DISSERTATION

EFFECTIVENESS AND ACCEPTABILITY OF CONGESTION PRICING

Submitted by

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Abstract

Effectiveness and Acceptability of Congestion Pricing

Urban congestion is a pervasive and growing problem in developed and developing countries. The lack of excludability for scarce urban space, specifically roads and parking spaces, creates a common resource problem yielding a congestion externality that generates many external costs. Marginal social cost pricing has long been advocated as a means of alleviating market failures resulting from such negative (environmental) externalities. Congestion pricing comes in numerous forms (e.g., tolls on roads or express lanes), but has only been sporadically adopted despite congestion being a growing problem. The literature argues that concerns on equity and fairness issues and revenue redistribution are major hurdles of making an effective congestion pricing policy politically feasible and publicly acceptable. This dissertation investigates the effectiveness and acceptability of congestion pricing schemes in different contexts and examines whether individual beliefs in addition to the objective welfare effects determine voter acceptability. The first chapter employs laboratory experiments to examine the evolution of voting behavior after individuals become accustomed to the congestion problem and the congestion pricing policy, and the nature of the experience from the congestion policy. The congestion pricing policy exogenously creates inequitable outcomes which in some cases makes some people worse off. The second chapter develops and examines a three-player bottleneck congestion game and examines the *ex-ante* and *ex-post* welfare implications of an *ex-ante* efficient tolling policy. The third chapter examines the effectiveness and acceptability of tolls in the three-player bottleneck congestion game using laboratory experiments where equity concerns are endogenously determined. The results suggest policymakers should be open to and considerate of the equity effects, the characteristics and beliefs of their constituents, and how to earmark revenues before implementing efficiency enhancing environmental policies.

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CHAPTER 1

INTRODUCTION

Urban congestion is a pervasive problem in developed and developing countries. The lack of excludability for scarce urban space, specifically roads and parking spaces, creates a common resource problem yielding a congestion externality that generates many external costs. Many economists recommend that policymakers facing natural physical constraints of expanding capacity consider incentive-based mechanisms to mitigate congestion. Congestion pricing is argued to mitigate congestion by lowering travel time costs and therefore improving overall efficiency. The theoretical understanding of improving societal welfare by imposing an externality correcting tax (or toll), equaling the marginal external (congestion) costs at the efficient level, has been around since Pigou (1924). However, such "Pigouvian" policies can create negative distributional effects, making many policymakers and the public averse to such welfare enhancing incentive-based policies.

Given basic assumptions and conditions, and if government puts revenue aside, then Pigouvian tolls or congestion pricing on a road will achieve a Pareto efficient outcome, but will make all individuals worse off (Hau, 1992). The government will be the only entity that will made better off from the increased revenue. According to Hau (1992), the individuals paying the toll will incur an additional cost of the toll, which may surpass the value-of-time savings so they are worse off. And the motorists priced off the road to an inferior off-peak time, inferior mode of travel, or different route to avoid paying the toll are also worse off. Additionally, the individuals already on other roads are worse off if congestion arises from motorists using their route as an alternative to avoid paying the toll. The welfare improvement from the congestion pricing policy relies upon how the government spends or reallocates the toll revenues. After redistribution, inequities will usually remain, creating "winners" and "losers."

Despite the efficiency gains, equity and fairness concerns as well as a general lack of knowledge of the efficiency gains may be reasons why congestion pricing is not implemented more in practice. Congestion pricing has been sporadically applied by either using cordon zone pricing of a central business district, variable pricing (or peak pricing) of toll roads, variable pricing of high occupancy toll (HOT) lanes (i.e., express lanes), and/or responsive pricing to manage parking demand. The lack of further implementation of such pricing can be explained by the barriers of political feasibility, public acceptability, and general knowledge of the Pigouvian objective of the congestion pricing instrument. The equity concerns seem to dominate. Even under the assumption of heterogeneous time preferences where high-values-of-time users are better off with the toll by decreasing their travel time, the other users are made worse off by being incentivized to make less preferred travel decisions (Small and Verhoef, 2007). Further, users that might be made better off from the toll may still not find the toll acceptable, as was the case when tax aversion of efficiency improving Pigouvian taxes were observed empirically by Kallbekken et al. (2011) and Cherry et al. (2013). Beliefs and idiosyncratic behaviors may be significant factors.

In a review of literature on how to address equity concerns of road pricing, Levinson (2010) finds recycling collected toll revenues can address such concerns. Yet a tradeoff exists between alleviating fairness and equity concerns and improving system efficiency when considering or designing a pricing policy. Policymakers have to weigh the political feasibility of a congestion policy and whether it will be politically acceptable. Levinson (2010) remarks that the perception of equity is highly subjective and satisfying certain groups is necessary to obtain acceptability of a congestion program. Furthermore, these subjective perceptions of the objective effects of a congestion policy may be driven by beliefs and idiosyncrasies of individuals. In a review of issues influencing the implementation of road user charging, Ison and Rye (2005) identify the need to have a clear strategy when raising and earmarking revenues, handling equity and exemptions, and gaining trust from the general public as crucial to the implementation of any road user-charging fee. They also detail other key issues relating to the implementation of road user charging such as having a sympathetic local environment regarding the timing and severity of congestion and the technology requirements and privacy concerns of the type of charging scheme.

There is a need for both a theoretical framework and empirical evidence that demonstrates the effectiveness of congestion pricing, the expected welfare effects from congestion pricing, as well as the likelihood of acceptability. The empirical data ought to control for individual beliefs when examining individual subjective perceptions to the objective effects of a congestion policy. A lack of empirical evidence of the effectiveness of congestion pricing policies reinforces the perception of the political infeasibility of introducing such policies, thus handicapping and preventing congestion pricing policies from being implemented more in practice. Only with a better understanding of the foundations of congestion pricing can the potential benefits be confidently and openly communicated so that congestion pricing will be more likely to be implemented and accepted in practice. Moreover, there is a need to better understand what drives an individual's acceptability of congestion pricing than just welfare predictions.

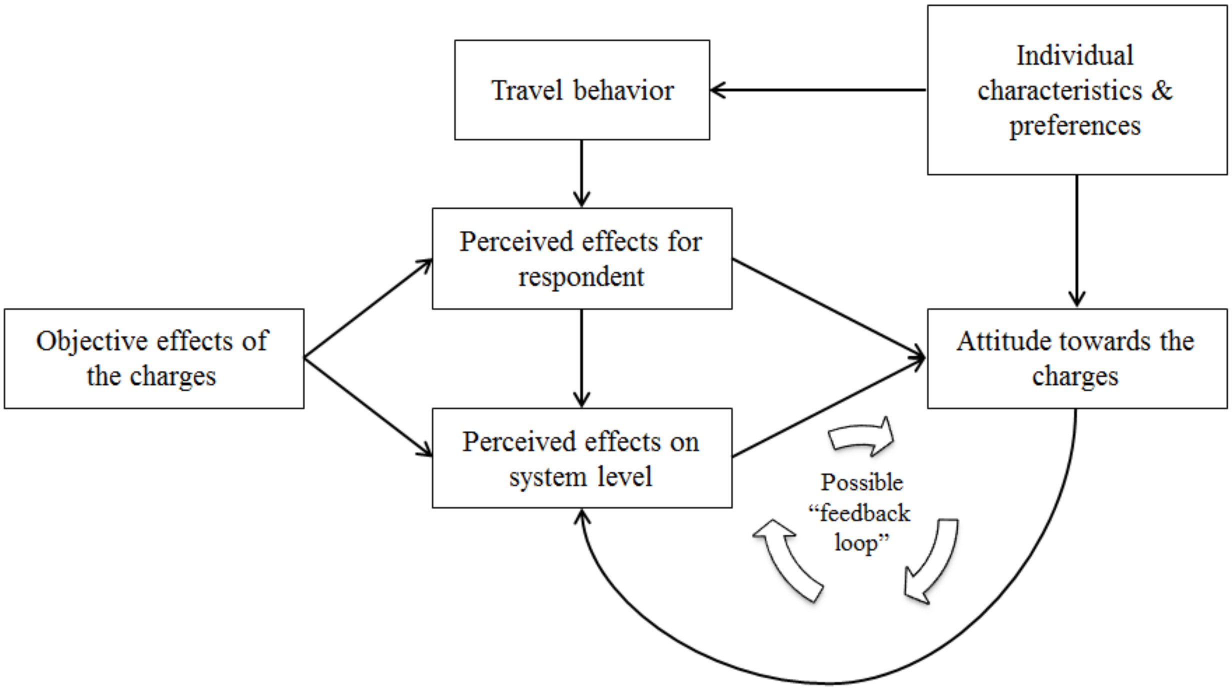
This dissertation proposes to theoretically illustrate the potential benefits of congestion pricing and empirically explore the effectiveness and behavioral motivations for the acceptability of congestion pricing. It contributes to the literature by investigating theoretically and empirically the behavioral motivations for why barriers to implementing efficiency-enhancing congestion pricing policies currently exist. Three research questions motivate the three chapters of the dissertation:

- Does experience of congestion pricing predict acceptability or do personal traits predict acceptability?
- What makes congestion pricing effective and why would anyone be opposed to such an efficiency-enhancing policy?
- What motivates an individual to want to opt in or opt out of a congestion pricing policy when equity effects are endogenously determined?

The first question is addressed in Chapter 2 using empirical data generated from a laboratory experiment. Chapter 3 use a game-theoretical approach to answer the second question. And Chapter 4 addresses the third question by generating empirical data in a laboratory experiment using the model described in Chapter 3. All three chapters address how important equity concerns are to overcoming the hurdle of public acceptability of congestion policy. Chapters 2 and 4, in addition, investigate whether personal attributes or self-interest determine the acceptability of a congestion pricing.

The dissertation will incorporate and build upon the immense existing theoretical and empirical transportation literature (Small and Verhoef, 2007). Much of the literature on congestion pricing in transportation uses the bottleneck congestion model first introduced by Vickrey (1969) that examines departure times for a single route. It has been improved upon recently by Arnott et al. (1990b), and it illustrates the tradeoff motorists face between travel time and schedule delay (arriving early or late). The model provides theoretical predictions of outcomes and welfare implications with and without congestion pricing. It has been developed to incorporate heterogeneous users in travel time preferences, scheduling preferences, parking, and other additions. Other transportation literature examines route-choice behavior in transportation networks empirically and sometimes in laboratory environments (Small and Verhoef, 2007; Anderson et al., 2008; Hartman, 2012).

These chapters contribute to the growing literature of investigating the acceptability of incentive-based environmental policies. Congestion pricing is not limited to transportation, but has numerous applications such as tables at popular restaurants, ski lift lines, tickets to popular events, as well as the management of environmental and natural resources. The experiments from Chapters 2 and 4 contribute to the modest but growing literature of examining congestion pricing using laboratory experiments. Moreover, the two experiments make a significant contribution by incorporating the cultural cognition thesis research (Kahan et al., 2011, 2012). Kahan et al. (2012) find that public divisions over the risk of climate change stem from values of characteristic of groups with which they identify rather than comprehension of the problem itself. Kahan et al. (2011) examine how cultural cognition shapes individuals beliefs about the existence of scientific consensus relating to climate change, the disposal of nuclear waste, and the effect of permitting concealed possession of handguns. The data collected from the experiments in Chapters 2 and 4 are used to match an individual's cultural cognition measures as well as other belief measuring altruism and sensitivity toward the environment to their voting behavior (acceptability) of congestion pricing. I argue that grouping individuals based on their answers to these sensitive questions that gauges their



Source: Figure 5 from Börjesson et al. (2012).

Figure 1.1. Interactions Between Attitudes, Travel Behavior And The Objective Effects Of The Charges

personal beliefs is more dependable, accurate, and transferable method of understanding behaviors than individuals self-identifying themselves by political ideology or party.

Understanding what determines an individual's opinion on congestion pricing and how their opinion evolves is important for policy-making. Figure 1.1 depicts a flow diagram from Börjesson et al. (2012) that suggests how attitudes toward congestion pricing are determined. It shows that individual characteristics and preferences (e.g., personal beliefs) can affect attitudes, but there may be a feedback loop from the perceived (subjective) effects from experiencing congestion pricing. This feedback may evolve over time. Chapters 2 and 4 investigate the evolution of this feedback loop.

The culmination of these chapters will provide economists and policymakers the behavioral motivations on why there exists an apprehensiveness to implement potentially efficiency-improving congestion pricing. This dissertation will incorporate both theoretical approaches of looking at route-choice decisions and departure-time decisions to answer the primary research questions. Chapter 2 uses a two-route network in a laboratory experiment to examine the effectiveness of congestion policy on route-choice decisions and the evolution of acceptability of a toll (congestion pricing). The chapter makes a contribution by providing an innovative experimental design that allows for incentive-compatible observations of the evolution of approval rates (acceptability) when inequities are exogenous imposed. Chapter 3 formally develops a three-player bottleneck congestion game with and without congestion pricing. The chapter critically examines the game theory perspective first introduced by Levinson (2005) and adds to the literature by describing and illustrating the endogenous welfare effects and principles of congestion pricing of a three-player game instead of a two-player game. Having more than two players creates unique congestion scenarios that do not exist in a two-player game framework. Chapter 4 applies the three-player bottleneck congestion model developed in Chapter 3 to a laboratory experiment. The experiment examines the performance of group departure times and the acceptability of congestion tolls when inequities are determined endogenously. Chapter 4 compares theoretical game theory predictions to empirical results as well as investigating the motivations on why individuals are more likely to opt in or opt out of a congestion pricing policy. Chapter 5 provides conclusions.

CHAPTER 2

ACCEPTABILITY OF CONGESTION PRICING: WORLDVIEWS VERSUS EXPERIENCE

2.1. INTRODUCTION

Urban congestion is a growing problem that creates many external costs. Congestion pricing is seen as a potential solution. Although congestion pricing, with correctly set prices works in theory and in textbooks, it is only sporadically implemented in practice. Barriers such as public acceptability, political feasibility, a general understanding of the congestion problem, and uncertainty of the effectiveness of congestion pricing instruments prevail despite growing congestion costs. According to the 2012 Urban Mobility Report (Schrank et al., 2012) 5.9 billion hours were lost in 2011 from the additional travel time from congestion in the United States and 2.9 billion gallons of fuel were wasted. This increased fuel consumption in turn released an additional 26 million metric tons of carbon dioxide, which is the equivalent to six times the annual greenhouse gas emissions that is estimated to be saved by the removal of conventional vehicles by the current fleet of hybrid and electric vehicles in 2013 (Hall, 2013). The Urban Mobility Report estimates average annual costs of congestion in 2011 to be \$818 per United States commuter compared to an inflated-adjusted cost of \$342 in 1982.[1] Despite the various successes highlighted in a recently sponsored United States Federal Highway Administration technical report of metropolitan areas effectively managing congestion (Mahendra et al., 2012), congestion pricing policy proposals remain hindered by equity and fairness concerns.

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[1] Time-delay costs are found to be the largest external costs from congestion when compared to other external costs borne by users and non-users of vehicle travel (Small and Verhoef, 2007)

Congestion pricing is argued to be an efficient tool to tackle the congestion problem and lessen its costs by optimizing road use (and congestion). The theoretical understanding that adding a congestion tax, or toll, on a road can improve outcomes has been around since Pigou (1924), and since then the welfare impacts have been studied extensively (Small and Verhoef, 2007). Set at the correct level, congestion pricing equals the marginal external congestion cost a traveler creates so that all trips made provides benefits as least as great as its social costs (Small and Verhoef, 2007). Examples of congestion pricing policies used in practice include cordon zone pricing of a central business district, variable pricing (or peak pricing) of toll roads, variable pricing of high occupancy toll (HOT) lanes (i.e., express lanes), and responsive pricing to manage parking demand.

Despite the potential efficiency improvements, congestion pricing creates distributional and fairness concerns since some groups are made worse off (Hau, 1992; Small and Verhoef, 2007). Referring to the classic short run bottleneck congestion model, Hau (1992) mentions that under "normal" traffic conditions and if the road pricing revenue is put aside, then an optimal toll achieves an efficient outcome but would definitely make society worse off. However, in a review on how equity concerns of road pricing, Levinson (2010) finds that such welfare and equity concerns can be addressed by the way collected toll revenues are recycled back into society. Yet a tradeoff exists between alleviating fairness and equity concerns via redistribution of revenue and improving system efficiency when designing a pricing policy. Policymakers have to weigh the political feasibility of a congestion policy. Levinson (2010) remarks that the perception of what constitutes equity is highly subjective and satisfying some subsets of the general population is necessary to obtain acceptability of a congestion pricing policy.

The lack of public acceptability may stem from a general misunderstanding of the Pigouvian objective of a congestion pricing instrument and the uncertainty surrounding the effectiveness of congestion pricing since the public have never been accustomed the effects of the policy. Many papers investigate the public acceptability of incentive-based mechanisms that deal with congestion (Schade and Schlag, 2003; Marcucci and Marini, 2001; Ison and Rye, 2005; Winslott-Hiselius et al., 2009; Larson and Sasanuma, 2010; Anas and Lindsey, 2011; Kallbekken et al., 2011). A 2013 study exploring the public opinion of congestion pricing was carried out by the National Capital Region Transportation Planning Board in partnership with the Brookings Institute using deliberative forums in Washington, DC.[2] The study found that participants were generally unaware of how transportation is funded and that the federal gasoline tax has not been raised in twenty years and is not indexed to inflation. Moreover, other studies have shown tax aversion of efficiency improving Pigouvian policies have been observed empirically (Kallbekken et al., 2011; Cherry et al., 2012). There appears to be a general reluctance to raise usage taxes. Yet the implementation of congestion pricing in practice has had mixed outcomes in its effectiveness and acceptability. Congestion pricing has been successfully implemented and accepted in Stockholm, London, and Singapore, while it has failed in places like Edinburgh, Hong Kong, and Manhattan.

Although observing both the performance and acceptability of congestion pricing at an individual level in the real world would be ideal, such data collection would be too costly and almost impossible to implement. Falk and Heckman (2009) argue that laboratory experiments complements other empirical methods and data sources in the social sciences. Laboratory experiments allow for a low financial and political cost alternative. They create

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[2] What Do People Think About Congestion Pricing? National Capital Region Transportation Planning Board Metropolitan Washington Council of Governments. September 2013. http://www.mwcog.org/uploads/pub-documents/pl5cWl820131118131930.pdf

a controlled environment that can examine actual incentive-compatible behavior and can be used to examine how policies would perform and be accepted in the real world. Instead of implementing a politically risky and potentially expensive pilot programs, policymakers would be interested in utilizing such laboratory investigations to guide their policy making when campaigning for successful and publicly acceptable congestion pricing policies.

