if the minimum reported wave height at 6:00 a.m. was greater than 3 feet. $south_i$ is an indicator variable equal to one if the hospital is located in the South Bay region. The four hospitals for which $south_i = 1$ are Scripps Mercy Hospital - Chula Vista, Sharp Chula Vista Medical Center, Sharp Coronado Hospital, and Paradise Valley Hospital. The number of beds for each hospital is included to control for the relative size of each hospital. Indicator variables for year and month are included to control for time fixed effects.

The coefficient of interest is δ, which represents the triple interaction between the variables *closed, surf,* and *south.* This represents the effect of one 'risky' day, defined as a day in which the water is impacted ($closed = 1$) and the surfing conditions are above average ($surf = 1$), on the number of cases of a particular ailment reported in per hospital in the South Bay ($south = 1$). If individuals age 18-35 are more likely to enter the water when the surf is good, this variable will capture the effects of water pollution on the number of reported cases for each particular health outcome analyzed. The analysis will include three placebo conditions which should not be correlated with exposure to dirty water.

The split sample specification will utilize a standard difference in differences (DD) approach to estimate the impact of water pollution on public health outcomes in the South Bay. The split sample analyses are estimated using the following equation,

$$\begin{aligned}\text{outcome}_{i,t} &= \beta_0 + \beta_1\text{closed}_{i,t} + \beta_2\text{surf}_{i,t} + \delta(\text{closed}_{i,t} \cdot \text{surf}_{i,t}) \\ &\quad + \beta_3\text{beds} + \beta_4\text{year}_t + \beta_5\text{month}_t + \beta_6\text{hosp}_i + \epsilon_{i,t}\end{aligned} \tag{3.2}$$

The variable definitions are the same as in equation 1. In addition to controlling for year and month fixed effects, the split sample DD specification includes hospital specific fixed effects. The hospital fixed effects are not included in the full sample DDD specification because the *south* variable is a linear combination of the hospital dummies. The coefficient of interest is δ which captures the effect of one 'risky' day on the number of reported cases of a particular ailment per hospital. Similar to the full sample case, the analysis will include three placebo outcomes which should not be correlated with exposure to dirty water.

Because severe pollution is assumed to be present only at beaches located in the South Bay, the DD specification will estimate the impact of pollution on health outcomes only for those hospitals that service the South Bay region ($south = 1$). If the estimates reveal significant effects for the sample of South Bay hospitals, then running the same DD specification for hospitals that only service the north ($south = 0$) should reveal effects statistically indistinguishable from zero. Of course, this assumes that severe pollution is truly limited to the South Bay region, and due to geographic barriers surfers are at least partially limited in their ability to avoid pollution by commuting to beaches located in the northern part of the county. Additionally, this assumes that individuals who choose to surf in Imperial Beach live in the South Bay and that individuals who live in the northern part of the county do not typically choose to surf in Imperial Beach. Because the coastlines are similar and face in the same direction, on any given day the surfing conditions at beaches located in the north are very similar to conditions in the South Bay. Thus, surfers who live in the north would have to incur an unnecessary travel cost to surf in the South Bay.

Standard errors are not clustered for any of the included estimations. The appropriate level for clustered standard errors would be at the hospital level if the key regressors were not randomly assigned. Because the Tijuana River only flows into the ocean after significant precipitation in the watershed, this treatment variable is effectively randomly assigned. Surfing conditions and wave height are determined by offshore swells generated by weather systems often thousands of miles away. Thus, the surf variable is also a randomly assigned regressor. Because the key regressors are randomly assigned the within-cluster correlation of the regressors is likely to be zero [Cameron and Miller, 2013].

In addition to the DDD and DD specifications above, which are estimated using ordinary least squares (OLS), I will also analyze DD weighted least squares specification to estimate the effect of pollution on the rate of reported cases per bed. The error matrix in this specification is weighted by the number of beds. Recall that the number of beds is an included regressor in the previous DDD and DD OLS specifications. The full sample DDD weighted least squares estimate analyses are estimated using the following equation:

$$\begin{aligned}\text{outcome/beds}_{i,t} = {} & \beta_0 + \beta_1\text{closed}_{i,t} + \beta_2\text{surf}_{i,t} + \beta_3\text{south} + \beta_4(\text{closed}_{i,t} \cdot \text{surf}_{i,t}) \\ & + \beta_5(\text{closed}_{i,t} \cdot \text{south}_{i,t}) + \beta_6(\text{surf}_{i,t} \cdot \text{south}_{i,t}) + \delta(\text{closed}_{i,t} \cdot \text{surf}_{i,t} \cdot \text{south}_{i,t}) \\ & + \beta_7\text{year}_t + \beta_8\text{month}_t + \epsilon_{i,t}\end{aligned} \tag{3.3}$$

The split sample DD weighted least squares analyses are estimated using the following equation,

$$
\begin{aligned}
(\text{outcome/beds})_{i,t} = \beta_0 + \beta_1 \text{closed}_{i,t} + \beta_2 \text{surf}_{i,t} + \delta(\text{closed}_{i,t} \cdot \text{surf}_{i,t}) \\
+ \beta_3 \text{year}_t + \beta_4 \text{month}_t + \beta_5 \text{hosp}_i + \epsilon_{i,t}
\end{aligned}
\tag{3.4}
$$

Similar to the split sample DD OLS specification, the coefficient of interest is δ. In this case δ represents the effect of one 'risky' day on the number of reported cases of a particular ailment per hospital bed. Equation 3 is estimated using both the sample consisting of only hospitals located in the South Bay ($south = 1$) and the sample of consisting of only those hospitals located in the northern part of the county ($south = 0$). Similar to the previous specification, analysis of the sample consisting only of northern hospitals will serve as a second placebo test, assuming pollution only affects South Bay beaches.

Beginning January 1, 2009, Scripps Mercy Hospital - Chula Vista merged with its parent hospital, Scripps Mercy Hopsital - San Diego. After the merge, both hospitals reported cases to OSHPD as a single entity. Thus, all reported cases for any ailment from Scripps Mercy Hopsital - Chula Vista, were combined with the same ailments from Scripps Mercy Hopital - San Diego and reported as one figure under the name of the parent hospital. This means that there were no observations from Scripps Mercy Hospital - Chula Vista after the merger. Because observations taken in the north are indistinguishable from those taken in the south after the merger date, I deleted any observations from Scripps Mercy Hospital - San Diego after January 1, 2009 in all of the above specifications.

Scripps Mercy Hospital - San Diego is the third largest hospital in the county with 420 beds, representing 21% of hospital beds in the north sample. Scripps Mercy Hopsital - Chula Vista is much smaller with 130 beds; however this represents 14% of hospital beds in the South Bay region. In order to correct for the lost precision of the data after the merger, I will also estimate equation (1), equation (2), and equation (3), using a reduced sample from 2001-2008, which includes the full set of distinguishable observations from the two hospitals mentioned above throughout the entire sample period.

3.5 Results

Table 3.2 shows the results of estimating equation (1), the effect of one 'risky' day on the reported number of cases of cellulitis, staph infection, hepatitis A, sinusitis, appendicitis, fractures of the radius or ulna, and fractures of the tibia or fibula, per hospital located in the South Bay. The last three conditions represent the three placebo conditions that should be unaffected by exposure to contaminated water. The top half of Table 3.2 includes estimates for the full sample, including hospitals located both in the north and the south, for years 2001-2012 (excluding Scripps Mercy Hospital -San Diego and Scripps Mercy Hopsital - Chula Vista after January 1, 2009). The bottom half of Table 2 includes estimates from the reduced sample, including hospitals located both in the north and south, for years 2001-2008.

The only statistically significant coefficient on the triple interaction term ($Closed \times Surf \times South$) is for staph infections in the sample from 2001-2008. The estimation suggests that for each risky day the reported number of cases of staph infection at hospitals located in the South Bay increases by 0.03. This estimate is significant at the 10% level with a t-statistic of 1.90 and an associated p-value equal to 0.057.

Table 3.3 shows the results of estimating equation (3) using weighted least squares, with the error matrix weighted by the number of beds. Recall that this method removes the variable *beds* from the right hand side of equation, (1) and instead uses *beds* to divide the outcome variable on the left hand side of the equation. Equation (3) estimates the effect of one 'risky' day on the reported number of cases of the outcome variables per South Bay

Table 3.2: DDD Estimation Results (Sum)

DDD (2001-2012)	Conditions Associated w/ Exposure				Placebo Conditions		
	Cellulitis	Staph	Hepatits A	Sinus Problems	Appendicitis	Fracture (Arm)	Fracture (Leg)
Intercept	0.886	0.182	-0.084	0.092	3.023***	0.004	0.507
	(0.675)	(0.506)	(0.085)	(0.133)	(0.582)	(0.376)	(0.384)
Closed	0.236	-0.074	0.063	0.023	0.559	0.417	-0.682**
	(0.498)	(0.376)	(0.062)	(0.098)	(0.429)	(0.278)	(0.284)
Surf	0.724	0.014	0.050	0.168	0.303	0.072	0.449
	(0.590)	(0.445)	(0.074)	(0.116)	(0.509)	(0.329)	(0.336)
South	-4.694***	-3.021***	-0.026	-0.163***	-4.425***	-1.962***	-2.051***
	(0.304)	(0.229)	(0.038)	(0.060)	(0.262)	(0.169)	(0.173)
Closed × Surf x South	1.497	0.511	0.158	0.324	-0.115	0.987	0.013
	(1.801)	(1.357)	(0.226)	(0.355)	(1.552)	(1.005)	(1.026)
n	39081	39081	39081	39081	39081	39081	39081
R squared	0.025	0.017	0.001	0.003	0.02	0.016	0.016
DDD (2001-2008)	**Cellulitis**	**Staph**	**Hepatits A**	**Sinus Problems**	**Appendicitis**	**Fracture (Arm)**	**Fracture (Leg)**
Intercept	1.044	-0.085	-0.128	-0.016	3.124***	0.038	0.546
	(0.732)	(0.557)	(0.104)	(0.152)	(0.637)	(0.426)	(0.436)
Closed	-0.183	0.369	0.102	-0.001	-0.085	0.271	-0.584
	(0.553)	(0.420)	(0.079)	(0.115)	(0.481)	(0.324)	(0.330)
Surf	0.843	0.240	-0.023	0.187	-0.077	0.155	0.604
	(0.720)	(0.547)	(0.103)	(0.150)	(0.627)	(0.422)	(0.429)
South	-3.920***	-2.525***	-0.031	-0.117	-4.309***	-1.960***	-1.983***
	(0.346)	(0.263)	(0.049)	(0.072)	(0.301)	(0.203)	(0.206)
Closed × Surf x South	2.101	3.094*	0.293	0.153	-0.516	0.826	1.153
	2.137	1.624	(0.305)	(0.445)	(1.859)	(1.251)	(1.273)
n	27393	27393	27393	27393	27393	27393	27393
R squared	0.022	0.02	0.001	0.003	0.019	0.016	0.016

Note: All coefficient estimates multiplied by 100; * Significant at 10% level; ** Significant at 5% level; *** Significant at 1% level

Table 3.3: DDD Estimation Results (Rate)

DDD (2001-2012)	Conditions Associated w/ Exposure				Placebo Conditions		
	Cellulitis	Staph	Hepatits A	Sinus Problems	Appendicitis	Fracture (Arm)	Fracture (Leg)
Intercept	1.518***	0.753***	0.022	0.133***	1.594***	0.662***	0.865***
	(0.190)	(0.142)	(0.022)	(0.037)	(0.162)	(0.095)	(0.098)
Closed	0.063	-0.023	0.018	0.005	0.161	0.113	-0.189
	(0.149)	(0.111)	(0.017)	(0.027)	(0.127)	(0.074)	(0.077)
Surf	0.204	-0.007	-0.013	0.045	0.085	-0.017	0.119
	(0.176)	(0.132)	(0.020)	(0.032)	(0.150)	(0.088)	(0.091)
South	-0.147***	-0.954***	-0.017	-0.720***	-1.319***	-0.735***	-0.769***
	(0.095)	(0.071)	(0.011)	(0.017)	(0.081)	(0.047)	(0.049)
Closed × Surf x South	0.602	0.233	0.068	0.111	0.031	0.283	0.021
	(0.604)	(0.451)	(0.069)	(0.110)	(0.515)	(0.301)	(0.311)
n	39081	39081	39081	39081	39081	39081	39081
R squared	0.01	0.008	0.001	0.002	0.01	0.01	0.01
DDD (2001-2008)	**Cellulitis**	**Staph**	**Hepatits A**	**Sinus Problems**	**Appendicitis**	**Fracture (Arm)**	**Fracture (Leg)**
Intercept	1.582***	0.715***	0.013	0.115***	1.636***	0.692***	0.877***
	(0.208)	(0.155)	(0.027)	(0.040)	(0.179)	(0.107)	(0.111)
Closed	-0.064	0.089	0.029	0.023	-0.024	0.071	-0.167*
	(0.169)	(0.126)	(0.022)	(0.032)	(0.145)	(0.087)	(0.090)
Surf	0.249	0.073	0.005	0.049	-0.019	0.047	0.163
	(0.222)	(0.166)	(0.029)	(0.042)	(0.191)	(0.114)	(0.119)
South	-1.258***	-0.831***	-0.020	-0.063***	-1.316***	-0.761***	-0.762***
	(0.111)	(0.083)	(0.015)	(0.021)	(0.096)	(0.057)	(0.056)
Closed × Surf x South	0.909	1.063*	0.131	0.080	-0.136	0.236	0.337
	(0.741)	(0.553)	(0.096)	(0.140)	(0.636)	(0.382)	(0.396)
n	27393	27393	27393	27393	27393	27393	27393
R squared	0.01	0.01	0.001	0.002	0.01	0.01	0.01

Note: All coefficient estimates multiplied by 10,000; * Significant at 10% level; ** Significant at 5% level; *** Significant at 1% level

hospital bed. Similar to Table 3.2, the top half of Table 3.3 includes estimates for the full sample for years 2001-2012, while the bottom half of Table 3 includes the reduced sample covering years 2001-2008.

Just as in the DDD estimation for equation (1), the only significant coefficient on the triple interaction term $Closed \times Surf \times South$ is for staph infections in the reduced sample covering years 2001-2008. The results suggest that for each 'risky' day the reported number of cases of staph infection per South Bay hospital bed increases by 0.0001. This estimate is significant at the 10% level with a t-statistic of 1.92 and an associated p-value of 0.054.