This chapter examines why there is a deficient use of congestion pricing by answering three questions regarding the effectiveness and acceptability of congestion pricing. These questions are addressed by employing a two-route congestion game that contains inequitable outcomes. That is, the welfare and behavioral effect of a toll varies by individual and to a varying degree where the toll can sometimes make some individuals worse off. First, does congestion pricing (a toll on a congestible route) work in the lab? Second, does experience influence acceptability? Third, do individual attributes determine the acceptability of tolls and does this acceptability evolve when an individual becomes accustomed to the problem and policy?

The two-route congestion game emulates a tragedy of the commons where groups of six individuals with heterogeneous time preferences choose between two routes where one route is shorter but congestible and the other route has a longer but constant travel time. Subjects make decisions on which route to take based on their value of time and expected travel time costs. Travel time costs are a function of the individual's route-choice and the route-choices of the other members in their group. Groups participate in three rounds of 10 periods of making route-choices where only one of three rounds is randomly selected to count towards a subject's monetary earnings. Groups experience the game with and without tolls whilst deciding using three potentiality binding referendum votes on whether the last round should have a toll. Votes occur before and after experiencing the game and congestion problem without tolls on the congestible route, and then after the second round when everyone has experienced the game with and without tolls. Groups see all voting outcomes only after the third vote is cast, and that is when one of the three votes is selected to be binding using a random selection process. The votes are important; they provide a measure of the evolution of the acceptability of the toll by first obtaining an initial stated preference of tolls given exogenous characteristics, and then any changes in attitudes from being accustomed to the congestion problem and the congestion pricing policy.

A 2 × 2 treatment experiment design is utilized to address the above research questions. Different expected welfare effects from the toll are varied based on how much toll revenue is redistributed lump-sum: all individuals should either all be better off by varying amounts (100% revenue redistribution) or some individuals are made better or worse off by varying amounts (40% revenue redistribution). The other variation of treatments is aimed at answering the last two research questions on voting behavior by investigating an individual's reaction if they observe the welfare effects and inequities from the toll of all members of their group. One treatment has, before the third vote, information on the individual's average total costs between the first two rounds and how much their costs change from the toll. The alternative treatment discloses the same performance information for the individual, but also discloses ranked performance information of all six members in the group. Individuals might react and vote differently and not in their self-interest if they see the toll creates inequities. At the end of the experiment, survey responses from questions that gauges an individual's cultural worldviews (Kahan et al., 2011), altruism, and views of the environment (Kotchen and Moore, 2007), their political ideology, as well as other demographic information were collected. These responses are paired with an individual's voting behavior to investigate whether individual beliefs predict an individual's evolution of acceptability of congestion pricing. This chapter contributes to the literature by both being the first the test the effect of a toll on congestion performance of heterogeneous users, and by designing an experiment to allow for the observation of the evolution of acceptability using incentive-compatible votes.

The results show that the tolls achieve the objective of reducing congestion and increasing societal welfare. Given their externally endowed preferences, no robust pattern of subjects voting based on their self-interest for the first vote was observed. Being accustomed to the congestion problem and the toll matters in determining the acceptability of a toll, and that self-interest, unsurprisingly, appears to be a major determinant after individuals are accustomed to the problem and are provided a measure of the toll's effects on their costs. However, some individuals did not vote in their own self-interest. Lastly, personal attributes and beliefs were not a major determinant on initial feelings of congestion pricing; however, these attributes did become significant after everyone became accustomed to the congestion problem.

These results provide experimental evidence to the lessons of understanding the issues influencing the implementation of road user charging as outlined by Ison and Rye (2005). Such (laboratory) experimental methods contribute to the literature and help policymakers understand that positive or negative experiences of the congestion policies matter. A congestion pricing instrument and the redistribution of toll revenue ought to be carefully designed to make it acceptable so that the majority of the effected population benefits. Personal attributes matter, but appear to matter only after an individual has a chance to be accustomed to a problem. Whether initial attitudes on congestion pricing are based on personal beliefs, cultural worldviews, and group association remains an open question. Moreover, the controlled environment in the experiment does not examine whether acceptance may rely on outside influences such as local political party affiliation and their position on congestion pricing, an individual's geographical location and proximity to congestion tolls, and local opinions.

Provided in the following sections are a review of field and experimental literature on the performance and acceptability of congestion pricing (Section 2.2), an explanation of the theoretical two-route congestion model used in the experiment (Section 2.3) and the design of the experiment (Section 2.4). Section 2.5 provides the empirical results, and the chapter concludes with Section 2.6.

2.2. Literature Review

2.2.1. Field.

The experience in Stockholm provides a telling story on how the efficiency-enhancing effects of a Pigouvian toll policy and of the experience the policy led to an evolution of public opinion and eventual success of the program. After a one-year pilot program in 2006, a referendum to keep the congestion policy permanent overcame an initial negative view and passed. Before the pilot program a poll showed 36 percent favorability, after the pilot the referendum to keep the congestion policy permanent passed with 51.3 percent of inhabitants of the city of Stockholm approving, and a 2011 poll showed more than seventy percent approve the tolls (Winslott-Hiselius et al., 2009; Börjesson et al., 2012). The referendum passed despite some regressive effects of the policy identified by Karlström and Franklin (2009), who assessed the horizontal and vertical equity effects of the Stockholm Trial. Anas and Lindsey (2011) find that road pricing is more likely to be accepted in cities like Stockholm which have good existing public transport since those that do not pay tolls will gain if toll revenues are earmarked towards public transportation.

Congestion is seen as a growing problem in many cities, yet many attempts for congestion pricing on roads and urban areas have failed. Proposals for cordon zones in Manhattan, Chicago, and San Francisco are occasionally considered but never get full interest from politically minded policymakers. San Francisco's demand-response parking pilot program started in 2011 and it used variable (responsive) pricing to manage demand of on-street and off-street parking. The program did achieve some of its intended objectives of decrease occupancy and cars cruising for parking, but the program still has many critics and the acceptability of the program is unknown.[3] However, a November 2014 proposition that changes transportation and parking priorities in San Francisco (Measure L) to prevent policies used by the parking pilot program was rejected by 62.9 percent of voters.[4] The experience in Hong Kong, Edinburgh, and Manchester provides cautionary tales of implementing congestion tolls. Voters in Edinburgh in 2005 and Manchester in 2008 rejected proposals for cordon zone schemes. (Gaunt et al., 2007; Anas and Lindsey, 2011). Gaunt et al. (2007) reviewed self-reported questionnaires and found the principal determinant of voting behavior in Edinburgh was car use. They find that the pricing scheme was seen as too overly complex and that car owners did not understand the potential benefits.

The experience in Hong Kong was similar to the Stockholm experience except the electronic road pricing program was repealed. Despite having a 21-month long trial run starting in July 1983, Hong Kong had several contributing reasons for why their electronic road pricing system failed even though the reported benefit-cost ratio of the policy was a ratio of 14 to

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[3] SFpark Pilot Project Evaluation. June 2014. http://sfpark.org/about-the-project/pilot-evaluation/.

[4] http://www.sfelections.org/results/20141104/. Accessed March 10, 2015

1 (Hau, 1990): a weakening economy, the distributional concerns from some vehicles receiving exemptions, the lack of public outreach, and distrust of government's promise of fulfilling earmarks. Even with the positive objective results from road pricing reducing congestion by time of day and location, the policy could not overcome the hurdle of public acceptability. However, Ison and Rye (2005) find in the literature discussing the Hong Kong experience that the severity of the congestion problem was exaggerated, making for the wrong backdrop to implement a successful policy.

People also have mixed feelings of congestion pricing mechanisms like HOT lanes and responsive pricing for parking. HOT lanes are often touted as "Lexus lanes" for their regressivity. Others believe that increasing the prices of road-use or parking makes the system less fair and equitable. In parking for example, some would prefer a system of underpriced parking where all income groups have a chance to search and find affordable parking.[5] Policymakers sometimes alleviate these concerns at the expense of efficiency by allowing exemptions to some groups. Other officials avoid issues of income inequality created by pricing altogether by having quota policies instead using high occupancy vehicle (HOV) lanes (i.e., carpool lanes) as opposed to HOT lanes. For example, unlike the priced cordon zone in London, the cordon zone in Jakarta, Indonesia, is based on passenger occupancy of the vehicle and not prices.[6]

Equity issues can be addressed with intelligent mechanism design that provides both the right incentives and the allocation of collected revenues achieve desired equitable ends (Levinson, 2010). When discussing comprehensive pricing of roads, Levinson (2010) suggests that

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[5] Leon Neyfakh, "The case for the $6 parking meter," Boston Globe. January 15, 2012.

[6] Sandy Hausman, "Poor Indonesians make money in Jakarta's traffic as jockeys," Public International Radio. September 8, 2011. http://www.theworld.org/2011/09/poor-indonesians-make-money-in-jakartas-traffic-as-jockeys/

revenue recycling offers a way of alleviating adverse equity impacts of drivers having to avoid a toll by switching modes, destinations, or time of day. Many strategies of allocating revenue to relieve inequity and also increasing public acceptability have been suggested (Levinson, 2010). Small and Verhoef (2007) find evidence that British citizens prefer revenue earmarked towards financing public transportation, while people in the U.S. prefer road construction or tax reduction. Eliasson (2009) comments that unlike the predicted theoretical outcomes and the imperfect nature of pricing schemes in practice, the benefits from congestion pricing do not necessarily guarantee they will outweigh the set-up and operating costs.

Public acceptability and opinion may also depend on initial understanding of congestion tolls and public outreach and education. In 2013 the Metropolitan Washington Council of Governments conducted a study using deliberative forums titled: "What Do People Think about Congestion Pricing?" The authors of the study elicited the opinions of 300 people on several types of congestion pricing before and after an information session and a deliberation on congestion problems and current and projected states of transportation funding. Many participants were unaware of how transportation is funded and the current revenue shortfall from the federal gasoline tax not being raised in two decades. This finding provides a glimpse on how people understand and value the problem when accustomed to it. The study found that although acceptability increased after the deliberations (39 percent to 49 percent), negative feelings also increased (29 percent to 33 percent). The actual change was 32 percent of people had neutral feelings towards congestion pricing and that reduced down to 18 percent at the end of deliberations. More information and education about congestion pricing did indeed change acceptability; these stated preferences, however, did not have actual outcomes at stake. The opinions of participants in our experiment, however are incentive compatible, with money at stake.

2.2.2. Experimental Studies. Laboratory experiments–where subjects are compensated based on their performance–provide a low-cost method of collecting data to test congestion theories that would otherwise be infeasible or too costly in the real world. Several laboratory experiments have examined route-choice, mode-choice behavior and how congestion pricing, information disclosure, and a new link in transportation system affect user travel behavior, specifically, testing the Pigou-Knight-Downs, Downs-Thomson, and Braess Paradoxes (Hartman, 2007, 2012; Ziegelmeyer et al., 2008; Selten et al., 2007; Anderson et al., 2008; Denant-Boemont et al., 2009; Morgan et al., 2009; Dechenaux et al., 2013). No laboratory congestion experiments that I know of incorporate voting or measures of public acceptability. However, there are several laboratory experiments that examine factors impacting acceptability of environmental policies (Kallbekken et al., 2011; Cherry et al., 2012, 2013).

Of the experimental literature, the most relevant laboratory congestion experiments on congestion pricing use two-route networks to investigate the Pigou-Knight-Downs paradox.[7] Anderson et al. (2008) and Hartman (2007, 2012) investigate the effects of an efficient toll and information disclosure of past entrants and do find similar results regarding the effect of information and that the toll has their intended effects. Hartman (2006) also examines travel behavior when individuals have heterogeneous preferences. Some experiments using two-route networks are not interested in the effects of pricing but other observations from congestion. For example, Selten et al. (2007) find that route-choice decisions over a long

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[7] Charles Holt provides a publicly accessible classroom experiment that demonstrates the effectiveness of tolling in a congestion/entry game. (http://veconlab.econ.virginia.edu/)

period of time, 200 periods, improve with the presence of information "feedback" on previous road times. Most of these two-route experiments are with subjects with homogeneous values participating in large groups of 12, 15, or 18 subjects. This experiment will have a smaller group (six in a group) and will be first to compare route-choice behavior of heterogeneous individuals with and without a toll.

Recent laboratory experiments examining public acceptability of Pigouvian have provided contributions on the factors that contribute to the (un)acceptability of Pigouvian policies. Cherry et al. (2012) found that experience of a trial run of a Pigouvian tax increases the acceptability of the tax and that the positive experience can overcome misperception and biases. Kallbekken et al. (2011) found that a lack of understanding of the workings and effects of a Pigouvian tax instrument does not influence the opposition of such policies. These experiments also observed Pigouvian tax aversion–opposition to taxes that can increase individual and social welfare. The existence of this aversion challenges the behavioral notion that people act on their own self-interest. This result reveals a barrier in implementing potentially efficient policies. This research contributes by examining personal attributes that may affect acceptability as well have a context where a policy either creates all "winners" or "winners" and "losers" with unequal outcomes. Explaining why someone does or does not vote on their own self-interest by identifying and matching a person's voting behavior and their beliefs motivates this research.

2.3. THEORETICAL MODEL

A two-route congestion model is used where Route A is congestible while the other route, Route B, is not. The travel time of Route A, TT_a, depends on the number of Route A users,

x, and is found by:

$$TT_a = a + bx \tag{1}$$

where a and b are time parameters.

The travel time, TT_b, of Route B is constant at c. The user equilibrium without tolls follows Wardrop's first principle, which states that for a origin-destination (OD) pair all used routes (those with positive flows) should have equal average cost, and there should be no unused routes with lower costs (Small and Verhoef, 2007). That is, the user equilibrium is when the travel times of the two routes are equal. This occurs when the number of Route A entrants equals $x^* = (c - a)/b$. But the user equilibrium is not optimal; there exists a marginal external congestion cost, b, that increases the total travel time of previous Route A entrants that users are not accounting for. The social planner minimizes total travel time, TT, of N users by solving

$$\underset{x}{\text{Min}} \qquad TT = x(a + bx) + (N - x)c \tag{2}$$

The optimal number x^{**} of Route A users is exactly half than the user equilibrium, x^*, where $x^{**} = (c - a)/2b$. This is where the externality or marginal social cost (MSC), b, of each additional user is equal to the time savings of taking Route A over Route B. The marginal private cost is assumed to be zero making the marginal social cost, b, being identical to the the marginal external (congestion) cost. Implementing the optimal toll follows Wardrop's second principle, which states that in a system optimum, all used routes for an OD-pair have identical marginal costs equal to the marginal benefits for that OD-pair, and there are no unused routes with marginal costs lower than this (Small and Verhoef, 2007). The toll is equal to additional travel time Route A users have to pay to achieve the system optimum. By substituting x^{**} in the time savings of using Route A also known as the user's marginal private benefit (MPB), $c - a + bx$, an optimal toll (measured in travel time) of $(c - a)/2$ is obtained.[8]

Putting dollar values on time follows the same theoretical framework and allows for tolls to take on a monetary value and to have users with heterogeneous values of time. With travel time monetized, the social planner then can minimize total social costs rather than travel time. That is, each user's travel time is multiplied by their respective values of time. If using heterogeneous values of time, it is ambiguous what efficient toll to use. It is also ambiguous whether the toll should be based on the group's average value of time or the value of time of the marginal user entering Route A. The toll can take on multiple values as long as it achieves the social planner's objective of obtaining the optimal number (or intended users) of Route A intended users, which minimizes system wide total travel costs.[9] Furthermore, the method and rate of revenue redistribution to individuals may affect their incentives and undermine the social planner's objective.

Having a "small" group of users, where N is less than x^*, with heterogeneous time preferences generates inequitable impacts from the toll. Anderson et al. (2008), Hartman (2007, 2012), and Selten et al. (2007), did not use a "small" group of users and instead used groups larger than the predicted number of users entering the congestible route without a toll, x^*.

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[8] The Hartman (2007, 2012) experiments have a treatment where subjects have to physically wait the extra time.

[9] The marginal external congestion costs of large populations are typically assumed to be convex. The small group environment in the lab makes it difficult to design a transportation system that achieves pure strategy Nash equilibria for both institutions with and without a congestion toll without creating enormous differences in player endowments. Having a non-convex linear marginal external congestion costs function still creates large differences in travel times between Route A and Route B users, but for the purpose of answering the stated research questions, these differences will be unreasonably large if marginal external costs are convex. The current model and experimental design creates conditions sufficient to answer the proposed research questions.

As predicted by the equilibrium condition stated by Wardrop's first principle, users will then x^* users will enter Route A where all users will have the same travel costs. However, by having N users less than x^* ensures welfare impacts of a toll before revenue redistribution and for users to clearly identify and understand the congestion problem since no user will have the incentive to enter Route B without a toll. The experiment uses $N = 6$, $a = 4$, $b = 1$, $c = 12$ as the parameters of the congestion game. The six individuals are split into users with high values of time 12, 11, and 10 tokens per minute and users with low value of time 4, 3, and 2 tokens per minute. These values of times, the congestion toll, and redistribution rates are selected for the intended welfare effects and the existence and uniqueness of pure strategy Nash equilibria both with and without the toll.[10] These parameters create the possible travel time outcomes displayed in Table 2.1. A user's travel cost is then their travel time multiplied by their value of time.

Consider the intuition for the possible travel outcomes detailed in Table 2.1. Without a toll, Route B is always inferior to Route A and all six users will use Route A creating a total travel time of 10 minutes for each of the six users, or 60 total minutes. The theoretical optimal outcome is for four entrants, or for 4 people to use Route A and two to go Route B. However, with the experiment's given values of times for the six participants (2, 3, 4, 10, 11, and 12 tokens per minute), the optimal level is for the three high-value users to use Route A and the three low-value users to use Route B. The user equilibrium yields a total social travel time cost of 420 tokens, while the travel time cost minimizing value is 339. The price of anarchy (the ratio of user equilibrium and social optimal) in terms of travel costs, a

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[10] The predicted pure strategy Nash equilibrium if $N > 8$ is for eight users to enter Route A, however a Nash equilibrium exists in mixed strategies. By having N less than eight ensures a unique pure strategy Nash equilibrium and should allow all individuals have the same experience without a toll.

TABLE 2.1. Possible Travel Time Outcomes (N=6, a=4, b=1, and c=12)

	Total Travel Time (in minutes)	
Number of people using Route A	**Route A**	**Route B**
1	5	12
2	6	12
3	7	12
4	8	12
5	9	12
6	10	12

measure of inefficiency compared to the social optimal is 1.234. This measure states that the theoretical predicted user equilibrium without any intervention is 23.4 percent inefficient.

Figure 2.1 illustrates the two-route problem by showing the marginal benefit and marginal costs for each Route A entrant for heterogeneous users with values of times of 12, 11, 10, 4, 3, and 2 in descending order. Notice the time externality–the marginal social cost increases for each additional user entering Route A. The externality that is imposed on users currently taking Route A is reflected by the decline in the marginal benefit function. Users do not internalize this externality, therefore all six users will use Route A since they will gain positive marginal private benefits. However, to incentivize users in the system to obtain the social optimal, a toll should be placed $50 \geq toll > 16$ ignoring any cost adjustments users may make from revenue redistribution.

In this two-route network with heterogeneous users, an efficient toll reduces total group costs but makes some users worse off. Notice that without any revenue redistribution, the increased costs from a toll paid by those three highest-value users entering Route A is still socially superior in minimizing total costs than the user equilibrium without any toll revenue redistribution. However, the three low-value of time users taking Route B are worse off from the increased travel costs from the longer route. The level of the toll and type of revenue

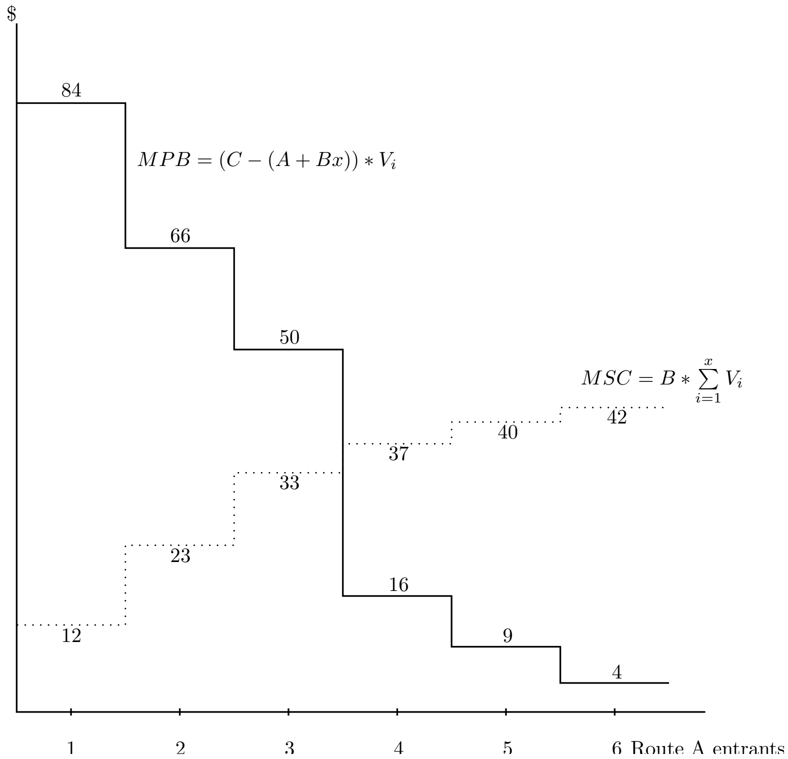

Figure 2.1. Graphical Representation of MPB and MSC

redistribution can compensate some or all of those losses. As described in the next section, I chose a 21-token toll and manipulated the level of lump-sum redistribution (100% or 40%) to obtain the desired welfare effects for addressing the objectives of this study.

2.4. Experimental Design

To answer the three research questions, an environment is designed so that both, route-choice decisions and voting behavior, can be examined. Subjects are assigned to groups of six for the entire experiment, and each subject makes a total of 33 decisions. Table 2.2 summarizes the timeline of the experiment. Subjects participated in three ten-period stages in which they make route-choice decisions. There is no toll in the first stage, while in the second stage a 21-token toll is imposed for those users using Route A. It is up to the group of six to determine whether there will be a toll in the third stage. At the end of the experiment,

Table 2.2. Summary Of Experiment

Vote 1	**Stage 1**	**Vote 2**	**Stage 2**	**Vote 3**	**Stage 3**
	10 Periods		10 Periods		10 Periods
	No Toll		*Toll*		*Toll or no toll*

one of the three stages is randomly chosen to determine the subjects' monetary payoffs. This gives each vote more significance compared to if the monetary outcomes were determined by the sum of the performance of all three stages.

As seen in Table 2.2, participants are given a chance to vote three times to determine what happens in the third stage. The vote elicits an individual's acceptability of a toll before experiencing the congestion problem, after experiencing the congestion problem, and finally after experiencing what happens after the toll. The design emulates the experience in Stockholm 2006, with the second vote resembling the pre-trial olls and the third vote as the equivalent to the after-trial referendum. The first vote, however, tries to gauge an individual's stated preference of an abstract environmental tax (i.e., their "knee-jerk" reaction to an environmental policy). A group's voting outcomes are not revealed until after the third vote is cast. At that time, the experimenter has a volunteer roll a die to determine which of the three votes count for all groups in the session.[11] Each vote is then potentially binding, which provides an incentive-compatible measure of how an individual feels about the toll. Since there are groups of six, a volunteer is asked to pull from a deck of cards to determine what the tiebreaker would be if any group in the session has a 3-to-3 tie for chosen vote. The design mitigates any endogeneity concerns for how an individual performs in Stage 1 and 2; the examination of voting behavior ends after the 20th period with the exception of

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[11] A session's binding stage is chosen using the same process at the entire experiment and after survey questions have been answered.

Table 2.3. Treatments

	Information on how the toll affects individual average costs before 3rd Vote	Information on how the toll affects individual average costs for entire group before 3rd Vote
100% Redistribution (Everyone better off)	8 group of 6 subjects	8 group of 6 subjects
40% Redistribution (Winners and Losers)	8 group of 6 subjects	8 group of 6 subjects

the survey given at the end of the experiment. The third stage exists primarily as a possible binding outcome that can elicit both an individual's stated and revealed preferences.

The experiment follows a 2 × 2 design that varies the welfare impacts of the toll and the disclosed information of the effect of the toll. As shown in the theoretical section, the level of the toll and the redistribution rate can vary to achieve intended welfare effects of the toll (see Table 2.3). There exists two settings: one where all participants are better off and are all "winners" with the toll (100% toll revenue redistribution) and another where there are "winners" and "losers" of the toll (40% toll revenue redistribution). To motivate research questions on voting behavior, a treatment varies the information that is disclosed immediately before the third vote. In one session the individual sees their average total costs of Stages 1 and 2 and the percentage change in costs, in the other they see their cost information as well as the same information for all six individual group members ranked by highest cost reduction. Observing varying outcomes of other members of the group may entice some individuals to value their experience differently and vote counter to what they otherwise would have.

The earnings of individuals depend on their decisions and their value of time. Each individual is privately provided their endowment for that period. However, the language in the experiment focuses on (adjusted) cost reductions rather than changes in earnings. Most of the discussion of congestion pricing is on the reduction in costs and not on the increase in consumer surplus or earnings.

Table 2.4 reports the net earnings calculations without the toll and the theoretically predicted welfare effects by individual values of time and redistribution rates. These welfare impacts assume rational agents and are the differences in net earnings when comparing the Nash equilibria with and without the 21-token toll. Note that without a toll, all earnings are the same for all individuals and the welfare impacts with the toll are not perfectly correlated with an individual's value of time. Individuals with the lowest values of time are not the worst off with a toll. Although the experiment's model considers value of travel time preferences and not schedule delay preferences, van den Berg and Verhoef (2011) find that with heterogeneity in value of schedule delays the welfare impacts of first-best pricing are not perfectly correlated with value of time; welfare impacts depended on relative values of schedule delay and travel time preferences. Similar to this model's prediction, they find that those with intermediate values of times were the worst off.

Table 2.4 suggests that self-interested individuals should always vote for the toll when there is 100% redistribution since everyone gains, while in treatments with 40% redistribution the individuals with a value of 3 and 4 tokens per minute should always vote against the toll. The level of the toll and the given parameters were selected because of their specific welfare effects as seen in Table 2.4 and to observe how sensitive individuals are to them.[12]

The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007). Subjects are given and read aloud the Instructions that also had practice questions

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[12] Parameters where individuals had a value of time of 10, 9, 8, 4, 3, and 2 tokens per minute and toll of 24 tokens with a one-third redistribution rate or to have a higher toll of 28 tokens for the current experiment was considered. The current experiment's parameters of value of time of 12, 11, 10, 4, 3, and 2 tokens per minute and a toll of 21 tokens with a two-fifths redistribution rate was selected because of their more interesting inequality effects. All these parameters achieve a binding toll that obtains cost-minimizing social costs.

Table 2.4. Individual Welfare Effects From The Toll (In Tokens)

		Effect on costs				**Effect on earnings**			
Value of time	**Endow-ment***	**Cost w/o toll**	**Cost (No redist.)**	**Cost w/ toll (40% redist.)**	**Cost w/ toll (100% redist.)**	**Earn-ings w/o toll**	**Earn-ings w/ toll (No redist.)**	**Earn-ings w/ toll (40% redist.)**	**Earnings w/ toll (100% redist.)**
12	**145**	120	105	100.8 (-16.0%)	94.5 (-21.3%)	25	40	44.2 (+76.8%)	50.5 (+102%)
11	**135**	110	98	93.8 (-14.7%)	87.5 (-20.5%)	25	37	41.2 (+64.8%)	47.5 (+90%)
10	**125**	100	91	86.8 (-13.2%)	80.5 (-19.5%)	25	34	38.2 (+52.8%)	44.5 (+78%)
4	**65**	40	48	43.8 (+9.5%)	37.5 (-6.3%)	25	17	21.2 (-15.2%)	27.5 (+10%)
3	**55**	30	36	31.8 (+6.0%)	25.5 (-15.0%)	25	19	23.2 (-7.2%)	29.5 (+18%)
2	**45**	20	24	13.5 (-1.0%)	19.8 (-32.5%)	25	21	31.5 (+0.8%)	25.2 (+26%)

*Participants are unaware of the endowment values of other individuals in their group.

that emphasized the possible outcomes of route-choice decisions and the congestion problem. To prevent anchoring, no question showed a positive (or negative) individual welfare impact of the toll.[13] At the beginning of the experiment individuals knew their endowment, their value of time, and how their value of time compared to the values of other group members. All subjects knew that these values would not change throughout the entire experiment.

In each period of a stage, subjects were asked which route to take: Route A or Route B. Before each decision, subjects were provided the possible time outcomes listed in Table 2.1 as well as their private travel costs without considering a toll for each possible outcome, and, if applicable, the level of the toll and redistribution rate. After a decision is made, subjects received feedback on which route they took, the number of Route A users, their travel time, and their travel costs for that period, and if applicable, the period toll revenue generated, their share of toll revenue, and adjusted travel costs after redistribution. Subjects were also given the option to see their history of previous decisions and number of entrants of Route A

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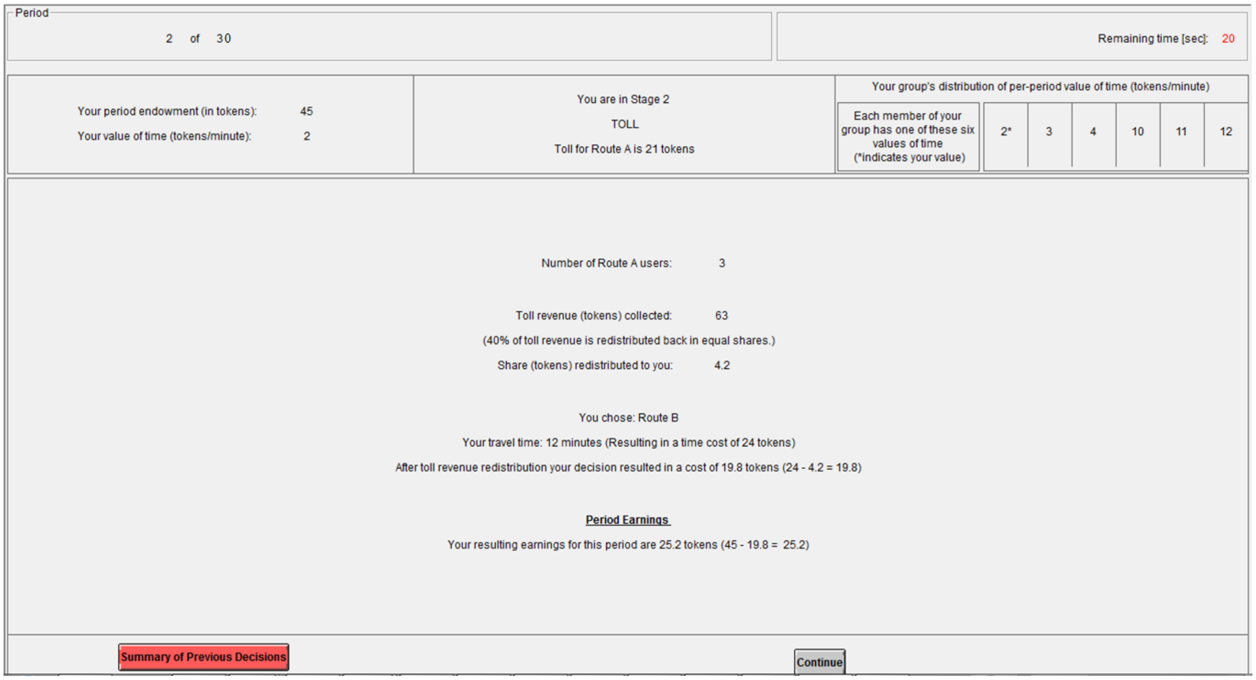
[13] A copy of the Instructions for the 100% revenue redistribution treatment is provided in Appendix A.4.



2 of 30

Your period endowment (in tokens): 45
Your value of time (tokens/minute): 2

You are in Stage 2
TOLL
Toll for Route A is 21 tokens

Your group's distribution of per-period value of time (tokens/minute)						
Each member of your group has one of these six values of time (*indicates your value)	2*	3	4	10	11	12

Number of Route A users: 3

Toll revenue (tokens) collected: 63
(40% of toll revenue is redistributed back in equal shares.)
Share (tokens) redistributed to you: 4.2

You chose: Route B
Your travel time: 12 minutes (Resulting in a time cost of 24 tokens)
After toll revenue redistribution your decision resulted in a cost of 19.8 tokens (24 - 4.2 = 19.8)

Period Earnings
Your resulting earnings for this period are 25.2 tokens (45 - 19.8 = 25.2)

FIGURE 2.2. Screenshot Of Route-Choice Decision Feedback

entrants (see Figure 2.2). Anderson et al. (2008) found that providing information disclosure on previous entrants during a period allowed for more stable equilibria. Selten et al. (2007) find that information feedback on the previous period slightly reduced variation around the equilibrium. Following the Börjesson et al. (2012) flow chart in Figure 1.1 from Chapter 1, the aim of this study is to observe the evolution of public acceptability of toll over time given the toll has its intended objective effects on route-choice decisions.

Subjects participate in three referendum votes; each vote elicits the acceptability of toll before and after being accustomed of the congestion problem and the implementation of a toll. The first vote occurs after the Instructions are read and subjects are given their endowed values. The congestion problem of what happens when an additional person uses Route A is objectively explained as well as shown in the instruction's practice problems.

The Instructions state that the toll is set at a level that optimizes the use of Route A.[14] The redistribution rate is also stated in the Instructions. The experimenter suggests subjects consult Table 2.1 (given in the Instructions and shown on the laboratory projector) of possible travel time outcomes before their first vote. Subjects discover the level of the toll at the first referendum vote as well as their endowed values: value of time and where their value of time is distributed among the group of six the level of the toll. Since before the third vote individuals are provided information, the treatment with the ranked group information also displays performance based on values of time. By having subjects know the size of their value of time relative to the values of the group members throughout the entire experiment, subjects are then reacting to the performance information rather than a discovery of the heterogeneous information of the value of times of the other group members.

If all subjects acted as if they had perfect knowledge of the game, any simulated route-choice decisions and votes would be obvious since all would have knowledge of Table 2.4. However, this experiment resembles the Stockholm experience and provides a controlled environment to examine how personal characteristics and experience (accustomation and performance measures) affect feelings toward an environmental tax.[15] The results may provide policymakers an idea of the barriers to public and political acceptability of a toll on whose opinions are worth targeting and communicating before the implementation of a toll and which individuals are positively or negatively affected after tolls are implemented.

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[14] "Optimize throughput at free-flow speeds" was language used for explaining the toll policy goals of California 91 Express Lanes in Orange County. The Orange County Transportation Authority. http://www.91expresslanes.com/policies.asp. Accessed March 24, 2014.

[15] The laboratory setting is absent of any partisan political language and anchoring, and also does not include geographical preferences. Someone living outside a tolled zone would be expected to have a different voting preference than someone inside a tolled zone living in a central business district.

2.5. Results

In April 2014, 192 undergraduates from Colorado State University were recruited from Principles of Economics courses, yielding 32 group observations of 30 periods and 6336 total individual experimental observations including 576 voting observations (192 for each of the three votes). A session lasted seventy-five minutes and the average compensation was $18.74 with a range of $11.75 to $30.25. One token in the experiment equals $0.06. Eight groups of six subjects participated in each of the four treatments. The average age was 19.3 with 93 females participating. At the end of the experiment, all subjects answered a survey that elicits demographic information and beliefs on several dimensions. The data are used to answer three research questions investigating the performance of the toll and whether the effect of accustomation can predict the acceptability of the toll.

2.5.1. Question 1: Does congestion pricing (a toll on a congestible route) work in the lab?

The objective of the toll is to reduce the number of entrants of Route A users to only three, with those three entrants being the individuals with the highest values of time. Recall that the toll incentivizes the low-value users to use Route B to minimize their travel time costs. Without the toll, all six individuals should enter Route A, since as was seen in Table 2.1, a travel time of 10 minutes is always less than 12 minutes. Table 2.5 reports the average number of Route A entrants and percentage entering Route A by type of individual (all individuals, individuals with high values of time–those that should use Route A regardless, and individuals with low values of time–those that should switch to Route B with a toll) for the three 10-period stages. The average number of Route A entrants in Stage 1 without a toll is near 6 with an average of 5.61 entrants. The same is true for those groups who self-selected to not have a toll in Stage 3 and which have an average of 5.88 Route A entrants. The stages with a toll reduced the number of Route A entrants. In Stage 2 the average number of entrants is 3.62 and in Stage 3 those groups that self-selected to have a toll have an average of 3.54 entrants.