Table 3.4 presents results from the split sample DD estimation of equation (2) covering years 2001-2012. The top half of Table 3.4 presents results from South Bay hospitals only, while the bottom half of the table contains estimates using only those hospitals located in the north. The coefficient of interest for the remaining analyses is the interaction term $(closed \times surf)$. The interaction term for the South Bay hospitals has significant coefficients for cellulitis and hepatitis A, while the sample with only northern hospitals has no significant coefficients on the interaction term. The results suggest that one 'risky' day is associated with a 0.015 increase in the number of reported cases of cellulitis per hospital, and an increase of 0.002 in the reported number of cases of hepatits A per hospital. The coefficient on cellulitis is significant at the 10% level with a t-statistic of 1.89 and an associated p-value of 0.059. The coefficient on hepatitis A is also significant at the 10% level with a t-statistic equal to 1.80 and an associated p-value of 0.072.

While the coefficients on staph infections and sinus problems are not significant at the 10% level, they are relatively close to being significant. The t-stat for staph infections is 1.31 with an associated p-value of 0.192, while the t-stat for sinus problems equals 1.41 with an associated p-value of 0.16. The coefficients on the three placebo conditions are statistically indistinguishable from zero, and none of these three conditions have a t-statistic over 0.72.

Table 3.4: DD Estimation Results 2001-2012 (Sum)

South (Sum)	Conditions Associated w/ Exposure				Placebo Conditions		
	Cellulitis	Staph	Hepatits A	Sinus Problems	Appendicitis	Fracture (Arm)	Fracture (Leg)
Intercept	-1.317*	-0.988**	0.009	-0.024	0.561	-0.258	0.121
	(0.736)	(0.488)	(0.108)	(0.108)	(0.527)	(0.169)	(0.213)
Closed	-0.059	-0.277	-0.012	-0.038	0.235	-0.113	-0.069
	(0.358)	(0.238)	(0.053)	(0.052)	(0.256)	(0.082)	(0.103)
Surf	-0.325	-0.466	-0.063	0.018	-0.216	-0.118	-0.016
	(0.430)	(0.285)	(0.063)	(0.063)	(0.308)	(0.099)	(0.124)
Closed × Surf	1.559*	0.715	0.218*	0.171	0.423	0.089	0.1490
	(0.825)	(0.548)	(0.121)	(0.121)	(0.590)	(0.189)	(0.238)
n	16071	16071	16071	16071	16071	16071	16071
R squared	0.01	0.006	0.003	0.003	0.002	0.003	0.004
North (Sum)	**Cellulitis**	**Staph**	**Hepatits A**	**Sinus Problems**	**Appendicitis**	**Fracture (Arm)**	**Fracture (Leg)**
Intercept	0.193	-0.968	-0.113	0.145	1.704*	-0.776	0.024
	(1.055)	(0.812)	(0.128)	(0.216)	(0.934)	(0.631)	0.640
Closed	0.304	0.022	0.085	0.003	0.719	0.426	-0.755**
	(0.614)	(0.473)	(0.075)	(0.126)	(0.544)	(0.367)	(0.373)
Surf	0.670	0.060	-0.024	0.151	0.336	0.015	0.410
	(0.719)	(0.553)	(0.087)	(0.147)	(0.635)	(0.429)	(0.436)
Closed × Surf	-0.395	-0.014	0.014	-0.108	0.471	0.826	0.126
	(1.390)	(1.071)	(0.169)	(0.285)	(1.230)	(0.831)	(0.843)
n	23010	23010	23010	23010	23010	23010	23010
R squared	0.017	0.01	0.002	0.003	0.013	0.01	0.01

Note: All coefficient estimates multiplied by 100; * Significant at 10% level; ** Significant at 5% level; *** Significant at 1% level

Table 3.5: DD Estimation Results 2001-2012 (Rate)

South (Rate)	Conditions Associated w/ Exposure				Placebo Conditions		
	Cellulitis	Staph	Hepatits A	Sinus Problems	Appendicitis	Fracture (Arm)	Fracture (Leg)
Intercept	-0.030	-0.165	0.025	0.019	0.513***	-0.051	0.021
	(0.244)	(0.161)	(0.031)	(0.036)	(0.176)	(0.051)	(0.070)
Closed	-0.023	-0.112	-0.005	-0.016	0.095	-0.046	-0.029
	(0.149)	(0.098)	(0.019)	(0.022)	(0.108)	(0.031)	(0.043)
Surf	-0.130	-0.186	-0.025	0.007	-0.086	-0.047	-0.007
	(0.177)	(0.117)	(0.023)	(0.027)	(0.128)	(0.037)	(0.051)
Closed × Surf	0.619*	0.285	0.086**	0.068	0.167	0.037	0.0600
	(0.340)	(0.224)	(0.043)	(0.051)	(0.245)	(0.071)	(0.098)
n	16071	16071	16071	16071	16071	16071	16071
R squared	0.01	0.006	0.003	0.003	0.002	0.003	0.004
North (Rate)	**Cellulitis**	**Staph**	**Hepatits A**	**Sinus Problems**	**Appendicitis**	**Fracture (Arm)**	**Fracture (Leg)**
Intercept	3.858	0.184	0.014	0.171	2.299***	0.417**	0.660***
	(0.344)	(0.264)	(0.039)	(0.065)	(0.303)	(0.188)	(0.192)
Closed	0.082	0.007	0.023	0.001	0.196	0.116	-0.204
	(0.177)	(0.136)	(0.020)	0.034	(0.156)	(0.097)	(0.099)
Surf	0.182	0.014	-0.007	0.042	0.090	-0.004	0.112
	(0.208)	0.160	(0.023)	0.040	(0.183)	(0.114)	(0.116)
Closed × Surf	-0.108	-0.001	0.004	-0.031	0.129	-0.222	0.032
	(0.401)	(0.308)	(0.045)	(0.076)	(0.354)	(0.219)	(0.224)
n	23010	23010	23010	23010	23010	23010	23010
R squared	0.013	0.01	0.0014	0.002	0.01	0.005	0.005

Note: All coefficient estimates multiplied by 10,000; * Significant at 10% level; ** Significant at 5% level; *** Significant at 1% level

The bottom half of table 3.4 shows the coefficient estimates from estimating equation (2) using only those hospitals located in the north and covering years 2001-2012. In the north only sample, there are no significant coefficients on any of the conditions analyzed. Moreover, the standard errors on the interaction terms are all much larger than the coefficient estimate. The one exception is for the placebo condition fractures of the radius or ulna, which has a standard error only slightly larger than the corresponding point estimate.

Table 3.5 presents estimates of equation (4), the effect of one 'risky' day on the rate of reported cases per hospital bed during years 2001-2012. The top half of Table 3.5 presents estimates for the South Bay hospitals only. Similar to Table 3.4, I find significant coefficients on the interaction term ($south \times closed$) for cellulitis and hepatitis A. The results suggest that for each 'risky' day the reported number of cases of cellulitis per South Bay hospital bed increases by 0.00006, and the reported number of cases of hepatitis A per South Bay hospital bed increases by 0.000009. The coefficient for cellulitis is significant at the 10% level with a t-statistic equal to 1.82 and an associated p-value of 0.069. The coefficient on hepatitis A is significant at the 5% level with a t-statistic equal to 1.99 and an associated p-value of 0.047. Similar to Table 3.4, the coefficients on the interaction term for staph infection and sinus problems are marginally significant. The coefficient on the interaction term for staph infection has a t-statistic equal to 1.27 with an associated p-value of 0.204. The coefficient for sinus problems has a t-statistic equal to 1.34 with an associated p-value of 0.181. The three placebo conditions are all insignificant and none of the coefficients for the placebo conditions have a t-statistic above 0.68.

The bottom half of Table 3.5 presents estimates of equation (4) using only those hospitals located in the north for years 2001-2012. Similar to the north only sample in Table 3.4, there are no significant coefficients on any of the conditions analyzed. Once again the standard errors on the interaction terms are all much larger than the coefficient estimate, with the only exception being the placebo condition for fractures of the radius or ulna. This coefficient has a standard error slightly smaller than the corresponding point estimate.

The results of Table 3.4 and Table 3.5 suggest that water pollution does have a negative impact on public health outcomes, especially cellulitis and hepatitis A. Moreover, the negative health effects associated with water pollution appear to be isolated to hospitals located in the South Bay.

Table 3.6 presents estimation results from equation (2) using the reduced sample covering years 2001-2008. The top half of Table 3.6 presents estimates for hospitals located only in South Bay. The results are interpreted as the impact of one 'risky' day on the number of reported cases of the outcome variable per South Bay hospital for white males age 18-35. Using the reduced sample I find significant coefficients on the interaction term ($south \times closed$) for cellulitis, staph infection, and hepatitis A. The coefficients for cellulitis and staph infection are significant at the 5% level, while the coefficient for hepatitis A is significant at the 1% level. The coefficients suggest that one 'risky' day is associated with a 0.024 increase in reported cases of cellulitis, a 0.015 increase in the number of reported cases of staph infection, and a 0.004 increase in the number of reported cases of hepatitis A. The t-statistic for cellulitis equals 2.27 with a p-value of 0.023. The t-statistic for staph infection equals 2.12 with a p-value of 0.034. The t-statistic for hepatitis A equals 2.66 with a p-value of 0.008. The coefficient on sinus problems is marginally significant with a t-statistic equal to 1.48 with an associated p-value of 0.139. All three coefficients on the placebo conditions remain insignificant with the largest t-statistic equal to 0.56.

The bottom half of Table 3.6 shows results from estimating equation (2) for hospitals in the north using the reduced sample covering years 2001-2008. The results are interpreted as the impact of one 'risky' day on the number of reported cases of the outcome variable per northern hospital for white males age 18-35. Similar to Table 4, none of the outcome variables are statistically indistinguishable from zero. The standard errors on the interaction terms are all much larger than the coefficient estimate, with the only exception being staph infection. This coefficient has a standard error slightly smaller than the corresponding point estimate.

Table 3.7 presents weighted least squares estimates of equation (4) for South Bay hospitals, using the reduced sample covering years 2001-2008. The estimates are interpreted as the impact of one 'risky' day on the rate of reported cases of the outcome variable per South Bay hospital bed for white males age 18-35. The estimated coefficients for cellulitis and staph infection are significant at the 5% level, while the coefficient on hepatitis A is significant at the 1% level. The coefficients suggest that one 'risky' day is associated with a 0.0001 increase in the rate of reported cases of cellulitis, a 0.00006 increase for staph infection, and a 0.000016 increase for hepatitis A. The t-statistic for cellulitis equals 2.21 with a p-value of 0.027. The t-statistic for staph infection equals 2.06 with a p-value of 0.040. The t-statistic for hepatitis A equals 3.07 with a p-value of 0.002. The coefficient on sinus problems is marginally significant with a t-statistic equal to 1.44 with an associated p-value of 0.149. All three coefficients on the placebo conditions remain insignificant with the largest t-statistic equal to 0.56.

The bottom half of Table 3.7 presents weighted least squares estimates of equation (4) for northern hospitals, using the reduced sample for years 2001-2008. The estimates are interpreted as the impact of one 'risky' day on the rate of reported cases of the outcome variable per northern hospital bed for white males age 18-35. Similar to Table 3.5, none of the outcome variables are statistically indistinguishable from zero. The standard errors on the interaction terms are all much larger than the coefficient estimate, with the only exception being staph infection. This coefficient has a standard error slightly smaller than the corresponding point estimate.

Table 3.6: DD Estimation Results 2001-2008 (Sum)

South (Sum)	Conditions Associated w/ Exposure				Placebo Conditions		
	Cellulitis	Staph	Hepatits A	Sinus Problems	Appendicitis	Fracture (Arm)	Fracture (Leg)
Intercept	-1.234	0.901	-0.020	-0.048	0.391	-0.239	0.059
	(0.881)	(0.580)	(0.125)	(0.147)	(0.584)	(0.193)	(0.278)
Closed	-0.162	-0.370	-0.063	-0.048	0.190	-0.086	-0.052
	(0.418)	(0.275)	(0.059)	(0.070)	(0.277)	(0.092)	(0.132)
Surf	-0.152	-0.628*	-0.065	0.020	-0.241	-0.105	0.000
	(0.549)	(0.361)	(0.078)	(0.092)	(0.364)	(0.120)	(0.001)
Closed × Surf	2.370**	1.455**	0.392***	0.258	0.044	0.071	0.1840
	(1.043)	(0.687)	(0.147)	(0.174)	(0.692)	(0.228)	(0.329)
n	11688	11688	11688	11688	11688	11688	11688
R squared	0.012	0.008	0.003	0.003	0.002	0.002	0.005
North (Sum)	**Cellulitis**	**Staph**	**Hepatits A**	**Sinus Problems**	**Appendicitis**	**Fracture (Arm)**	**Fracture (Leg)**
Intercept	1.346	1.076	-0.187	-0.019	2.205**	-0.731	0.194
	(1.155)	(0.903)	(0.165)	(0.250)	(1.049)	(0.737)	(0.742)
Closed	-0.245	0.352	-0.131	0.073	0.016	0.255	-0.691
	(0.679)	(0.531)	(0.097)	(0.147)	(0.617)	(0.434)	(0.436)
Surf	0.825	0.285	0.017	0.187	-0.040	0.184	0.522
	(0.878)	(0.686)	(0.126)	(0.190)	(0.797)	(0.560)	(0.564)
Closed × Surf	-0.139	-1.684	0.004	0.130	0.696	-0.634	-0.960
	(1.685)	(1.317)	(0.242)	(0.365)	(1.530)	(1.076)	(1.082)
n	15705	15705	15705	15705	15705	15705	15705
R squared	0.017	0.01	0.002	0.005	0.012	0.01	0.01

Note: All coefficient estimates multiplied by 100; * Significant at 10% level; ** Significant at 5% level; *** Significant at 1% level

Table 3.7: DD Estimation Results 2001-2008 (Rate)