Table 2.5 also reports statistical significance of two-sample mean tests, which measure if the samples of two stages are statistically different. The declines in Route A entrants are statistically significant when comparing Stage 1 and Stage 2 and the endogeneous treatment in Stage 3. Note that the optimal number of Route A users that minimizes total travel time is four users, but with the heterogeneous values the travel-cost-minimizing level is when the three highest-value users enter Route A. The reported average numbers of Route A entrants with and without a tolls shows that despite some noise subjects mostly behaved according to theoretical predictions. Subjects could be still learning the game in the early periods of a stage and their best response or the noise could also be from idiosyncratic behavior such as altruism.[16]

The results do indeed show that the users with the lowest value of time use Route A less intensely with a toll. The average percentage of times an individual entered Route A are reported in Table 2.5. The users with the lowest values of time shift to Route B when there is a toll and the result is more apparent when comparing the endogenously selected no toll and toll cases in Stage 3. In Stage 2, the users with the lowest value of time enter Route A 31.4% of the time, but when examining the last five periods of Stage 2, the percentage of those users entering Route A drops to 21.5%. As expected, users with the highest value of

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[16] Indeed, when focusing on the last five periods of a stage the results are closer to the theoretically predicted outcomes. In regards to the idiosyncrasies of subjects, one subject in the 40% redistribution and no ranked information treatment who had a value of time of 2 tokens per minute left the following comment regarding their strategy: "I made most of my decisions based on the idea that I wanted to make money myslef (sic) but understood that when other[s] sacrificed, I gained. So i (sic) tried to make decsions (sic) for myself about 70% of the time and help others on the other 30%." This type of altruistic behavior greatly benefited the group; this person took the longer route at an additional travel cost of 4 tokens ($0.24) while benefiting the other five in Route A by 40 tokens ($2.40).

Table 2.5. Number Of Route A Entrants And Percentage of Individuals Entering Route A

Population	No Toll (Stage 1)	Toll (Stage 2)	No Toll (Stage 3)	Toll (Stage 3)
Total entering Route A (out of 6)				
Group of 6	5.61 (320 obs.)	3.62*** (320 obs.)	5.88 (80 obs.)	3.54*** (240 obs.)
Percent Entering Route A				
All Individuals	93.50% (1920 obs.)	60.4%*** (1920 obs.)	97.90% (480 obs.)	59.0%*** (1440 obs.)
Low Value (2,3,4)	92.90% (960 obs.)	31.4%*** (960 obs.)	99.20% (240 obs.)	21.4%*** (720 obs.)
High Value (10,11,12)	94.20% (960 obs.)	89.4%***,^^^ (960 obs.)	96.7%^ (240 obs.)	96.7%^^^ (720 obs.)

Two-sample t-tests: ***, **, *, represent that when comparing samples across (single border) columns of either Stage 1 and Stage 2 or within Stage 3 samples of a given population are statistically different at the 1%, 5%, 10% level, respectively; ^^^, ^^, ^, represent that when comparing samples across adjacent (single border) rows of Low Value and High Value individuals for a given stage are statistically different at the 1%, 5%, 10% level, respectively.

time entered Route A almost every time, roughly greater than or equal to ninety percent of the time across all three stages. The results suggest that individuals had similar experiences without the toll and that the toll achieved most of the objectives of changing group behavior.

The efficiency, or lack thereof, of the controlled transportation system by redistribution rate can be measured using what is referred to as the price of anarchy (Skinner and Carlin, 2013). The price of anarchy is a ratio of user equilibrium to the social optimal of travel times or travel costs. As was seen in Section 2.4, the social optimal of $x^{**} = 3$ when the three entrants have the highest value of time yields a minimized social time cost of 339 tokens. The predicted user equilibrium without a toll is 420 tokens, therefore the theoretically predicted price of anarchy is 1.239. The system will be efficient if the user equilibrium is 339 resulting in a price of anarchy of 1. Table 2.6 gives the average price of anarchy by redistribution rate. That is, when there is a toll the theoretically predicted price of anarchy for 100% redistribution is 1 while with 40% it is 1.112. Since 60% of the toll revenue

TABLE 2.6. Measures of Inefficiencies Using The Price of Anarchy

Social Optimal (SO)=339 (Parentheses: SO with 40% redistribution of toll = 376.8)	**No Toll (Stage 1)**	**Toll (Stage 2)**	**No Toll (Stage 3)**	**Toll (Stage 3)**
All	1.218	1.143***	1.235	1.116***
100% Redistribution	1.226^^^	1.087***,^^^	1.234	1.064***,^^^
40% Redistribution	1.210 (1.088)	1.200 (1.079)	1.235 (1.111)	1.161*** (1.044***)

- Two-sample t-tests: ***, **, *, represent that when comparing samples across (single border) columns of either Stage 1 and Stage 2 or within Stage 3 samples of a given population are statistically different at the 1%, 5%, 10% level, respectively; ^^^, ^^, ^, represent that when comparing samples across adjacent (single border) rows of redistribution rates for a given stage (not in parentheses) are statistically different at the 1%, 5%, 10% level, respectively.
- Values without parentheses are measures relative to the predicted social optimal at total cost of 339 tokens. Measures in parentheses assumes a higher social optimal considering the minimum possible system cost of a system with a toll with 40% redistribution, 376.8.

is leaving the system the outcome is perceived as inefficient. However, as seen in Table 2.6, and to not account for the 60% loss of revenue, a second price of anarchy measure of the 40% redistribution rate is provided which uses a social optimal value of 376.8 tokens instead. The experiment never identifies where the revenue is allocated other than the rate of redistribution to the subjects. Small and Verhoef (2007) mention studies that revenue allocation being identified as a key determinant of the acceptability of congestion pricing.

As seen in Table 2.6, the toll improves the efficiency of the transportation system with the greatest improvement being observed when 100% of the toll revenue is allocated. The improvement in efficiency is smaller with 40% redistribution which can be explained by welfare leaving the system.[17] Assuming that revenue for the 40% case will be eventually redistributed back to society, the outcome can be viewed as achieving a similar efficiency improvement as the 100% redistribution rate. Although the average results do not show

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[17] Theoretically, any method of reallocating the toll revenue will achieve the same group travel time outcome since these are transfer payments from the experimenter to users. Yet the method of relocation and which group receives the transfer payments may affect the acceptability of the toll. Additional treatments could examine the acceptability of the toll by different redistribution targeting across users.

that the toll achieved the most efficient outcome on average (all price of anarchy measures are statically different than 1), the improvement in efficiency of the system across both redistribution rates should affect users' acceptability, measured in votes, after experiencing system with and without the toll.

Answer to Research Question 1: The toll improves social efficiency in the lab by adequately reducing Route A entrants to those users with the highest value of time.

2.5.2. QUESTION 2: DOES EXPERIENCE INFLUENCE ACCEPTABILITY? Subjects participate in three referendum votes; each vote elicits the acceptability of toll before and after being accustomed of the congestion problem and implementation of a toll. The first vote occurs before any route decisions are made and gauges their initial taste of a toll given the redistribution rate and the subject's exogenously imposed value of time. This vote occurs after the Instructions are read. The congestion problem of what happens when an additional person uses Route A is explained as well as a practice problem also re-emphasizes the congestion problem.[18]

Before casting their first vote, the subject is given information regarding their value of time and how that value of time is distributed among the group of six, the level of the toll, and the redistribution rate. The redistribution rate is also stated in the Instructions. Before

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[18] None of the practice questions asked how a toll would affect a user's costs. A question on the effect of the toll could show an individual either worse off, better off, or indifferent with a toll. Not including a toll question eliminated the possibility of anchoring a subject's opinion by eliminating the exercise of them manually comparing the welfare effects of the toll. Given a subject's value of time, their distribution among their group, the redistribution rate, I wanted their vote to elicit their subjective opinion of tolls. Regarding the description of the congestion problem, the Instructions state: "As was shown in [Table 2.1], each additional user of Route A increases the travel time for everyone else using Route A. For example, the travel time for everybody when three people use Route A is 7 minutes per person. If instead four people use Route A, then the fourth person increases the travel time for each of the original three people from 7 minutes per person to 8 minutes per person (and this fourth person also has a travel time of 8 minutes). In other words, by choosing Route A instead of Route B, this individual increases the total travel time of those three people in Route A by 3 minutes (1 minute each)."

the first vote, the experimenter suggests subjects consult Table 2.1 that is in the Instructions and is displayed on the lab's projector that reports the possible travel times outcomes.

If subjects were given perfect information on the objective effects of the toll on their earnings, profit-maximizing individuals in the 100% redistribution should unanimously be in favor of the toll while the individuals in the 40% redistribution rate with value of times of 3 and 4 tokens per minute should be opposed to the toll. Because of this treatment effect, subjects are placed in one of three groups depending on their values of time: strictly better off (values of times of 10, 11, 12), weakly better off (value of time of 2), and mixed (value of times of 3 and 4). Table 2.7 reports the approval percentage by individual's value of time and the redistribution rate treatment. Table 2.7 also displays the theoretically objective effects of the toll on costs and earnings as well as the actual average percentage change in costs by an individual's value of time. Focusing on the first vote, their appears to be no noticeable pattern on voting sensitivity by redistribution rate and an individual's value of time. Surprisingly, individuals in the 40% treatment appear to be were more likely to vote in favor of the toll compared to those individuals in the 100% treatment. For example, the individuals with the highest value of time, 12 tokens per minute, who have the most at stake regarding the imposition of the toll were not in favor of the toll initially in the 100% redistribution treatment with 37.5% voted in favor. The lack of self-interest observed in the first vote by all individuals and whether individual attributes predict voting behavior is explored in Research Question 3.

The second and third votes help measure the evolution of an individual's acceptability after experiencing the congestion problem and after experiencing a toll that mitigates the congestion problem. Since the group's voting outcomes are not revealed until after the final

TABLE 2.7. Approval Percentage of Each Vote By Predicted Outcomes Over Individual's Value of Time

Value of time	**2**		**3**		**4**	
Redistribution Rate	**40%**	**100%**	**40%**	**100%**	**40%**	**100%**
Predicted Change in Earnings	0.80%	26%	-7.20%	18%	-15.20%	10%
Predicted Change in Costs	-1%	-32.50%	6%	-15%	9.50%	-6.30%
Actual Change in Costs	*13.60%*	*-29.60%*	*10.90%*	*-8.10%*	*15.10%*	*-5.50%*
Vote 1	56.30%	37.50%	50%	50%	56.30%	50%
Vote 2	68.80%	43.80%	56.30%	43.80%	68.80%	62.50%
Vote 3	37.50%	87.50%	12.50%	75%	12.50%	75%

Value of time	**10**		**11**		**12**	
Redistribution Rate	**40%**	**100%**	**40%**	**100%**	**40%**	**100%**
Predicted Change in Earnings	52.80%	78%	64.80%	90%	76.80%	102%
Predicted Change in Costs	-13.20%	-19.50%	-14.70%	-20.50%	-16%	-21.30%
Actual Change in Costs	*-3.60%*	*-9.20%*	*-4.60%*	*-12.20%*	*-5.50%*	*-11.70%*
Vote 1	62.50%	62.50%	68.80%	56.30%	56.30%	37.50%
Vote 2	62.50%	75%	62.50%	50%	68.80%	75%
Vote 3	93.80%	81.30%	62.50%	81.30%	81.50%	81.30%

Value of time	**ALL**		
Redistribution Rate	**40%**	**100%**	**ALL**
Predicted Change in Earnings	28.80%	54.00%	41.40%
Predicted Change in Costs	-10.30%	-19.30%	-14.80%
Actual Change in Costs	*-0.80%*	*-11.30%*	*-6.10%*
Vote 1	58.30%	49.00%	53.60%
Vote 2	64.60%	58.30%	61.50%
Vote 3	50%	80.20%	65.10%

vote, each vote discloses an individual's sole acceptability of the toll independent of the favorability of the other group members. The opinions of other individuals have no influence on the individual's voting behavior.[19] The reported results in Table 2.7 show an increase

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[19] In Stockholm, it is suggested that the referendum vote that passed the imposition of congestion tolls fell on party lines. The design of this experiment wanted to keep a controlled environment that kept political party affiliation absent in the experiment. A possible treatment exploration is to examine whether the inclusion of political party affiliation to favorability of the toll in the text of the referendum vote influences voting behavior.

in favorability of the toll, even for the two individuals in the 40% redistribution treatment where these individuals are made worse off once the toll is introduced. Across all treatments, the percentage voting in favor of the toll increased from 56.3% in the first vote to 61.5% in the second vote. Perhaps the individuals now voting in favor of the toll experienced the noticeable difference in travel costs and gains to the system when comparing outcomes of a period when at least one subject took Route B with a period when everyone went Route A. Such an observation would make both the problem and the described effect of the toll more salient.

The third vote captures the acceptability of the toll after users are accustomed to the problem with and without the toll and with disclosure on objective measures on how the toll affected costs.[20] This vote helps reveal an individual's subjective value on the toll's objective effects. Some of the subjects see additional information that shows the ranked information of other individuals in their group. Table 2.7 compares the predicted change in costs to the average actual change in costs by individual. Subjects noticeably did not minimize total costs, but as seen in the discussion of the result of the first research question, the toll did achieve the intended reduction of Route A users that created varying welfare effects. Shown in Table 2.7 and Figure 2.3, these observed and experienced effects noticeably affected the third vote.

Due to the shorter travel times, the toll allowed the higher-time-value subjects to enjoy lower travel costs despite payment of a toll, while the lower-time-value subjects were either made better or worse off by taking the longer Route B depending on the redistribution rate. As seen in Table 2.7, all individuals that expected an increase in earnings, with the exception

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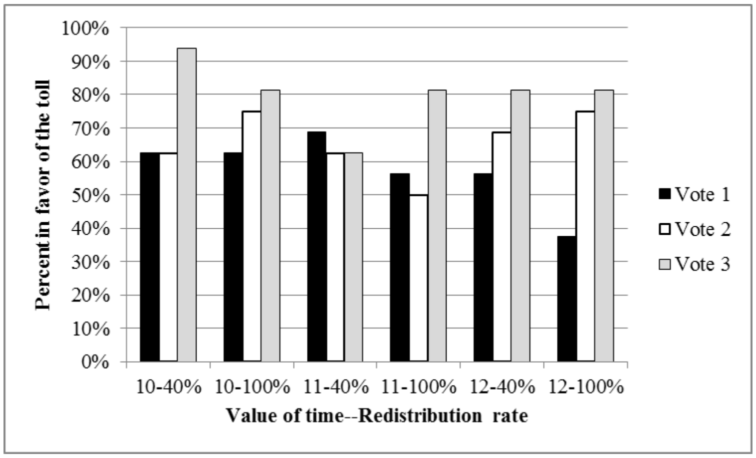
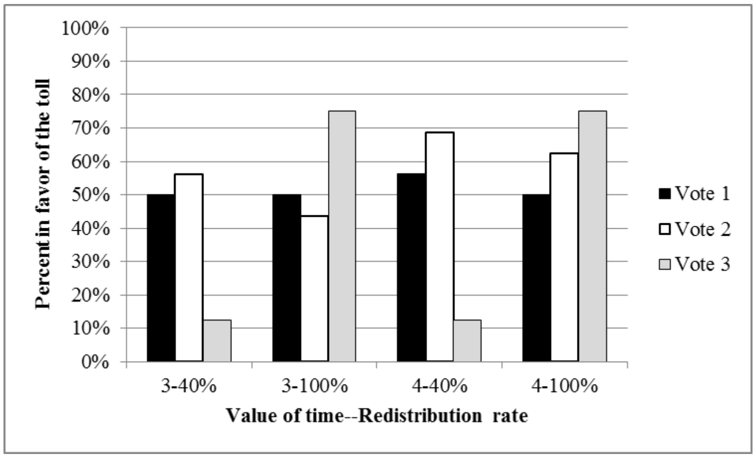
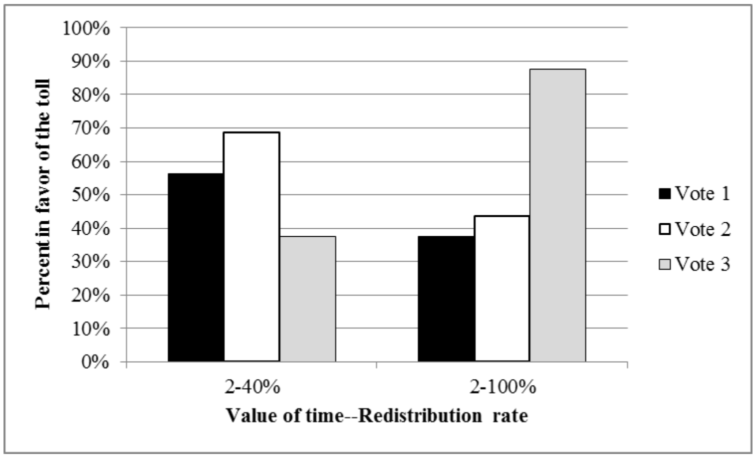
[20] Recall that before the third vote subjects are shown information that compares their average total costs of the first two stages and the percent change in costs.



(A) Strictly-Better-Off Group (Value Of Time: 10, 11, 12)



(B) Mixed Group (Value Of Time: 3 and 4)



(C) Weakly-Better-Off Group (Value Of Time Of 2)

FIGURE 2.3. Approval Rates Across Three Votes By Sub-Sample And Redistribution Rate

of people with a value of time of 11 tokens per minute in the 40% redistribution treatment, were more likely to vote for the toll in the third vote.[21] Notice that those that were predicted to be harmed by the vote (the individuals in the 40% redistribution treatment with a value of time of 3 and 4) dropped their favorability of the toll to 12.5% approval. The toll for the lowest-time-value user in the 40% redistribution treatment, on average, actually increased their costs instead of an expected decline of 0.8 percent. Their favorability of the toll at the end is 37.5%. A noticeable difference in favorability of the toll is observed between redistribution rates: 80.2% favored the toll with 100% redistribution and 50% voted for the toll in the 40% treatment (see Table 2.7).[22]

The evolution of voting behavior by sub-sample (individuals in the strictly-better- off, weakly-better-off, and mixed groups) is displayed in Figure 2.3. Figures 2.3b and 2.3c show large differences in approval ratings between the same individual across the redistribution treatment. The majority of the individuals with a value of time of 2 (weakly better off) did not vote in favor of the toll in the 40% redistribution treatment since most were actually made worse off the toll (see Table 2.7; the average cost increase in this group was 13.6%). Although the theoretical prediction is for these individuals not to be worse off, this result suggests that the nature of the experience of the toll matters in determining acceptability. The nature of the experience depends on the individual and the decisions made by other members in the group.