South (Rate)	Conditions Associated w/ Exposure				Placebo Conditions		
	Cellulitis	Staph	Hepatits A	Sinus Problems	Appendicitis	Fracture (Arm)	Fracture (Leg)
Intercept	-0.044	-0.187	0.024	0.028	0.470**	-0.048	-0.005
	(0.290)	(0.191)	(0.035)	(0.048)	(0.193)	(0.058)	(0.089)
Closed	-0.068	-0.155	-0.026	-0.020	0.080	-0.036	-0.022
	(0.180)	(0.119)	(0.022)	(0.030)	(0.120)	(0.036)	(0.055)
Surf	-0.064	-0.263*	-0.027	0.008	-0.101	-0.044	0.000
	(0.237)	(0.156)	(0.028)	(0.039)	(0.158)	(0.048)	(0.073)
Closed × Surf	0.993**	0.610**	0.164***	0.108	0.019	-0.030	0.0770
	(0.449)	(0.296)	(0.054)	(0.075)	(0.299)	(0.090)	(0.138)
n	11688	11688	11688	11688	11688	11688	11688
R squared	0.011	0.007	0.004	0.003	0.002	0.002	0.005
North (Rate)	**Cellulitis**	**Staph**	**Hepatits A**	**Sinus Problems**	**Appendicitis**	**Fracture (Arm)**	**Fracture (Leg)**
Intercept	4.118***	1.667***	0.009	0.137*	2.420***	0.442**	0.766***
	(0.385)	(0.298)	(0.051)	(0.076)	(0.351)	(0.223)	(0.227)
Closed	-0.067	0.097	0.036	0.020	0.004	0.070	-0.188
	(0.199)	(0.154)	(0.027)	(0.039)	(0.181)	(0.115)	(0.117)
Surf	0.231	0.077	0.004	0.053	-0.013	0.052	-0.146
	(0.259)	(0.201)	(0.035)	(0.051)	(0.236)	(0.150)	(0.153)
Closed × Surf	-0.046	-0.459	0.002	0.034	0.194	-0.173	-0.269
	(0.495)	(0.383)	(0.066)	(0.097)	(0.451)	(0.287)	(0.291)
n	15705	15705	15705	15705	15705	15705	15705
R squared	0.012	0.01	0.002	0.003	0.01	0.005	0.004

Note: All coefficient estimates multiplied by 10,000; * Significant at 10% level; ** Significant at 5% level; *** Significant at 1% level

3.6 Discussion

The estimation results suggest that 'risky' days, defined as days when the water was polluted and the surfing conditions were above average, significantly increase the number of reported cases of Cellulitis, Hepatitis A, and Staphylococcus Infection. Additionally, there is marginal evidence supporting a positive relationship with the number of reported cases of acute sinus problems. Placebo tests indicating that 'risky' days have no effect on the number of reported cases of the three placebo conditions suggest that results are driven by white males aged 18-35 entering contaminated water to surf. Comparing DD results from the south to those in the north indicates that adverse health effects, caused by bathing in contaminated costal water, are isolated in San Diego's South Bay Region.

For the DDD estimation the only significant result is found on the triple interaction term for staph infections in the reduced sample covering years 2001-2008. The coefficient on the triple interaction term in the bottom of Table 3.2 implies that each risky day is associated with a 0.031 increase in the number of reported cases of staph infection for white males age 18-35. The average number of reported cases of staph infection per non risky day, across all South Bay hospitals, is 0.0087. This represents a 356% increase in the number of reported cases of staph infection relative to non-risky days. This coefficient of 0.031 can also be interpreted as 32 'risky' days are associated with one additional case of staph infection in the South Bay.

Similar results are found in Table 3.3 for the weighted least squares estimates of the DDD model applied to the rate of reported cases per hospital bed. The results suggest that one 'risky' day is associated with a 0.000106 increase in the reported number of cases of staph infection per hospital bed in the South Bay. The average number of cases per bed in the South Bay on non-risky days is 0.0000395. The coefficient implies that 'risky' days are associated with a 268% increase in the rate of reported cases of staph infection per bed, relative to non-risky days.

The split sample DD estimates from Table 3.4 suggest that each ‘risky’ day is associated with a 0.016 increase in the number of reported cases of cellulitis in the South Bay for white males age 18-35, and a 0.002 increase in the number of reported cases of hepatitis A. The average number of reported cases on non-risky days is 0.018 for cellulitis and 0.0004 for hepatitis A. The results suggest that ‘risky’ days are associated with a 89% increase in the number of reported cases of cellulitis in the South Bay for white males age 18-35, and a 565% increase in the number of reported cases of hepatitis A, relative to non-risky days. The coefficient estimates of 0.016 and 0.002 on cellulitis and hepatitis A, respectively, can also be interpreted as 62 ‘risky’ days are associated with one additional case of cellulitis in the South Bay, and 500 risky days are associated with one additional case of hepatitis A.

Table 3.5 displays results for weighted least squares estimates of the DD model applied to the rate of reported cases per hospital bed. The estimates suggest that each ‘risky’ day is associated with a 0.000062 increase in the number of reported cases of cellulitis per South Bay hospital bed, and a 0.0000086 increase in the number of reported cases of hepatitis A per hospital bed. The average number of reported cases per bed on non-risky days is 0.00008 for cellulitis and 0.0000012 for hepatitis A. The results in Table 5 suggest that each risky day is associated with a 77% increase in the number of reported cases of cellulitis per South Bay hospital bed, and a 716% increase in the number of reported cases of hepatitis A, relative to non-risky days.

Table 3.6 shows results for the years 2001-2008, the years in which Scripps Mercy Hospital - Chula Vista and Scripps Mercy Hospital - San Diego reported their hospitalization data separately. The results suggest that each ‘risky’ day is associated with a 0.024 increase in the number of reported cases of cellulitis in the South Bay for white males age 18-35, a 0.015 increase in the number of reported cases of staph infection, and a 0.004 increase in the number of reported cases of hepatitis A. The average number of reported cases for white males age 18-35 on non-risky days from 2001-2008 is 0.019 for cellulitis, 0.009 for staph infections, and 0.00035 for hepatitis A. The estimates suggest that each 'risky' day is associated with a 126% increase in the number of reported cases of cellulitis, a 166% increase in the number of reported cases of staph infections, and a 1114% increase in the reported number of cases of hepatitis A. The coefficient estimates also suggest that every 41 'risky' days is associated with one extra case of cellulitis for white males age 18-35 in the South Bay, every 66 'risky' days is associated with one extra case of staph infection, and every 250 'risky' days is associated with one extra case of hepatitis A.

Table 3.7 displays results for weighted least squares estimates of the DD model applied to the rate of reported cases per hospital bed from 2001-2008. The results suggest that the each 'risky' day is associated with a 0.0001 increase in the number of reported cases of cellulitis per South Bay hospital bed, a 0.00006 increase in the number of reported cases of staph infections, and a 0.000016 increase in the reported number of cases of hepatitis A. The average number of cases per bed in the South Bay for white males age 18-35 is 0.00009 for cellulitis, 0.0000395 for staph infections, and 0.000001 for hepatitis A. The results imply that each 'risky' day is associated with a 113% increase in the number of reported cases of cellulitis per South Bay hospital bed, a 152% increase in the number of reported cases of staph infections, and a 1451% increase in the number of reported cases of hepatitis A.

While the estimated effects for hepatitis A seem very large when compared to the mean for non-risky days, it is worth noting that there were only seven reported cases of hepatitis A for South Bay hospitals from 2001-2012, and only five cases from 2001-2008. Thus, this is an extremely rare condition for white males age 18-35, and small increases in the number of reported cases on risky days will yield large coefficient estimates relative to the non-risky day mean.

These results likely represent a lower bound on the true impacts of water pollution on public health outcomes. This is because the sample consists of white males age 18-35, not all of whom are surfers. Even if all white males age 18-35 were surfers, it is likely that some of them would avoid the water or drive north to a beach that is not impacted on days when the beaches were closed due contamination. Also, many surfers who live in Imperial beach are vaccinated for hepatitis A [Gill, 2009]. Thus, some members of my sample are immune to infection for hepatitis A. Another factor that contributes to these estimates representing a lower bound is that the prime aged males age 18-35 likely have stronger immune systems relative to young children or elderly adults. Lastly those individuals in the sample with historical susceptibility to illnesses such as ear or sinus infections are the individuals most likely to demonstrate avoidance behavior when closure signs are posted due to elevated bacteria levels.

3.7 Conclusion

The evidence presented in this paper indicates that surfers who choose to enter the water in Imperial Beach when the water is impacted by the Tijuana River are at increased risk of being hospitalized for cellulitis, staph infection, or hepatitis A. This finding provides insight into the public health effects of contaminants recently found in coastal waters in San Diego's South Bay region. This paper also provides evidence of the severity of illness associated with bathing in contaminated recreational waters. Up until this point there have been suspicions of adverse public health effects, but no research has yet to uncover a link between 'risky' days and an increase in hospitalizations for specific illnesses.

Unlike the results for cellulitis, staph infection, hepatitis A, and acute sinus problems, placebo tests on three conditions likely to be unrelated to exposure to contaminated water indicate no effect from 'risky' days. The placebo results suggest that the four outcomes analyzed are positively related to individuals braving polluted conditions when the surf is above average.

Split sample DD estimates for hospitals in the north and south, respectively, indicate that the adverse health effects on 'risky' days are found in South Bay hospital only. DD estimates for northern hospitals show no significant effects for any of the outcome variables or placebo conditions included in the analysis. This result supports the claim that due to geography and ocean conditions, pollution from the Tijuana River ocean outfall negatively impacts water quality for South Bay beaches only.

The findings in this paper indicate that urban runoff from the Tijuana River ocean outfall is a serious public health problem for individuals who surf or swim at beaches in the South Bay. Not only is pollution present after significant rain events, but when the surf is good individuals who enter the water, despite warning signs about health risks from contamination, are being hospitalized for serious illnesses including cellulitis, staph infection, and hepatitis A.

Appendices

A Cooperation and the 'Surfer's Dilemma: An Experimental Study

A.1 Experiment Instructions

The following replicates the instruction screens verbatim.

Welcome Screen:

Welcome to this experiment at UC Irvine. Thank you for participating.

Please turn off your cell phone.

You are about to participate in a study of decision-making, and you will be paid for your participation in cash, privately at the end of this session. It is important that you do not communicate with any other participants during the session. You will be made aware when the session.

The entire session will consist of several games. Within each game there will be multiple rounds. Before each new game begins everyone in the room will be randomly assigned into groups of four. You will remain in the same group throughout each individual game, but you will be randomly re-assigned into a new group of four at the beginning of every new game.

The exact number of rounds per game is determined randomly after each game begins. For example the first game may continue for 5 rounds, the second game may continue for 9 rounds, the third game may continue for 3 rounds, etc. Specifically, after each round is complete the current game will continue for one more round with **probability 90%**.

If the game does not continue for another round, everyone in the room will be made aware that the current game has ended. You will be randomly re-assigned into a new group of four and you will begin the first round of the next game. The exact number of games for this session will depend on the number of rounds per game. If the number of rounds per game is small, then we will have more games relative to the case when the number of rounds per game is large.

During each game, you will amass points which will be exchanged for US currency. You earn $1.00 for every point earned over the entire session. What you earn each game depends partly on your decisions and partly on the decisions made by the other members of your group.

Your earnings for each game will be added to your 'show up fee,' which equals $7, in order to determine your total payout for the session. All rounds will take place through the computer terminals and all decisions will be made by using your mouse.

When you are ready to proceed, please click "Continue" to go to the instructions.

Basic Instructions I:

In every round, players will be asked to select a number between one and ten with the restriction that only one person can select any given number.

Example:

If the first mover in any given round selects the number ten, then the second mover must select a number between one and nine. If the second mover then selects the number one, the third mover will only be able to select a number between two and nine.

At the beginning of each game (recall there will be multiple games) all four members of your group will be randomly assigned a rank. This rank will determine the order in which players select their number in the first round.

After the first round the number of participants and the order in which those participants select their number will be determined by a combination of the previous round's outcome and the initial rankings.

After all participants have selected their number, each participant will have the opportunity to 'Claim' or 'Not Claim' the number they just selected. This decision will occur sequentially with the order determined by the values of each participant's selected number.

The player who selected the largest number will have the opportunity to 'Claim' or 'Not Claim' their number first. The player who selected the second-largest number will make this decision second. This continues such that the last player who decides to 'Claim' or 'Not Claim' will be the player who selected the smallest number.

Basic Instructions II:

The player who decides to 'Claim' the lowest number in any given round will receive points equal to the number he claimed. All other players will receive zero points for that round.

Example:

Suppose in round 1 four participants select the numbers 7, 8, 9, and 10. If everybody decides to 'Claim' their number, then the player who decided to 'Claim' number 7 will be the person who claimed the lowest number. Therefore, that player would receive 7 points for that round while all other players would receive zero points.

Alternative Example:

Suppose in round 1 four players selected the numbers 7, 8, 9, and 10. If only the two players who selected 9 and 10 decide to 'Claim' their numbers while the players who selected 7 and 8 decide to 'Not Claim' their numbers, then the player who decided to 'Claim' number 9 will be the player who claimed the lowest number. He will receive 9 points for that round while all other players will receive zero points.

In order to have a chance to receive points in any given round, you must decide to 'Claim' your number. However any player that decides to 'Claim' their number will NOT be allowed to participate in the next round of play. For example, if you claim your number in round 1, then you will not participate in round 2 and you will re-enter the game in round 3.

If you decide to 'Not Claim' your number, you will receive zero points for the current round. However, you will be allowed to participate in the next round of play. Moreover, all players who decide to 'Not Claim' their number in the current round will be allowed to select their numbers before any players who are re-entering the game following a decision to 'Claim' their number.

The order in which players select their numbers is preserved for those who decide to 'Not Claim' their number. For example if you are the first mover and you decide to 'Not Claim' your number, you will remain the first mover in the next round. Alternatively, if you are the second mover and you decide to 'Not Claim' your number and the first mover decides to 'Claim' their number, you will become the first mover in the next round.

Basic Instructions III:

If more than one player decides to 'Claim' their number, then the order in which those players select their numbers upon re-entry depends on the value of the numbers they decided to 'Claim.'. The player who decided to 'Claim' the largest number will be the first re-entrant to select his number (after sitting out for one round), while the person who decided to 'Claim' the lowest number will select his number last. All re-entrants must wait for those players who decided to 'Not Claim' their number in the previous round to select a number before they can select a number for themselves.

Another example:

Suppose that in round 1 the first mover selects number 1, the second mover selects number 2, the third mover selects number 3, and the fourth mover selects number 4. If the two players who selected number 1 and number 2 decide to 'Not Claim' their number while the players who selected numbers 3 and 4 decide to 'Claim' their number, then the third mover would be the player to 'Claim' the lowest number and he would receive 3 points for round 1. All other players receive zero points for round 1.