The full experience of being accustomed and obtaining an objective measure of the congestion problem with and without the toll appears to matter; however, not all individuals

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[21] Some subjects communicated their new found appreciation of the effect of the toll. In the 100% treatment, a subject with a value of time of 10 tokens per minute commented in realization that they could have been the decisive vote since only two in their group voted in favor of the toll and the tiebreaker would have chosen a toll for the third stage: "Due to the tiebreaker, I wish that I had voted for the toll earlier to maximize my token amount."

[22] Appendix A.3 reports hierarchical voting decision trees by treatment sample.

voted in their self-interest. Research question three asks, when controlling for how accustomation and nature of the experience, whether individual attributes including reaction to the ranked information treatment predicts voting behavior.

Answer to Research Question 2: Experience and accustomation of the congestion problem with and without the toll matters; self-interest appears to be a major determinant on the opinion of the toll.

2.5.3. QUESTION 3: DO INDIVIDUAL ATTRIBUTES DETERMINE THE ACCEPTABILITY OF TOLLS AND DOES THIS ACCEPTABILITY EVOLVE WHEN AN INDIVIDUAL BECOMES ACCUSTOMED TO THE PROBLEM AND POLICY?

The observation in the previous section of not everyone voting in their own self-interest, even after being disclosed an objective measure of the effects of a toll for the third vote, suggests individual beliefs and attitudes may be a factor in determining acceptability. Understanding how and when these personal attributes affect the evolution of acceptability of a policy may make the obstacles more clear for policymakers when implementing acceptable and efficient congestion mitigation instruments. For many constituents, attitudes might be sensitive to feelings of government intervention, equity concerns, altruism, feelings toward the environment, and political ideology. This section will test hypotheses relating to prediction of voting behavior controlling for beliefs, accustomation of the problem and policy, and the nature of the experience.

After the experiment, subjects participate in a survey that elicits measures of their beliefs as well as their demographic information. The question is whether these measures as well as the treatment that shows the group's ranked information on the effect of the toll predicts voting behavior. The survey questions were based on research from Kahan et al. (2011)

on how individualism and hierarchy affect opinions on scientific evidence, questions of environmental concerns measured on the New Ecological Paradigm (NEP) Scale, and questions measuring altruism using aspects of the Schwartz's model (Kotchen and Moore, 2007), and political ideology questions regarding economic and social issues.

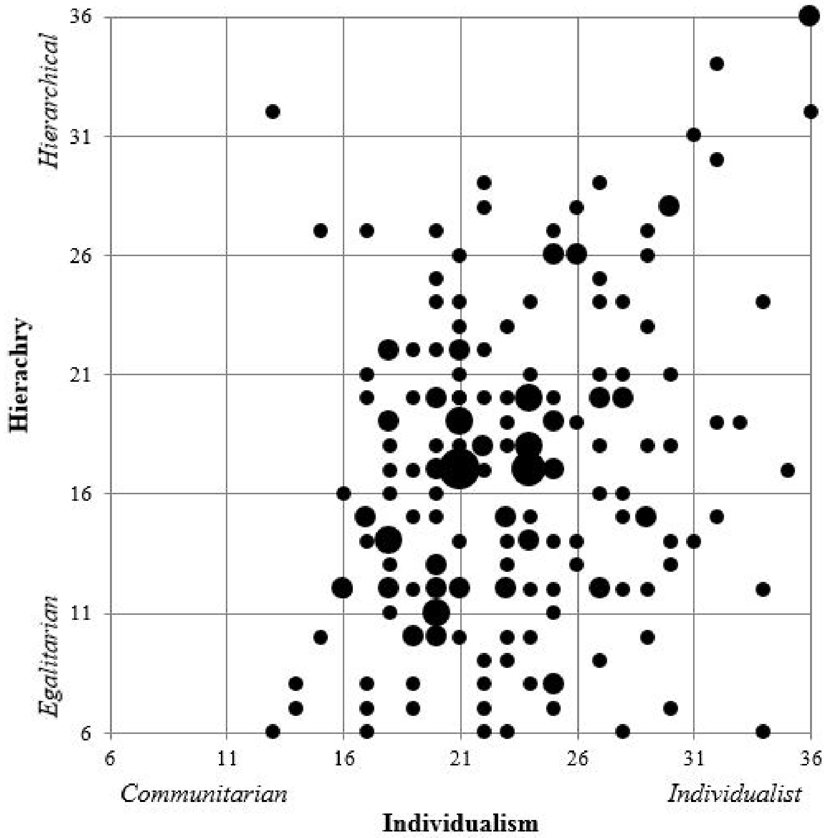
Kahan et al. (2011) measures individual worldview across two dimensions: hierarchy-egalitarianism and individualism-communitarianism. Six individual statements (individualism-communitarianism) focus on "attitudes toward social orderings that expect individuals to secure their own well-being without assistance or interference from society versus those that assign society the obligations to secure collective welfare and power to override competing individuals interests" (Kahan et al., 2011). And six hierarchical statements (hierarchy-egalitarianism) capture the "attitudes toward social ordering that connect authority to stratified social roles based on highly conspicuous and largely fixed characters such as gender, race, and class" (Kahan et al., 2011). Subjects indicate the extent that they agree with each of the statements using a six-level Likert scale which are translated to a score of 1 to 6 on their level of agreement towards a worldview. The sum of scores for each of the statements places their views on the respective hierarchy-egalitarianism and individualism-communitarianism spectrums (6 to 36). These worldview measures may help explain voting behavior.

Table 2.8. General Measures Of Beliefs

	Average	**Standard Deviation**	**Median**	**Range**
Individualism (6-36) **(higher value implies more individualistic)**	23.22	4.81	23	13-36
Hierarchy (6-36) **(higher value implies more hierarchical)**	17.13	6.47	17	6-36
Altruism (5-25) **(higher value implies more altruistic)**	17.27	3.36	13	5-25
NEP (5-25) **(higher value implies more concern for the environment)**	19.73	3.37	16	8-25
Stated Ideology (Economic Issues) **(1=Very Liberal; 5=Very Conservative)**	3.08	0.92	3	1-5
Stated Political Ideology (Social Issues) **(1=Very Liberal; 5=Very Conservative)**	2.73	1.07	3	1-5

Subjects' environmental concerns, altruistic values, and political ideologies were also included. Using a five-point scale, subjects were asked whether they agree or disagree with a series of five statements based on the Schwartz model of altruistic behavior (Kotchen and Moore, 2007). Similarly, subjects indicated their concern for the environment using the same five-point Likert scale with a series of five statements based from the New Ecological Paradigm (NEP) Scale (Kotchen and Moore, 2007). The responses for each set of respective statements can be summed to obtain measures of general concern for the environment and altruism (5-25). Finally, subjects were asked to state their political preferences on a liberal and conservative spectrum (1=Very Liberal, 2=Liberal, 3=Moderate, 4=Conservative, 5=Very Conservative) on social and conservative issues.

Table 2.8 reports the averages of the general attitudes and worldviews. The combined individual Kahan measures of individualisms and hierarchy are illustrated in Figure 2.4 and shows that the subjects had more individualistic feelings and were diverse on their opinions on hierarchy. Similar to Kahan et al. (2011) and Cherry et al. (2013), the hierarchy and individualism dimensions are combined where people that score above the median in



Note: densities of individuals (small mark=1 subject, largest mark=5 subjects)

FIGURE 2.4. Correlation Of Kahan et al. (2011) Worldview Scores

both dimensions are defined as Hierarchical-Individualist and those that scored below the median in both dimensions as Egalitarian-Communitarian.[23] The statements are reported in Appendix A.2.

A probit model with clustered errors by subject and instrumental variables is used on the panel data to estimate the effects of these personal attributes on voting behavior (Maddala, 1983; Cameron and Trivedi, 2005).[24] The panel data entails 192 individuals, i, voting 3 times, t, totaling 576 observations. The errors are clustered by subject since each individual

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[23] Cherry et al. (2013) extend these definitions further where subjects that scored in the top quartile of the Hierarchy and Individualism measures are additionally defined as Hierarchical and Individualist, respectively, while those that scored in the bottom quartile of each measure are defined as Egalitarian and Communitarian.

[24] In the literature examining voting and group behavior in the laboratory, Kallbekken et al. (2011) utilize a conditional logit model where two of the five have a random-effects specification and Cherry et al. (2012) employ a linear probability model with a random-effects specification.

makes three votes over time. The probability model is as follows:

$$
\begin{aligned}
Vote_{it} = {} & \beta_0 + \beta_1 HierarchicalIndividualist_i \\
& + \beta_2 EgalitarianCommunitarian_i + \beta_3 Altruism_i + \beta_4 NEP_i \\
& + \beta_5 Vote2_t + \beta_6 (Vote2_t \times HierarchicalIndividualist_i) \\
& + \beta_7 (Vote2_t \times EgalitarianCommunitarian_i) \\
& + \beta_8 (Vote2_t \times Altruism_i) + \beta_9 (Vote2_t \times NEP_i) \\
& + \beta_{10} Vote3_t + \beta_{11} (Vote3_t \times HierarchicalIndividualist_i) \\
& + \beta_{12} (Vote3_t \times EgalitarianCommunitarian_i) \\
& + \beta_{13} (Vote3_t \times Altruism_i) + \beta_{14} (Vote3_t \times NEP_i) \\
& + \beta_{15} (Vote3_t \times \widehat{Experience}) + \beta_{16} (Vote3_t \times RankTrmt_i) + \epsilon_{it}
\end{aligned}
\tag{3}
$$

A binary dependent variable, $Vote_{it}$, is used where a "yes" vote equals 1 and 0 otherwise for each i individual for one of the three votes, t. The independent variables consist of controls for the timing of the vote or accustomation of the problem or policy, and treatment effects that occur in the third vote. The following is a list of variables and their definitions:

- $Vote2$– "Vote is second of three votes–subject is accustomed to the problem (0 or 1)"
- $Vote3$ – "Vote is the third of three votes–subject is accustomed to the problem and toll policy (0 or 1)"
- $Experience$ – "An objective measure of the percentage change in individual average costs between stage one and stage two. (-47.7 to 29.2)"
- $RankTrmt$ – "Whether third vote occurs in the group ranked information treatment – Subjects saw the effect of toll on all group members' costs. (0 or 1)"

- *HierarchicalIndividualist* – "Above median of both Individualism and Hierarchy measures (0 or 1). On a scale of 6 to 36 Individualism measures attitudes toward social orderings that expect individuals to secure their own well-being without assistance or interference from society versus those that assign society the obligations to secure collective welfare and power to override competing individuals interests. On a scale of 6 to 36 Hierarchy measures attitudes toward social ordering that connect authority to stratified social roles based on highly conspicuous and largely fixed characters such as gender, race, and class"
- *EgalitarianCommunitarian* – "Below median of both Individualism and Hierarchy measures (0 or 1)."
- *Altruism* – "A measure of a subject's altruism (5-25)"
- *NEP* – "New Ecological Paradigm; general concern for the environment (5-25)"
- The percent predicted change in cost by subject by redistribution treatment reported in Table 2.7 is used to instrument for experience.

The model accounts for various experiences across subjects. In the experiment, subjects are randomly assigned to a computer and given their value of time. They bring with them just their idiosyncratic beliefs and behaviors. Any individual can affect their experience as well as the experience of other players of their group by making route-choice decisions that conflict with the model's prediction. To account for this endogenous experience, the predicted percentage change in cost of the toll reported in Table 2.7 is used for *Experience* in Equation 3. Furthermore, Equation 3 is estimated for different sub-samples: subjects that are predicted to be strictly better off (value of times: 10, 11, 12), weakly better off (value of time of 2), and mixed (value of times: 3 and 4). To account for the various equity effects of congestion pricing stated in the literature, this approach allows for close examination of the relationship between beliefs, accustomation, and nature of experience on acceptability.

Measures of political ideologies on economic and social economical issues are not included in the model specification because of their high correlation to the other measures.[25] Furthermore, the other worldview measures allow us to assign a more accurate description of an individual based on their responses rather than if subjects self-select their worldview or ideology. Such political ideology questions or questions on party affiliation make it difficult for a researcher to objectively classify a respondent's particular worldview. Placing individuals in groups based on answers to personal belief and worldview questions rather than utilizing stated political affiliations should provide a stronger and more externally valid empirical analysis of the motivations of constituents' political preferences.

The coefficient estimates reported in Table 2.9 are estimated by sub-sample and are used to test hypotheses to answer the third research question on whether individual attributes and timing of accustomation determine the acceptability of tolls. Four hypotheses are tested. First, votes are believed to be a function of beliefs and accustomation of the problem and policy. Second, given that subjects have not encountered this problem or understand the severity of congestion, beliefs are a major factor in predicting the first vote. Third, when determining approval of the policy, subjects rely less on their beliefs after being accustomed to the problem and policy. Fourth, subjects will vote in their self-interest after experiencing the toll and given an objective measure of the nature of their experience.

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[25] A principal component analysis that includes all six measures was conducted and identified two significant components: "Right-winger (left-winger)" and "Environmental Libertarian/Individualist." These components did not produce significant coefficients and their interpretation conflicts with the objective of the chapter of understanding individual's efficiency and fairness perceptions.

The sets of Wald hypothesis tests on voting behavior by sub-sample are reported in Table 2.10. To test the first hypothesis that personal attributes and accustomation do not matter, the coefficients for those variables are compared zero. To test the second hypothesis that beliefs do not predict the first vote, the coefficients that measure how the four belief measures affect the first vote are compared to zero individually and jointly. The third hypothesis is that accustomation and the influence of beliefs do not change voting behavior, and is tested in sets by comparing the coefficients representing accustomation and type of belief. Lastly, to test the fourth hypothesis that the total effect of accustomation and the nature of experience matters in the final vote, the coefficients representing the effect of the nature of experience on voting and the effect of the group ranked information treatment are compared to zero. The coefficient estimates of Equation 3 are reported in Table 2.9 and the hypothesis test results are reported in Table 2.10 by sub-sample.

Across all individuals, as well as all sub-samples, individual beliefs had no significant effect on voting behavior for the first vote, but these beliefs were significant after being accustomed to the problem. This result conflicts with the expectation of subjects relying on their "knee-jerk" reaction and relying on their beliefs for the vote and suggests that subjects could be using their best guess.[26] For the first and second vote, surprisingly no significant pattern of initial (un)acceptability explained by beliefs for a Pigouvian policy is observed. For all individuals, it appears that after experiencing the problem beliefs contribute to how an individual feels about a toll policy. Those identified as Hierarchical-Individualists (10% significance), Egalitarian-Communitarians (1% significance), and higher measures of altruism (10% significance) were significantly more likely to vote in favor of the policy compared

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[26] To better determine initial voting behavior, future research on voting behavior in a laboratory environment should have a third voting option of not casting a vote. Moreover, it could also be helpful to have a monetary cost to cast a vote.

to the first vote. Perhaps the group of Hierarchical-Individualists voted based on their perception of how the policy will affect their and the group's outcomes. And the Egalitarian-Communitarians felt more inclined to demand intervention after experiencing what they see is a market failure. It could be that beliefs matter in determining initial feelings for a policy, but beliefs will matter more if individuals are given the chance to be accustomed and understand the context of the problem. After all, the Instructions explicitly describes the externality problem, but individuals may first want to understand the severity of the congestion problem before confidently voting in favor of a policy. This is consistent with the Ison and Rye (2005) finding that the congestion problem needs to be severe enough for a policy to gain acceptance. However, these effects from beliefs dissolve in the final vote. Being accustomed to the problem and policy did not significantly affect voting behavior nor did the disclosure of information of ranked group performance information. Not surprisingly, experience appears to play a significant role in determining the final vote suggesting that self-interest is a significant component in determining acceptability.

Looking at the four hypotheses across all individuals reported in Table 2.10, it appears only some beliefs matter. The null hypothesis that votes are not a function of accustomation and beliefs is rejected. However, the second hypothesis that beliefs do not predict the first vote is not rejected. However, the hypothesis that Egalitarian-Communitarian are not sensitive to experiencing the problem and policy is rejected. These individuals are more likely to vote in favor of the policy after experiencing the problem than at any other time. Lastly, several of the last group of hypotheses were not rejected. The aggregate effect of being accustomed to the toll and the nature of the experience not affecting voting behavior being different than the probability of the first vote is not rejected. The nature of the experience affected the third vote while the group-ranked-information treatment had no significant effect. These results suggest that across all individuals certain beliefs are significant in predicting voting behavior only after the first vote. Beliefs appear play a significant role in predicting the final vote, while the relationship between voting and nature of an individual's experience closely overlaps with an individual's self-interest.