In round 2, the first and second mover from the first round will be the only participants because they decided to 'Not Claim' their numbers in round 1. Because the order is preserved for those players who decide to 'Not Claim' their number the first mover in the first round will also be the first mover in round 2. Similarly, the second mover from the first round will remain the second mover in round 2, The third and fourth movers from the first round will not be participating because they decided to 'Claim' their numbers in round 1.

Suppose the first mover in round 2 selects number 1 and decides to 'Claim' that number while the second mover selects number 2 and decides to 'Not Claim' that number. In this case the first mover will receive one point while the second mover will receive zero points. The first mover must sit out round 3, while the second mover will participate in round 3 and will have the opportunity to select a number first.

In round 3 the two players who decided to 'Claim' their number in round 1 will re-enter the game and join the one player who decided to 'Not Claim' their number in round 2. The one player who decided to 'Not Claim' his number in round 2 will select his number first in round 3. The player who decided to 'Claim' number 4 in round 1 will be the second mover in round 3 and the player who decided to 'Claim' number 3 in round 1 will be the third and final mover in round 3.

Test 1:

To test your understanding, please answer the following question.

1. What are your total points in a round if you select number 4 and decide to 'Claim' your number and another player selects number 2 and decides to 'Claim' that number?

Answers: 0, 1, 2, and 4

Test 1 Results:

If subjects answered correctly (the correct answer is zero) they were shown a screen that says That is CORRECT. Otherwise they are shown a screen that says That is INCORRECT. In both cases (correct or incorrect) the following explanation of the correct answer is shown.

The correct answer is 0. If you decide to 'Claim' your number but it is not the lowest number to be claimed that round then you will receive zero points. The person who decides to 'Claim' the lowest number will receive points equal to the number that was claimed.

Test 2:

Here is another question:

2. Suppose that you are the third mover in a round and you decide to 'Not Claim' your number. If the first mover decides to 'Claim' their number and the second mover decides to 'Not Claim' their number, when will you have the opportunity to select your number in the next round?

Answers: First, Second, Third, You will not be participating in the next round

Test 2 Results

If subjects answered correctly (the correct answer is second) they were shown a screen that says That is CORRECT. Otherwise they are shown a screen that says That is INCORRECT. In both cases (correct or incorrect) the following explanation of the correct answer is shown.

The correct answer is you will move second in the next round since the order is preserved for all players who decide to 'Not Claim' their number. Because the second mover also decided to 'Not Claim' his number and he selected his number before you this round, he will select his number before you in the next round.

Since the first mover decided to 'Claim' his number, he will sit out the next round.

Final Instructions:

In the first game, the computer will randomly assign you into groups of four. You will remain in that same group for the entire first game. When the first game ends, you will be randomly re-assigned into a new group of four for the second game. You will continue to be re-assigned to a new group of four every time a new game begins. You will be informed every time a new game is about to begin.

Recall that the number of rounds in each game is determined randomly. Specifically in every round after the first, the game will continue for one more round with **probability 90%**. Therefore, the number of rounds per game is likely to change from game to game.

After selections have been made, a results screen will be displayed. You will know the numbers already selected by other members of your group prior to selecting your number. You will also know whether those players who chose a larger number than you decided to 'Claim' or 'Not Claim' their number prior to deciding to 'Claim' or 'Not Claim' your number.

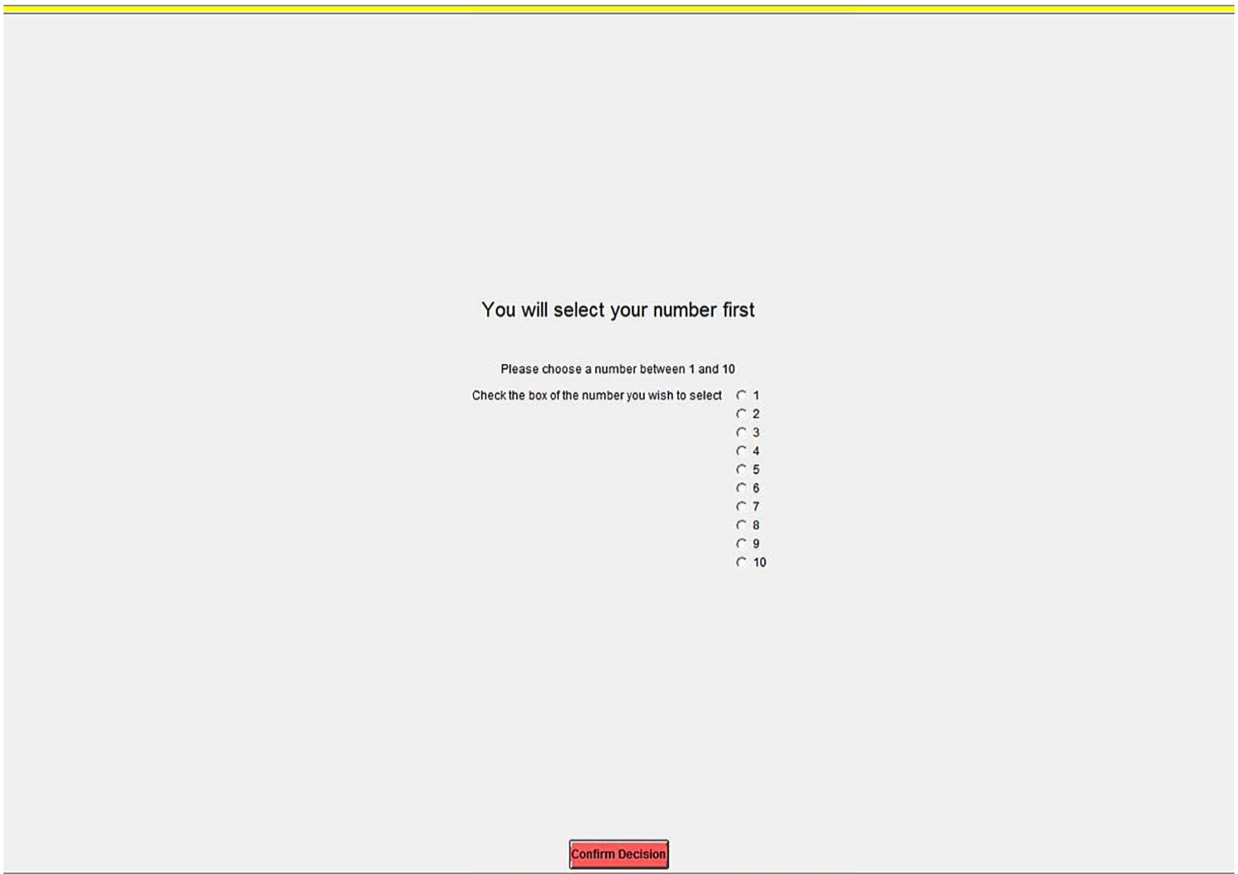
At the conclusion of each round you will be shown the decisions and resulting payoffs for all players in your group.

The experiment will last between 1 and 10 games. The exact number of games is determined by the number of rounds per game. The number of rounds per game is determined randomly by the computer.

Click OK to begin the first game.