Table 2.9. Probit Coefficient Estimates For Predicting Voting Behavior

Dependent Variable: Vote	**All Individuals**	**By Predicted Type of Individual** **Strictly Better Off (Value of time 10, 11, 12)**	**Mixed (Value of time 3 and 4)**	**Weakly Better Off (Value of time 2)**
HierarchicalIndividualist	-0.20 (0.25)	-0.38 (0.34)	-0.38 (0.46)	0.56 (0.544)
EgalitarianCommunitarian	-0.29 (0.23)	-0.21 (0.35)	-0.47 (0.39)	0.21 (0.62)
Altruism	-0.03 (0.03)	-0.01 (0.04)	-0.12 (0.08)	0.00 (0.7)
NEP	0.03 (0.03)	0.04 (0.04)	-0.03 (0.07)	0.10 (0.08)
Vote2	-1.10 (0.79)	-1.50 (1.25)	-1.87 (1.68)	0.44 (1.20)
Vote2×HierarchicalIndividualist	0.49 (0.26)*	0.74 (0.39)*	0.23 (0.42)	0.42 (0.74)
Vote2×EgalitarianCommunitarian	0.75 (0.27)***	1.13 (0.47)**	0.95 (0.46)**	-0.24 (0.36)
Vote2×Altruism	0.06 (0.03)*	0.07 (0.06)	0.12 (0.07)*	0.03 (0.06)
Vote2×NEP	-0.00 (0.34)	0.01 (0.05)	-0.03 (0.07)	-0.02 (0.07)
Vote3	-0.55 (0.99)	0.93 (1.36)	-4.90 (1.89)***	3.50 (2.85)
Vote3×HierarchicalIndividualist	0.44 (0.35)	0.41 (0.47)	1.37 (0.71)*	-1.37 (0.76)*
Vote3×EgalitarianCommunitarian	0.19 (0.32)	0.67 (0.64)	0.65 (0.49)	-0.93 (1.06)
Vote3×Altruism	0.01 (0.05)	-0.03 (0.06)	0.06 (0.10)	0.12 (0.13)
Vote3×NEP	0.03 (0.05)	0.01 (0.05)	0.15 (0.09)*	-0.20 (0.15)
Vote3×RankTrmt	-0.16 (0.18)	-0.31 (0.28)	0.36 (0.33)	-1.40 (0.76)***
Vote3×Experience	-0.01 (0.01)***	0.01 (0.03)	-0.02 (0.11)	-0.00 (0.01)
Constant	0.06 (0.70)	-0.19 (0.94)	3.03 (1.47)	-2.25 (1.83)
Number of observations	576	288	192	96
Number of individuals	192	96	64	32
Chi-square	35.2	35.2	37.58	26.08
p-value	0.00	0.00	0.00	0.05

Note: Standard errors in parentheses.

*Significant at 10%, **significant at 5%, ***significant at 1%

Table 2.10. Results Of Hypothesis Tests

Test	**All Individuals**	**By Predicted Type of Individual**		
		Strictly Better Off (Value of time 10, 11, 12)	**Mixed (Value of time 3 and 4)**	**Weakly Better Off (Value of time 2)**
Hypothesis 1: Votes are not a function of beliefs and accustomation of the problem and policy				
$H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = \beta_9 = \beta_{10} = \beta_{11} = \beta_{12} = \beta_{13} = \beta_{14} = 0$	30.28*** (14)	32.71*** (14)	34.41*** (14)	18.69 (14)
Hypothesis 2: Beliefs do not predict first vote				
$H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$	3.08 (4)	2.68 (4)	5.87 (4)	2.27 (4)
Hypothesis 3: Accustomation and the influence of beliefs do not change voting behavior				
Accustomation–timing of vote				
$H_0: \beta_5 = 0$	1.99 (1)	1.45 (1)	1.25 (1)	0.00 (1)
$H_0: \beta_{10} = 0$	0.31 (1)	0.46 (1)	6.74*** (1)	1.50 (1)
$H_0: \beta_5 = \beta_{10}$	0.33 (1)	4.03** (1)	2.48 (1)	1.23 (1)
Hierarchical-Individualist				
$H_0: \beta_1 = \beta_6$	2.46 (1)	3.08* (1)	0.66 (1)	0.02 (1)
$H_0: \beta_1 = \beta_{11}$	1.30 (1)	1.12 (1)	2.42 (1)	2.56 (1)
$H_0: \beta_1 = \beta_6 = \beta_{11}$	2.47 (2)	3.41 (2)	2.81 (2)	4.15 (2)
Egalitarian-Communitarian				
$H_0: \beta_2 = \beta_7$	5.51** (1)	3.58* (1)	3.57* (1)	0.33 (1)
$H_0: \beta_2 = \beta_{12}$	0.89 (1)	0.90 (1)	1.96 (1)	0.50 (1)
$H_0: \beta_2 = \beta_7 = \beta_{12}$	7.76** (2)	4.04 (2)	3.58 (2)	0.50 (2)
Altruism				
$H_0: \beta_3 = \beta_8$	2.41 (1)	0.81 (1)	3.32* (1)	0.05 (1)
$H_0: \beta_3 = \beta_{13}$	0.27 (1)	0.06 (1)	1.14 (1)	0.35 (1)
$H_0: \beta_3 = \beta_8 = \beta_{13}$	3.38 (2)	2.79 (2)	3.96 (2)	0.44 (2)
NEP				
$H_0: \beta_4 = \beta_9$	0.00 (1)	0.13 (1)	0.00 (1)	0.79 (1)
$H_0: \beta_4 = \beta_{14}$	0.89 (1)	0.10 (1)	1.50 (1)	1.87 (1)
$H_0: \beta_4 = \beta_9 = \beta_{14}$	0.89 (2)	0.13 (2)	5.00* (2)	1.93 (2)
Hypothesis 4: The nature of the experience matters in the final vote				
$H_0: \beta_{10} + \beta_{15} \times \overline{Experience} = 0$	0.25 (1)	0.38 (1)	6.97*** (1)	1.52 (1)
$H_0: \beta_{10} = \beta_{11} = \beta_{12} = \beta_{13} = \beta_{14} = 0$	8.92 (5)	16.61*** (5)	14.96** (5)	9.06 (5)
$H_0: \beta_{10} = \beta_{11} = \beta_{12} = \beta_{13} = \beta_{14} = \beta_{15} = 0$	16.53** (6)	16.71** (6)	18.09*** (6)	9.24 (6)
$H_0: \beta_{10} = \beta_{11} = \beta_{12} = \beta_{13} = \beta_{14} = \beta_{16} = 0$	9.26 (6)	17.61*** (6)	15.09** (6)	12.96** (6)
$H_0: \beta_{10} = \beta_{11} = \beta_{12} = \beta_{13} = \beta_{14} = \beta_{15} = \beta_{16} = 0$	17.00** (7)	17.78** (7)	18.15** (7)	12.96* (7)

Note: Reported are chi-squared statistics with degrees of freedom in parentheses.

*Significant at 10%, **significant at 5%, ***significant at 1%

The estimates of Equation 3 by sub-sample yield noteworthy inferences (See Table 2.10). As discussed in previous sections, this group should always be made better off since their optimal decision is always route A, and therefore should always be in favor of the toll policy. Two coefficients from the strictly-better-off group are positive and statistically significant: the second votes for Hierarchical-Individualist and Egalitarian-Communitarian. After being accustomed to the problem, Hierarchical-Individualists, at 10% significance, appear to understand that a policy will benefit themselves since they have the most value of time at stake and are more likely to vote for the policy. Their hierarchical worldview appears to be motivating their voting decision. These would be the same individuals that would be in favor of congestion pricing since they recognize and can afford the benefits of congestion pricing. This result suggests self-interest rather than considering the social good was a contributing factor in the vote. Egalitarian-Communitarians in this group also were significantly more likely to vote in favor of the policy after being accustomed to the problem. These people may have felt strongly that a problem existed and government was necessary to resolve the congestion problem. For this group, hypothesis three is noteworthy, especially for the timing of the vote (See Table 2.10). Although no statistically significant difference from the first vote is observed, the second and third vote are significantly different from each other. The average group member more likely voted in favor of the toll after being accustomed to both the problem and policy. As expected since these group members were predicted to be made better off, this result implies that these individuals will have greater favorability for a congestion pricing policy after being accustomed to its effects. However, the aggregate effect of accustomation and nature of the experience on the third vote that is tested in hypothesis four did not show statistical difference from the first vote.

The individuals in the mixed group should take Route B with the policy and are either made better off or worse off depending on the redistribution treatment. Similar to the previous sample estimations, Egalitarian-Communitarians in the mixed group were more likely to vote in favor of the toll after being accustomed to the congestion problem. The altruism scale measure also had a significant positive effect on voting behavior compared to the first vote. As expected, being accustomed to the toll policy negatively affected this group's views of the policy. The third vote by itself is significantly negative at 1% significance level. However, worldviews appear here to factor in the decision for the final vote. Hierarchical-Individualists were more likely to vote in favor of the policy. People with stronger (weaker) views on the environment measured on the NEP scale were more (less) likely to vote in favor of the toll at 10% significance. Of the four hypotheses, this group revealed that the combination of being accustomed to the problem and policy and the nature of the experience had a significant and negative effect on acceptability. However, the nature of the experience by itself has a significant impact. With the exception of Hierarchical-Individualists and individuals high on the NEP scale, policymakers should note people with such intermediate values of time will most likely be against congestion pricing after experiencing it and having to make alternative route-choice decisions. Without redistribution congestion pricing makes some people worse off and/or creates inequitable outcomes making it unlikely some groups will ever be in favor of the toll. Policymakers should account for the size of these groups when considering implementing a trial or permanent program. A large population of this group could create a political backlash if toll revenue does not adequately compensate for cost increases for these individuals.

The weakly-better-off group contains those individuals with the lowest value of time who should switch routes with the policy. The estimated model loses significance because of the amount of variables and number of observations in this small group. Hierarchical-Individualists in this group are less likely to vote in favor of the toll after experiencing the policy (10% significance). The ranked group information treatment significantly, at the 1% level, decreased the likelihood of voting in favor of voting for the policy as well. Members in this group are pivot voters, and it appears Hierarchical-Individualists are relying on a combination of their worldview against government intervention and their self-interest. However, the third set of hypotheses testing that the influence of these beliefs not changing voting behavior is not rejected. Weakly-better-off individuals appear to be sensitive to seeing the ranked group information on the inequitable impact the toll has on other group member's costs or how they ranked compared to the group. These results suggest policymakers need to be aware that when obtaining majority approval of congestion pricing that swing voters may be sensitive to information on the equity effects on tolls. However, as reported in Table 2.7 these group members made sub-optimal route-choice decisions in the 40% treatment making them worse off. Such a result suggests that the objective effects of a congestion pricing policy may not be achieved for all individuals and that predicting the *ex-ante* behavioral route-choice responses and perceptions of these marginal users is difficult.

Answer to Research Question 3: The combination of accustomation of the problem and policy, the nature of experience and individual beliefs can predict acceptability of a toll. Individual beliefs did not predict initial feelings toward the toll, but the evolution of voting behavior did depend on individual beliefs and exogenous values of time.

2.6. Conclusion

Urban congestion is a growing problem creating many external costs to users of the road and the environment. Theoretically, congestion-pricing policy instruments improve outcomes and efficiency, but they are seldom put to practice. Barriers such as political and public acceptability as well as general obliviousness by people and policymakers alike on how a transportation system works and is maintained hinder congestion pricing implementation. When considering congestion pricing to this common good problem, policymakers are aware (and are usually made aware by the public) that congestion pricing creates fairness and equity concerns. The experience of a trial period of congestion pricing in Stockholm in 2006 provides a telling story that experience matters. The initially reluctant Stockholmers ended up passing a referendum to keep the congestion pricing permanent after experience a trial-period of congestion pricing (Börjesson et al., 2012). The Stockholm experience is reproduced here in a laboratory setting to observe how beliefs, accustomation, and the nature of the experience explain the evolution of acceptability in a controlled environment.

The results provide an appealing complement to the understanding of some of the issues effecting the acceptability of incentive-based mechanisms on environmental problems. The experiment is used to examine situations where a congestion toll creates overall efficiency improvements but with inequitable outcomes, and in some case makes some individuals worse off. The results show the toll achieved the objective of reducing congestion and that individuals' acceptability of the toll is primarily based on the nature of their experience and being accustomed to the problem and policy. However, self-interest did not solely determine acceptability, and the results suggest that acceptability goes beyond standard self-interest. Beliefs and the type of user impacted by the policy are relevant, but no robust finding is observed that shows a strong pattern of negative sentiments explained by beliefs toward the tolling policy (or government intervention).

A key finding is that beliefs do not determine initial feelings for a toll policy and that initial feelings appear to be random including explicit states on varying the amount of redistribution of toll revenue. The expectation that these beliefs will be heavily relied upon for the first vote is unfounded. It is not until individuals become accustomed to the problem can some individuals comprehend the severity of the problem do some beliefs matter and can predict acceptability. The results suggests that those with both strong hierarchical as well as individualistic views and stand to benefit for the policy are unsurprisingly more likely to vote in favor of the policy. However, those with both strong egalitarian and communitarian views also are more likely to favor the policy even if it might make them worse off. The likely reason is that these people are more favorable to government intervention when realizing a problem. The results also find other beliefs predicting the timing of acceptability.

Similar to the Stockholm experience, the combination of accustomation, nature of the experience, and self-interest strongly determined acceptability of the toll. Policymakers should be aware that personal attributes may or may not matter when first introducing congestion pricing. A carefully implemented trial period similar to the experience in Stockholm may be worth considering when implementing congestion pricing or environmental policy. Policymakers should take these results and findings into account when implementing a trial or permanent congestion policy. Understanding the sizes of the populations of different groups impacted by the congestion policy is essential in predicting majority approval. Moreover, such analysis will help identify which groups to earmark revenues so to compensate for hardship the congestion policy creates. However, the upfront financial and administrative costs must be considered for such a policy to pass a benefit-cost test. But for successful implementation, benefits from the policy instruments should be felt and seen by the majority of users.

Please note that the marginal external congestion cost in this research focused entirely on value of time and did not consider environmental damages from increased emissions. Potentially in the two-route framework described, those with lower value of times are assumed to be those with lower incomes and therefore are more likely to have older vintage cars that may be more harmful to the environment. A congestion policy as described above may increase total amount of emissions by having these more polluting cars take longer routes and reducing the overall benefit of decreasing total travel times. Future laboratory experiments could create a setting where individuals create two negative externalities: the travel time externality that has heterogeneous effects and an emissions externality that has homogeneous effects but has heterogeneous sources that depends on the travel times of individuals that have varied values of time (i.e., different car vintages that have different emissions rates).[27] This type of frame-work can test the effectiveness of first-best and second-best pricing.

It is still an open question whether beliefs and characteristics determine initial feelings toward congestion pricing policies or other environmental policies. Future research should consider settings where there is an option to not vote, but to still have that vote be binding with a tie-breaker in place. Obtaining a censored data set may enhance the ability to predict initial feelings. Moreover, also creating a setting where individuals must incur some

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[27] Ideally, in a laboratory setting the costs of the second externality will not be felt immediately after a period but should be delayed sometime later in the experiment's round. Perhaps provide on the screen some measure showing total accumulation throughout a round.

cost (preferably a monetary cost) to vote could also provide insights on the confidence of individual's voting behavior and acceptability of the policy.[28]

Future experiments that test the validity of the survey instruments that measure these personal attributes as well as do similar experiments as done in the study are encouraged. Future experiments could have different redistribution rates, ordering effects of the toll, randomization of individuals' values of time within a session, or delaying and/or randomizing the amount of redistribution of the toll. The more laboratory and field studies from trials will help provide facts on the essence of aversion to congestion pricing. Policymakers will then have an easier time targeting public relations to groups on the margin to help assure a trial run and or permanent congestion pricing policy would be successful. Policymakers need to carefully design an instrument where the gains are noticeable and felt by the majority of constituents. Knowledge of worldviews may help in communicating and being open about the effects of the policy. As King et al. (2007) state, "congestion pricing will be implemented not when it is tolerable to the prospective losers, but when it is irresistible to the prospective winners."

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[28] A suggestion would be for subjects to pay for votes using money given to them as a show-up fee.

CHAPTER 3

A Three-player Bottleneck Congestion Game With And Without Efficient Pricing

3.1. Introduction

Congestion can be found everywhere, especially in transportation systems. Congestion creates problems from its external costs. For transportation, congestion affects important quality aspects like expected travel time, expected arrival time, reliability, convenience of travel, safety, and the environment. Policymakers face natural limitations of increasing infrastructure capacity in urban areas and should have a general understanding of the micro-foundations of congestion when alternative incentive-based demand-management mechanisms like congestion pricing are considered. The basic bottleneck model details the negative externality of the time costs users of a single route network impose on each other. The congestion literature has shown that time-delay and schedule-delay cost externalities are ranked highest as the costs of congestion in a list that includes external costs of accidents and environmental damage (Small and Verhoef, 2007; Anas and Lindsey, 2011). Discussing congestion and the bottleneck model at a discrete individual level of two and three people rather than of a theoretical discussion of a continuous environment of N individuals assumed in the basic bottleneck model may make understanding the technical foundations of congestion and congestion pricing more approachable and understandable to a broader audience, including policymakers.

Levinson (2005) formally provides a normal-form game structure for a bottleneck congestion game for two players with and without congestion tolls. The congestion problem ultimately can be reduced down to just two people. He then discusses the extension of the game to three players and how the game could be extended to N discrete players.[1] His three-player extension includes the methodology on how payoffs (penalties) are calculated and what are the predicted pure-strategy Nash equilibria (PSNE) for various time cost parameters. His discussion of the three-player game, however, does not include the general normal-form game structure or detailed formulas for calculating efficient congestion tolls seen in the two-player game discussion. This chapter presents the normal-form structure for a three-player bottleneck game and the derivation and inclusion of the efficient tolls. The predicted PSNE with and without the tolls are discussed.[2] This chapter comprehensively shows the essence of congestion pricing and why the toll should equal the negative externality a user imposes on society.

I expand from previous literature to formally show a prisoner's dilemma and the emergence of congestion in a three-player congestion game. I then show how congestion pricing is calculated, illustrate the problem, and how tolls can be used to mitigate congestion whilst addressing equity and behavioral impacts from redistribution of toll revenues. Unlike the discussion of a two-player game, the inclusion of a third player reveals the policy and welfare implications when two users generate a queue that negatively affects a third player. This simplified framework will help the reader comprehend the micro-foundations of a congestion problem as well as understand how variations of time and schedule delay affects the congestion problem and policy recommendations.

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[1] Note each additional player makes examination of the game exponentially more complex. The described model below will be worded so that one could expand the game to more than three players.

[2] A forthcoming corrigendum co-authored with David M. Levinson in the journal *Transportation Research Part A: Policy and Practice* corrects several of the predicted PSNE reported in Levinson (2005). See Appendix B.3.

This note has six sections. Section 3.2 provides a summary of the Levinson (2005) game-theoretical bottleneck congestion game and the formal development of the three-player game. Section 3.3 discusses the derivation of the tolls and how the tolls affect behavior. In Section 3.4 the congestion problem is illustrated using figures. Section 3.5 discusses how to solve for Nash equilibria (including mixed strategies), how the redistribution of revenue-neutral tolls affects player behavior, and how the model can be applied to laboratory experiments. Section 3.6 concludes. Suggested modifications for the model in Levinson (2005) including corrections to the PNSE for a three-player game are reported in the Appendix.

3.2. Three-player Bottleneck Congestion Game

In the Levinson (2005) congestion game based on the basic bottleneck model by Vickrey (1969) and Arnott et al. (1990b) among others, players (or vehicles) travel on a single link from a common origin to a common destination. Players simultaneously decide when to depart knowing that a bottleneck exists; their objective is to minimize their costs. Zou and Levinson (2006) extend the Levinson (2005) model by developing a generalized N-player game and comparing the model's simulated results to the basic bottleneck model. They find support that the game theory approach yields similar results. Xin and Levinson (2007) employ a similar stochastic congestion model and simulate different pricing schemes and various compositions of users' aversions of being late. The following fulfills a gap between a model with two players and N players by formalizing a three-player game that can provide insights to unique congestion situations that can only exist if there are more than two players.

In Levinson (2005), players make their departure decisions based on what they think the other players' departure decisions are. The model requires three variables: penalties for early arrival (E) and for late arrival (L), and the penalty for incurring a journey delay (D).

When there are three players, each player has the option of departing: Very Early (v), Early (e), On-time (o), or Late (l). The bottleneck allows for players to arrive only one at a time.

Each of the three players then can arrive in one of five arrival time slots: Very Early, Early, On-time, Late, Really Late (r), and Super Late (s).[3] Congestion occurs if two or more players depart at the same time. When congestion occurs then the way the congested players go through the bottleneck is randomly determined. For example, in a three-player game, if two players depart at the same time then one of the two will randomly be sorted to arrive at the intended departure time while the other player will arrive at the next time slot and incur a journey delay. Similarly, if all three players depart at the same time, then one of the three will randomly be determined to arrive at the intended time, another player will be bumped to the next time slot and incur a journey delay, while the third player will be bumped two time slots and incur two journey delays. Each player has the same probability of incurring zero, one, or two journey delays. If a player departs at a time slot immediately after two players depart at the same time, then that player is in a queue. Of the two congested players, one will arrive at their intended time while the other one will be journey delayed and arrive at the next time slot which is the departure time of the player that entered a queue. Since it is first-come-first-serve, the player that arrives in the back of the queue is journey delayed and arrives at the next time slot. In such a scenario where a player enters an existing queue by departing at the time slot immediately after two players create congestion, two of the three players each incur one journey delay. Without losing generality, assume that if there is no queue then travel time costs–considered here as journey delay costs–are zero. Journey delays are similar to congestion. The random determination

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[3] For a two-player game described in Levinson (2005), each decides to either depart: Early, On-time, or Late with the possible arrivals of Early, On-time, Late, and Very Late.

of how players go through the bottleneck functions the same in a game where there are more than three players, except there will be more possible departure and arrival time periods and more situations and varieties of queues existing.

This discretized model differs from those elsewhere in the existing literature. Ziegelmeyer et al. (2008) develop a similar discretized game-theoretical single-route bottleneck model containing travel and scheduling costs that is used for laboratory experiments of groups of four and sixteen. However, unlike the model presented in this chapter, their model contains no sorting mechanism when users encounter a bottleneck and create a queue (congestion)– users arriving at the queue at the same time are assumed to arrive at the destination at same time and incur the same costs. Breinbjerg et al. (2014) also develop a discretized bottleneck queueing model, but their model contains just travel delays (queueing time) costs and not any scheduling delay costs. Breinbjerg et al. (2014) vary in their model and examine in a laboratory experiment the outcomes and fairness perceptions of different sorting service mechanism of the queue created by the bottleneck. Users are either sorted by first-in-first-out, last-in-first-out, or service-in-random-order. The omission of scheduling costs, an essential component in the basic bottleneck model, hinders the discussion of welfare implications from the imposition of congestion pricing. The Ziegelmeyer et al. (2008) and Breinbjerg et al. (2014) models do not include discussion or derivation of efficient congestion tolls. The model presented here derives efficient tolls and discusses welfare implications of *ex-ante* and *ex-post* outcomes. The simplified model revealing both *ex ante* and *ex-post* outcomes ought to be more approachable to understand the essence of the basic bottleneck model and congestion pricing.[4]

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[4] The basic bottleneck model assumes users depart across continuous time and that a first-in-first-out queue is formed once the bottleneck reaches past its free-flow capacity. Therefore, unlike this discretized model

Similar to the continuous variables used in the basic bottleneck congestion model presented in the theoretical literature, behavior in the discrete game-theoretical model version depends on users' time and schedule delay preferences. A rational player knowing other players' departure decisions (t_{-i}) will then know their expected costs from the probability of arriving at a certain time and any expected journey delay. The sum of the expected cost of schedule delay and expected cost of the journey delay is the total expected cost for that departure time. Players try to minimize their total expected costs given the departure patterns of the other two players. The following equations are identical to those in Levinson (2005) except in equation (8) where θ is used to represent expected schedule delay costs instead of E to avoid confusion of nomenclature.[5]

Formally, the journey delay or what is referred to as the expected journey delay, $\varepsilon(d_t)$, at departure time t_i for individual i, depends on how many vehicles the bottleneck can service per unit of time and departure times of other players, t_{-i}. Assume the bottleneck services one vehicle per unit of time, thus the expected journey delay is measured as:

$$\varepsilon(d_t) = Q_t + 0.5(A_t - 1) \tag{4}$$

where $Q_t(t_i, t_{-i})$ is the standing queue at time t and is equal to the total number of other players remaining in the queue in the time period immediately before the player's departure time, t_i, after bottleneck has been serviced. The total number of departures at time t is

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that has a bottleneck with a random-sorting mechanism, the equilibrium *ex-ante* and *ex-post* outcomes in the basic bottleneck model are the same.

[5] A table of nomenclature can be found in Appendix B (see Table B.2.1).

Table 3.1. Expected Journey Delay Costs Given The Departure Strategies Of Other Two Players

	Player B	v	v	v	v	e	e	e	o	o	l
	Player C	v	e	o	l	e	o	l	o	l	l
Player A	v	D	$0.5D$	$0.5D$	$0.5D$	0	0	0	0	0	0
	e	$\mathbf{D}$	$0.5D$	0	0	D	$0.5D$	$0.5D$	0	0	0
	o	0	0	$0.5D$	0	$\mathbf{D}$	$0.5D$	0	D	$0.5D$	0
	l	0	0	0	$0.5D$	0	0	$0.5D$	$\mathbf{D}$	$0.5D$	D

represented by $A_t(t_i, t_{-i})$.[6]

$$C(d_t) = (Q_t + 0.5(A_t - 1))D \tag{5}$$

The expected costs of a journey delay, $C(d_t)$, is the expected journey delay multiplied by the delay penalty, D. Table 3.1 displays for a three-player game the expected journey delay costs which are the probabilities of a journey delay multiplied by the journey delay penalty (D) for each departure scenario. The three possible departure scenarios for Player A to depart and immediately enter behind a queue (Q_t=1) are highlighted in bold in Table 3.1: (Player A: Early, Player B: Very Early, Player C: Very Early), (Player A: On-time, Player B: Early, Player C: Early), and (Player A: Late, Player B: On-time, Player C: On-time).

The deviation from the time at which a player arrives at their final destination (as opposed to departs) and the desired, or On-time, period is the schedule delay (S_i). The schedule delay is

$$S_i = t_a + d_t - t_o \tag{6}$$

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[6] Independent of a queue and assuming one-at-a-time arrival, the expected journey delay from N users entering a time slot at time t is determined by the series $\sum_{i=1}^{N} \frac{N-i}{N}$ that can be simplified to $\frac{N-1}{2}$. This is displayed as $0.5(A_t - 1)$ where A_t is total number of players entering at time t.

where d_t is the journey delay, t_a is the player's departure time (also be interpreted as the arrival at back of queue), and t_o is desired arrival time, which is to be On-time at their final destination (also interpreted as the desired time of departure from front of queue). The value of being On-time is assumed to be zero, thus S_i can be negative or positive depending on whether a driver departs Early or Late relative to the On-time departure time. Negative values represent early arrival (arrival in front of queue), while positive values represent later departures (arrival in back of queue). The cost of a schedule delay is

$$C(S_i) = \begin{cases} E \times |S_i| & \text{if } S_i < 0 \\ L \times |S_i| & \text{if } S_i > 0 \end{cases} \tag{7}$$

The journey delay is determined probabilistically and is greater than or equal to zero since drivers can arrive at a time slot only one at a time and are sorted randomly when drivers depart at the same time. The schedule delay is calculated by solving and adding the schedule delay for each probability of journey delay. Note that the schedule delay is independent of journey delay. Schedule delay cannot be calculated from the expected value of journey delay since journey delay may be zero on average while sometimes schedule delay is positive and sometimes negative, which do not cancel each other out but are additive.[7] The expected schedule delay cost for traveler i, $\theta(S_i)$, is determined by the individual's departure time t_i (from the queue). The expected schedule delay costs for a three-player game are

$$\theta(S_i) = \sum_t P_t \prod_t = P(\overline{v}) \times 2E + P(\overline{e}) \times E + P(\overline{l}) \times L + P(\overline{r}) \times 2L + P(\overline{s}) \times 3L \tag{8}$$

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[7] For example in a three-player game, a player that departs early along with the other two players has the same probability of arriving Early, On-time, or Late yet their expected schedule delay is not zero (i.e., expected arrival of On-time.

where $1 = \Sigma_t P_t = P(\overline{v}) + P(\overline{e}) + P(\overline{o}) + P(\bar{l}) + P(\overline{r}) + P(\overline{s})$; $P()$ is the probability function for player i, displayed in Table 3.2; $\prod_t$ = penalty function = $(2E, E, 0, L, 2L, 3L)$; $\overline{v}, \overline{e}, \overline{o}, \bar{l}, \overline{r}, \overline{s}$ are the periods of arrival from the queue that starts at On-time, zero (Very Early (t_o - 2), Early (t_o - 1), On-time (t_o), Late (t_o + 1), Really Late (t_o + 2), Super Late (t_o + 3).[8]

Table 3.3 shows the expected schedule delay costs for a three-player game. The expected costs are the probability-average of all possible arrival times. It is found by summing the products of the probabilities of arrival outcomes from Table 3.2 and the penalty function for a player's departure time given the other players' departure times. Notice again that for scenario *eee* that the expected schedule delay is not zero, but is positive because the expected penalties are additive.

Consistent with the theoretical literature of users choosing an optimal schedule for their trip by trading off travel-time cost against schedule-delay cost, the play of the three-player game depends on one's expected time (journey delay) and schedule delay costs. For example, in equilibrium in the basic bottleneck model, the identical individuals have no incentive to change their departure time when minimizing their travel-time and schedule-delay costs implying that trip costs must be the same for all departure times (Arnott et al., 1990b; Small and Verhoef, 2007).[9] However, in our three-player game context, a player's travel time is assumed to be zero regardless of departure time unless the player incurs (expects) a journey delay. The total expected costs of a departure decision are the sum of the expected journey and schedule delay costs (the cell-by-cell sum of Table 3.1 and Table 3.3, respectively.)

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[8] Levinson (2005) also assumes a linear penalty function.

[9] In the three-player game, in equilibrium users could have *ex-ante* the same expected costs, but will *ex-post* end with different costs. The basic bottleneck model assumes the *ex-ante* and *ex-post* outcomes are the same.

Table 3.2. Arrival Probability Given Departure Strategies, Three-player Game

Player B	*v*	*v*	*v*	*v*	*e*	*e*	*e*	*o*	*o*	*l*
Player C	*v*	*e*	*o*	*l*	*e*	*o*	*l*	*o*	*l*	*l*
departure decision Player A	Arrival Probability									
very early (v)										
$P(\overline{v})$	1/3	0.5	0.5	0.5	1	1	1	1	1	1
$P(\overline{e})$	1/3	0.5	0.5	0.5	0	0	0	0	0	0
$P(\overline{o})$	1/3	0	0	0	0	0	0	0	0	0
$P(\overline{l})$	0	0	0	0	0	0	0	0	0	0
$P(\overline{r})$	0	0	0	0	0	0	0	0	0	0
$P(\overline{s})$	0	0	0	0	0	0	0	0	0	0
early (e)										
$P(\overline{v})$	0	0	0	0	0	0	0	0	0	0
$P(\overline{e})$	0	0.5	1	1	1/3	0.5	0.5	1	1	1
$P(\overline{o})$	1	0.5	0	0	1/3	0.5	0.5	0	0	0
$P(\overline{l})$	0	0	0	0	1/3	0	0	0	0	0
$P(\overline{r})$	0	0	0	0	0	0	0	0	0	0
$P(\overline{s})$	0	0	0	0	0	0	0	0	0	0
on-time (o)										
$P(\overline{v})$	0	0	0	0	0	0	0	0	0	0
$P(\overline{e})$	0	0	0	0	0	0	0	0	0	0
$P(\overline{o})$	1	1	0.5	1	0	0.5	1	1/3	0.5	1
$P(\overline{l})$	0	0	0.5	0	1	0.5	0	1/3	0.5	0
$P(\overline{r})$	0	0	0	0	0	0	0	1/3	0	0
$P(\overline{s})$	0	0	0	0	0	0	0	0	0	0
late (l)										
$P(\overline{v})$	0	0	0	0	0	0	0	0	0	0
$P(\overline{e})$	0	0	0	0	0	0	0	0	0	0
$P(\overline{o})$	0	0	0	0	0	0	0	0	0	0
$P(\overline{l})$	1	1	1	0.5	1	1	0.5	0	0.5	1/3
$P(\overline{r})$	0	0	0	0.5	0	0	0.5	1	0.5	1/3
$P(\overline{s})$	0	0	0	0	0	0	0	0	0	1/3

Source: Table 10 from Levinson (2005).

Table 3.4 reports the total expected costs and is the simplified normal-form bottleneck congestion game for one of the three players. If we assume homogeneous time preferences then Table 3.4 is sufficient to understand the three-player game. Numerous versions of the game

Table 3.3. Expected Schedule Delay Costs

	Player B	v	v	v	v	e	e	e	o	o	l
	Player C	v	e	o	l	e	o	l	o	l	l
Player A	v	E	$1.5E$	$1.5E$	$1.5E$	$2E$	$2E$	$2E$	$2E$	$2E$	$2E$
	e	0	$0.5E$	E	E	$\frac{E}{3}+\frac{L}{3}$	$0.5E$	$0.5E$	E	E	E
	o	0	0	$0.5L$	0	L	$0.5L$	0	L	$0.5L$	0
	l	L	L	L	$1.5L$	L	L	$1.5L$	$2L$	$1.5L$	$2L$

can be created using any combination of values of E, L, and D.[10]

Players use best-response strategies to minimize expected total costs given the other two players' departure decisions. Nash equilibria depend on values of E, L, and D and can be found by iterating among the outcomes from the best responses of the other homogeneous players.[11] Assuming that the cost penalties are non-zero, note that for five of the columns we can predict that there is at least one cost-minimizing strategy where expected costs equal zero by departing On-time. The best response for these same five are scenarios where Player A does not create congestion or departs behind a queue.

Note that players with homogeneous time preferences minimize total group time costs if each departed at separate time slots, yet no rational player has the incentive to do so. All players would prefer to depart and arrive On-time. Yet an On-time arrival is not guaranteed and players strategically schedule their departure patterns to minimize their total expected private costs. These strategies of the players without tolls emulates a three-person prisoner's dilemma where if they were to coordinate their actions they would reduce total

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[10] Much of the literature assumes $E < D < L$ reported in Small (1982), but here the framework remains general. A three-player game with heterogeneous time-preferences can be developed using the same theoretical framework.

[11] To solve for PSNE (if one exists), start at any given departures for the other two players to find best response. From that predicted outcome then iterate to find how the other player would respond. Iterate until you reach a Nash equilibrium where no player has the incentive to depart at a different time. In several cases, no PSNE solutions exist which implies that Nash equilibria exist in mixed strategies. See proceeding sections for a discussion of finding all Nash equilibria.

social costs.[12] Even with a prisoner's dilemma, players internalize congestion but only the increased congestion costs that are imposed on themselves and not others.

Equity and fairness concerns underlies the congestion game. Since the total cost minimizing departure pattern requires players to depart at separate times, this social optimum creates "winners" and "losers." A user equilibrium strategy that creates congestion may be perceived as fair because the chance by the inherent random sorting in the game may give everyone an equal opportunity *ex-ante* of obtaining a minimum-cost outcome. At the social optimal departure pattern, the game leaves open on how players coordinate to determine who gets which time slot.[13] The model can also provide theoretically predicted prices of anarchy which measures how the system's (game's) efficiency degrades compared to the social optimum. It is calculated by the ratio of the costs of user equilibrium and social optimum. For example, if the total costs at the social optimum is 8 and the user equilibrium costs are 12, then the price of anarchy would be 1.5, which implies that the user equilibrium degrades efficiency by 50%.

3.3. THREE-PLAYER BOTTLENECK GAME WITH CONGESTION TOLLS

The described bottleneck congestion game exemplifies the problem of a (time cost) congestion externality. A player does not account for the increased total (schedule and journey delay) costs they impose on other players when they depart at the same time as other players creating congestion. The model can be extended to include congestion pricing by imposing

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[12] Another interpretation is to assume an operator that is a social planner or monopolist decides the departure times of the three agents. Such an entity would thus coordinate the departure of the three agents as to minimize total costs. An example of such a entity could be an monopolist airline scheduling arrivals and departures.

[13] Keep in mind that if the game is repetitive and mechanisms are imposed so to achieve social optimal sorting, a player still might want to deviate from cost-minimizing behavior and try to punish another player to bump them out of their preferred time slot to enforce societal fairness norms. Even without a repeated context and when a PSNE does not exist, equlibria in mixed strategies exist.