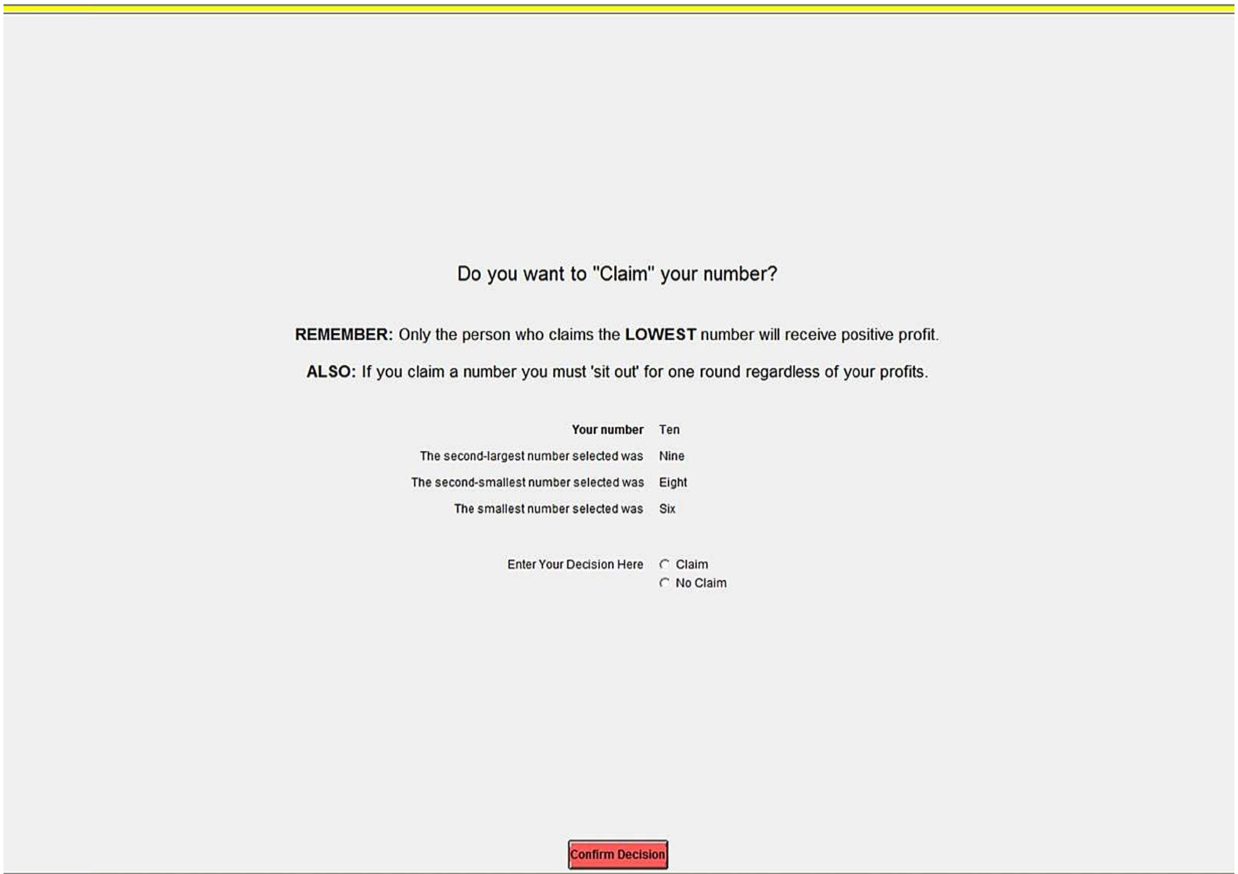
A.2 Screenshots of Experiment

Figure A.2: Select a Number



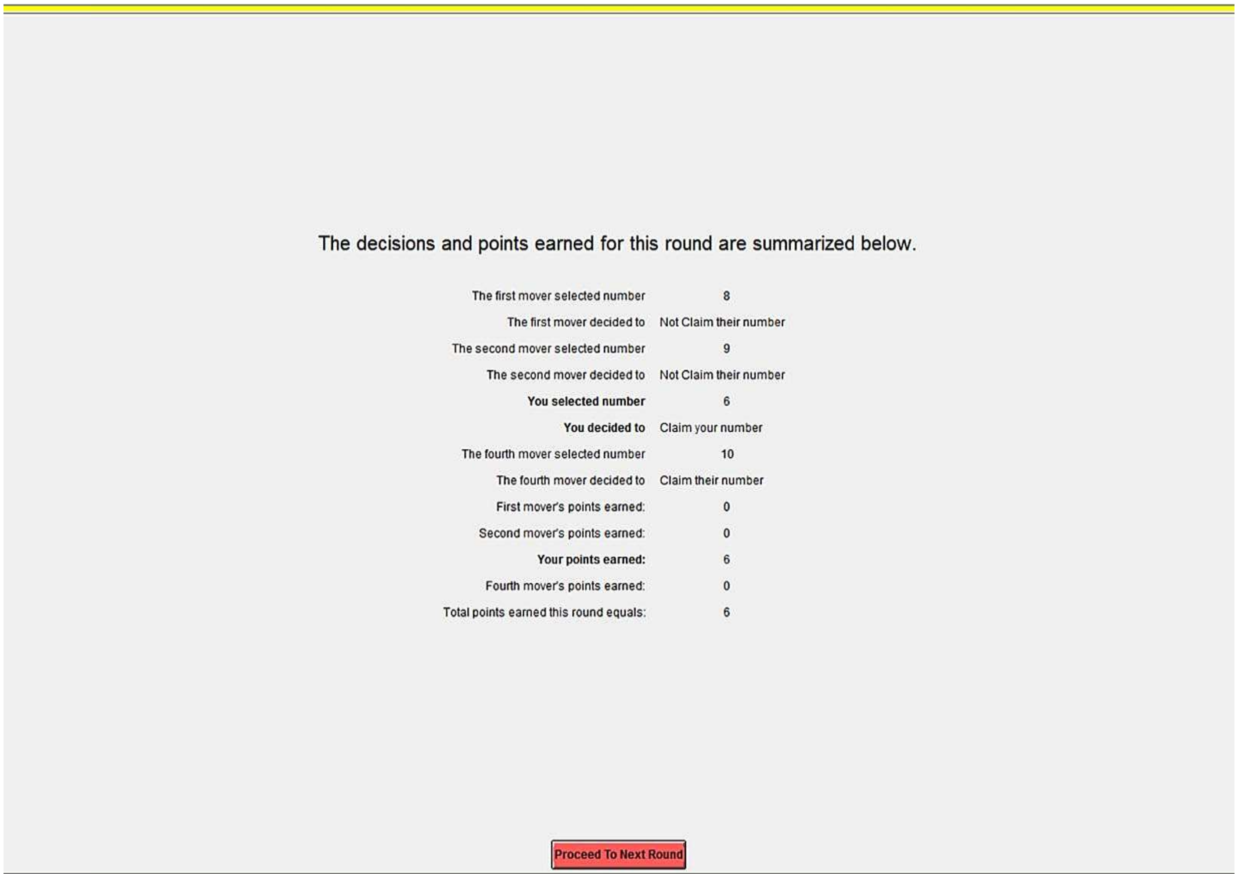
This screen is shown to the first mover as he decides what number to select.

Figure A.3: ‘Claim’ or ‘Not Claim’ a Number



This screen is shown when subjects are deciding to ’Claim’ or ’Not Claim’ their number.

Figure A.4: Profit Screen



A profit screen is displayed after all subjects have decided to 'Claim' their numbers or not.

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