TABLE 3.4. Expected Total Costs Without Congestion Tolls

	Player B	v	v	v	v	e	e	e	o	o	l
	Player C	v	e	o	l	e	o	l	o	l	l
Player A	v	$E+D$	$1.5E+0.5D$	$1.5E+0.5D$	$1.5E+0.5D$	$2E$	$2E$	$2E$	$2E$	$2E$	$2E$
	e	D	$0.5E+0.5D$	E	E	$\frac{E}{3}+D+\frac{L}{3}$	$0.5E+0.5D$	$0.5E+0.5D$	E	E	E
	o	0	0	$0.5D+0.5L$	0	$D+L$	$0.5D+0.5L$	0	$D+L$	$0.5D+0.5L$	0
	l	L	L	L	$0.5D+1.5L$	L	L	$0.5D+1.5L$	$D+2L$	$0.5D+1.5L$	$D+2L$

efficient tolls on congestible scenarios. A toll can be imposed in the cells in Table 3.4 where congestion occurs so that players can internalize the congestion costs (*mecc*) they impose on others. Sixteen congestible scenarios exist in a three-player game. The value of a toll depends on the particular congestion scenario–the departure pattern of players–and a toll is paid only if a player creates congestion. As Levinson (2005) mentions, since decisions are made simultaneously the tolls constitute a threat in that they might (or might not) be paid and are dependent on the actions of the other players. These tolls incentivize players to behave in a manner that steers them toward a socially optimal outcome that minimizes group costs.[14]

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[14] The most germane example of why players would allow an institution with self-imposed taxes or tolls comes from the story of missionaries visiting nineteenth-century China. Although the authenticity of the story is doubted, the point should not be. The potentially apocryphal tale exists in various versions in economics textbooks, writings, and podcasts (See Cheung (1983) where the example I believe first originated). The example goes that a group of missionaries arrive in China and observe a group of working men (called trackers) using ropes to pull a heavy barge up a river with a strong current. The missionaries were shocked to see a man on the barge with a long whip lashing out at any of the men that had slack on their rope. The shocked missionaries ran to the group men pulling the barge to tell them that they will help end such abuse. Yet instead of being welcomed by their concern, the men pulling the barge told the missionaries to calm down and mind their own business since it was them that own the barge. They informed the missionaries that the faster they get the cargo up the river the more they get paid. And they hired this man to be their monitor and whip them to reduce the incentive to shirk and free-ride on the effort of others. Thus like the Pigouvian tolls in congestion, a group might want to set up an institution that may seem punishing but can

A Pigouvian toll or tax is a fee that equals the aggregate marginal social cost or damage incurred by a user, excluding the marginal private cost borne by that user, when evaluated at the efficient level of pollution, or in this case, congestion. However, in this probabilistic and *ex-ante* context the toll cannot be evaluated in the typical *ex-post* context. If the Pigouvian tolls were evaluated using *ex-post* outcomes then the tolls would be zero since at the efficient level is when the group departs at different times, no congestion occurs, and group costs are minimized. Instead the efficient congestion toll is not Pigouvian by definition but instead equals the calculated *ex-ante* expected *mecc*.

The *mecc* is the difference between the incremental social cost a player creates by entering a congestible scenario and the player's own incremental private cost for entering that specific scenario.[15] Although decisions are made simultaneously, it is helpful to assume when considering the tolls that decisions are made in a sequential manner. In the model, total social cost (TSC) is not a continuous function but is a discrete function. So the incremental social cost (ISC) is the appropriate basis for calculating the price, where $ISC = \Delta TSC/\Delta q$, with q as the number of players. The incremental private cost (IPC) is the additional amount each player pays in the absence of tolls to take the trip, their own travel time. This cost is already internalized by the player and is excluded from the incremental (marginal) social cost value.[16] The appropriate efficient toll depends on the congestion scenario and is expressed by $\tau(t_i; t_{-i}) = ISC - IPC$. The toll for the given congestion scenario represents the incremental external congestion costs externality ($mecc$), which represents the increased

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and will make all members better off compared to the alternatives. The version by Cheung has this behavior occurring right before the communist regime and does not mention shocked Westerners.

[15] If using the Pigouvian toll definition, the toll will be evaluated at a efficient such as *veo* and since no player is creating *mecc*, the outcome is efficient and any toll would be valued zero. This is why the toll should not be evaluated at the efficient level.

[16] Not accounting for an individuals private cost, or own contribution to congestion, will inflate the toll to an inefficient level.

expected journey and schedule delay costs imposed on other players. The ISC is calculated by taking the difference between TSC under conditions with and without a marginal user creating congestion for each congestible scenario (see Table 3.5). The TSC with the marginal player is the sum of the expected costs from Table 3.4 for all three players for a given congestion scenario. The TSC without the marginal player is the sum of expected costs in Table 3.4 of the two players if the marginal player selected a non-congestible departure time or was absent from the game. That is, it is the TSC of the original two players before the marginal player makes a departure decision. The ISC is the difference between TSC with and without the marginal player. Similarly, the IPC can be thought as the individual effect of being the marginal player. It is the individual expected costs reported in Table 3.4 that can be thought of as the expected costs of entering the game and making a departure decision after the two other players have made their departure decisions.

For each congestion scenario, the efficient toll is the difference between ISC and IPC, which represents the *mecc* a player imposes on the group. As seen in Table 3.5, sixteen possible congestible scenarios, ignoring player identification, can occur.[17] The eight different *mecc* values of the sixteen scenarios in the game represent the eight efficient tolls for this game (τ_α, τ_β τ_δ, τ_Θ, τ_μ, τ_ε, τ_σ, and τ_λ; see Table 3.5). Tolls are imposed in appropriate cells in Table 3.4 to obtain Table 3.6. Note that depending on the parameters there may be fewer tolls actually imposed in the game since if the calculated toll (*mecc*) is negative it is maximized to zero.

Note in Table 3.5 that eight unique tolls exist in a three-player game. No tolls are incurred when a socially optimal Nash equilibrium departure pattern happens since no congestion occurs (*mecc* ≤ 0). Several congestion scenarios in Table 3.5 share the same toll value, and

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[17] Formulas for the tolls for a three-player game are not reported in Levinson (2005).

many require a maximization operator since the calculated tolls (*mecc's*) for departures before the On-time departure time could be negative. Depending on the time cost parameters, individuals that create congestion before the On-time time slot could potentially generate an incremental social benefit by journey delaying other players from an earlier time of arrival to a less costly On-time arrival time. This is why tolls in the earlier time periods must be greater than or equal to zero.[18] Moreover, the presence of negative *mecc* suggest that the socially optimal and acceptable level of congestion depends on the cost parameters and may not always be group departure patterns with absolutely no congestion. Some congestion could be socially acceptable.

With tolls, Table 3.4 is modified by adding in the toll (*mecc*) to the appropriate cells for each congestion scenario from Table 3.5. Table 3.6 now represents the formal normal-form bottleneck congestion game with efficient tolls. Situations where a player enters in a queuing scenario like *vve*, *eeo*, and *ool* do not have a toll. Under such a situation, a person that departs the period after a two-way congestion scenario will create costs only for themselves and does not create a time-delay externality on the other players. As such, the *mecc* of entering a queuing scenario is zero and a toll should not be imposed. Players should already internalize privately the costs associated with entering the back of a queue.

The introduction of efficient congestion tolls mitigates the prisoner's dilemma and allows players to cooperate and coordinate their decisions to reduce TSC.[19] But, as can be shown, a three-player game with homogeneous time preferences (cost parameters) does indeed create clear equity concerns with "winners" and "losers" *ex-ante*. At the social optimum, when

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[18] For example, if $E > D$ then arriving Early versus incurring a journey delay at Early and arriving On-time would be more costly. Note that if you consider a situation where $E = 5, D = 4, L = 5$, the non-toll PSNE departure pattern *eee* is unique.

[19] Note that a game with heterogeneous time preferences will yield individual-specific Pigouvian tolls.

players depart at different times, players will have unequal outcomes.[20] A discussion on how to solve for Nash equilibria with and without tolls follows below.

Analysts should note that this derivation of tolls is one of many pricing approaches that could be employed. Arnott et al. (1993) address in their bottleneck model different pricing scenarios such as no toll, uniform toll (constant throughout the day), fine toll (completely flexible; time-dependent), and coarse toll (intermediate between uniform toll and fine toll), but do not explicitly address the unique queue that occurs in a discrete three-player bottleneck game. Zou and Levinson (2006) examine the different pricing scenarios with their discretized model, but also do not explicitly address the unique queue. The Xin and Levinson (2007) N-player game employs two types of pricing schemes: omniscient pricing (all costs are known to a transportation administer) and observable pricing (only queuing delay costs are considered and not schedule delay costs). Omniscient pricing would have players paying for the additional externality of the schedule delay costs players avoiding congestion. Omniscient tolls are calculated as the (expected) difference in total social costs from an additional player (e.g., if two players depart On-time and Early, then the individual that departs On-time would pay the toll of the schedule delay costs, E, of the second player who is avoiding On-time congestion.). It is argued that since schedule delay costs of a traveler costs are unobservable, a more realistic approach would impose congestion pricing on queueing delay (this is consistent with the theoretical static analysis conducted by Walters (1961) where schedule delay is not considered). The pricing approach presented here lies somewhere in between the omniscient and queueing pricing approaches. Unlike other approaches, this

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[20] In a repeated game, the tolls help sustain a socially optimal departure pattern by providing a disincentive for players to punish and bump other players out of a superior time slot.

method explicitly shows the marginal social costs that occur when a player departs in a discrete time that is immediately after a departure time when congestion occurs. This situation cannot be observed in the context of a two-player game.

Efficient tolls (or Pigouvian tolls) or taxes ought to be zero in situations without the presence of any technological externalities; no potential Pareto improvements can be made. If players departed at different times then no tolls will be paid except for the more complete omniscient tolling approach where players will pay different toll rates depending on their departure time. Thus instead of tolls being used as threat, players paying omniscient tolls and are in an efficient departure pattern will now have additional private costs except by the player with the greatest schedule delay cost. Players (society) will understandably prefer having no tolls or the other pricing schemes compared to the omniscient toll approach. Departure patterns that do not create congestion *ex-ante* and *ex-post* and/or yield an *mecc* equal to or less than zero should not have any tolls imposed.

Table 3.5. The Incremental Costs And Calculated Toll In A Three-player Game When Creating A Congestible Scenario

Congestion Scenario	Total Social Cost (TSC) with marginal player	Total Social Cost (TSC) without marginal player	Incremental Social Cost (ISC)	Incremental Player Cost (IPC)	$Toll = ISC - IPC$ $(mecc)$	Toll Symbol
vvv	$3E + 3D$	$3E + D$	$2D$	$E + D$	$MAX(D - E, 0)$	τ_α
vve	$3E + 2D$	$3E$	$2D$	$1.5E + 0.5D$	$MAX(1.5D - 1.5E, 0)$	τ_β
vvo	$3E + D$	$2E$	$E + D$	$1.5E + 0.5D$	$MAX(0.5D - 0.5E, 0)$	τ_δ
vvl	$3E + D + L$	$2E + L$	$E + D$	$1.5E + 0.5D$	$MAX(0.5D - 0.5E, 0)$	τ_δ
eev	$3E + D$	$3E$	D	$0.5 \times (E + D)$	$MAX(0.5D - 0.5E, 0)$	τ_δ
eee	$E + 3D + L$	$E + D$	$2D + L$	$\frac{E}{3} + D + \frac{L}{3}$	$MAX(D + \frac{2L}{3} - \frac{E}{3}, 0)$	τ_Θ
eeo	$E + 2D + L$	E	$2D + L$	$0.5 \times (E + D)$	$MAX(1.5D + L - 0.5E, 0)$	τ_ε
eel	$E + D + L$	$E + L$	D	$0.5 \times (E + D)$	$MAX(0.5D - 0.5E, 0)$	τ_δ
oov	$2E + D + L$	$2E$	$D + L$	$0.5 \times (D + L)$	$0.5 \times (D + L)$	τ_μ
ooe	$E + D + L$	E	$D + L$	$0.5 \times (D + L)$	$0.5 \times (D + L)$	τ_μ
ooo	$3D + 3L$	$D + L$	$2 \times (D + L)$	$D + L$	$D + L$	τ_λ
ool	$2D + 3L$	L	$2 \times (D + L)$	$0.5 \times (D + L)$	$1.5 \times (D + L)$	τ_σ
llv	$2E + D + 3L$	$2E + L$	$D + 2L$	$0.5D + 1.5L$	$0.5 \times (D + L)$	τ_μ
lle	$2E + D + 3L$	$2E + L$	$D + 2L$	$0.5D + 1.5L$	$0.5 \times (D + L)$	τ_μ
llo	$D + 3L$	L	$D + 2L$	$0.5D + 1.5L$	$0.5 \times (D + L)$	τ_μ
lll	$3D + 6L$	$D + 3L$	$2D + 3L$	$D + 2L$	$D + L$	τ_λ

Table 3.6. Expected Total Costs With Congestion Tolls

	Player B	v	v	v	v	e
	Player C	v	e	o	l	e
Player A	v	$E + D + \tau_\alpha$	$1.5E + 0.5D + \tau_\beta$	$1.5E + 0.5D + \tau_\delta$	$1.5E + 0.5D + \tau_\delta$	$2E$
	e	D	$0.5E + 0.5D + \tau_\delta$	E	E	$\frac{E}{3} + D + \frac{L}{3}\tau_\Theta$
	o	0	0	$0.5D + 0.5L + \tau_\mu$	0	$D + L$
	l	L	L	L	$0.5D + 1.5L + \tau_\mu$	L

	Player B	e	e	o	o	l
	Player C	o	l	o	l	l
Player A	v	$2E$	$2E$	$2E$	$2E$	$2E$
	e	$0.5E + 0.5D + \tau_\varepsilon$	$0.5E + 0.5D + \tau_\delta$	E	E	E
	o	$0.5D + 0.5L + \tau_\mu$	0	$D + L + \tau_\lambda$	$0.5D + 0.5L + \tau_\sigma$	0
	l	L	$0.5D + 1.5L + \tau_\mu$	$D + 2L$	$0.5D + 1.5L + \tau_\mu$	$D + 2L + \tau_\lambda$

3.4. The Three-player Congestion Problem Illustrated

The twelve figures in Figure 3.1 best illustrate the three-player congestion problem and the *mecc* and resulting efficient congestion tolls for 13 of the 16 possible congestion scenarios.[21] Thinking of the game in a sequential manner, the figures reveal the costs and harm at the individual level when a player creates or increases congestion.[22] The figures use abstract terms E, D, & L and assume homogeneous players but has a relative scale by departure time of time value preferences of $E = 5, D = 4, L = 8$. The first row (Figures 3.1a- 3.1c) show the costs of individuals departing Very Early, Figures 3.1d- 3.1f show costs of individuals departing Early, Figures 3.1g- 3.1i show costs of individuals departing On-time, and Figures 3.1j- 3.1l show individual costs of departing Late.

To see an intuitive illustration of congestion, consider the congestion that can occur at the Early departure time in Figure 3.1. As expected in Figure 3.1d when only one person departs Early that person incurs a (expected) cost of E since no queue is generated ($Q = 0$).[23] The incremental private cost (appears as “MPC”) from zero to one departures at Early is E. Now consider the congestion with two people departing Early ($Q = 1$) as shown in Figure 3.1e. As mentioned above, with this two-way congestion, *ex post* one person will arrive Early incurring a cost of E, while the other incurs a journey delay and arrives On-time and incurs a cost of D. The TSC are $E + D$ and are represented by the area of the rectangle over the two users. The MPC for both players is $0.5(E + D)$ since each player has an equal chance obtaining their desired arrival time. Notice the grey region, the second

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[21] The remaining three congestion scenarios are when a player creates a queue (scenarios *vve*, *eeo*, and *ool*) are illustrated in the appendix in Figures B.1d- B.1f in Figure B.1.

[22] The reader may want to refer to the figures in Figure B.2 in the Appendix to see the cost curves drawn in the more traditional manner. The figures depict the same information, but the illustrations in Figure 3.1 best convey the congestion problem on all players’ private costs.

[23] This differs from the prior nomenclature where Q now represents the amount of other players departing at the same time rather than the amount of users delayed from prior departure times.

Early departure increased the original player's *ex-ante* expected costs from E to $0.5(E+D)$. This increase is the *mecc* imposed by the second player and equals the change in social costs minus the marginal entrant's MPC evaluated at two Early departures. The marginal entrant is assumed to know that there is already one person departing at that time. Again, the *mecc* cannot include a player's own congestion externality costs.

Continuing with the example of players departing Early, when there are three entrants ($Q = 2$) we can see in Figure 3.1f the *mecc* substantially increases. The interpretation and calculation of the *mecc* when $Q \geq 2$ can be tricky. Recall that the *mecc* equals the costs imposed on society that the marginal entrant creates. This is why the shaded *mecc* region in Figure 3.1e of two-way congestion is not included in *mecc*. The costs of the existing two-way congestion were going to occur anyway and the value of the *mecc* and resulting toll should capture just the external costs the *marginal* player creates.[24] This point is emphasize because it is not easily observed when using the more traditional approach of modeling costs depicted in Figure B.2 shown in the Appendix. In the context of a small group, these illustrations of the effects of individual costs can easily demonstrate the problems from congestion and the need and the essence of congestion pricing to a lay person. Unlike the continuous space illustrated in the basic bottleneck model, the discretized version allows us for comparisons of *ex-ante* and *ex-post* outcomes and the welfare created with and without congestion pricing.

The *mecc's* illustrated in Figure 3.1 do not have a linear pattern. The existence and sizes of a congestion scenario's *mecc* depend on the time cost preferences: E, D, and L. For example, compare two-way congestion for the Early and On-time departure times. The *mecc* is noticeably smaller in Figure 3.1e than in Figure 3.1h. As mentioned in the previous section,

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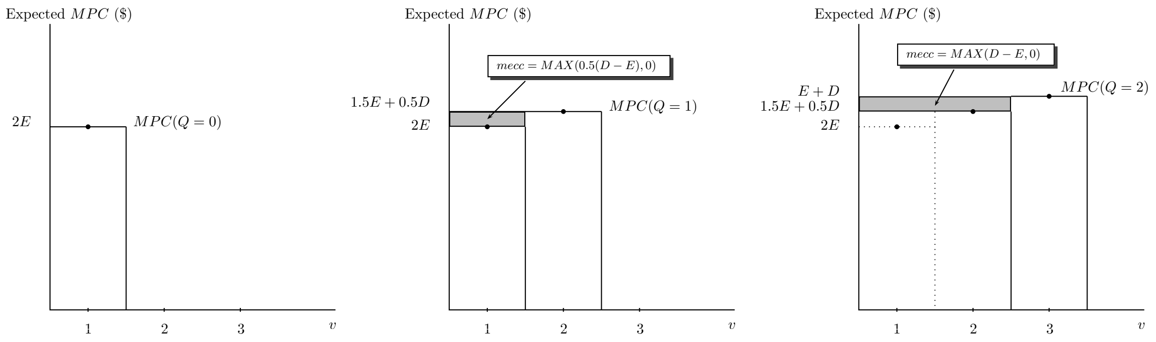
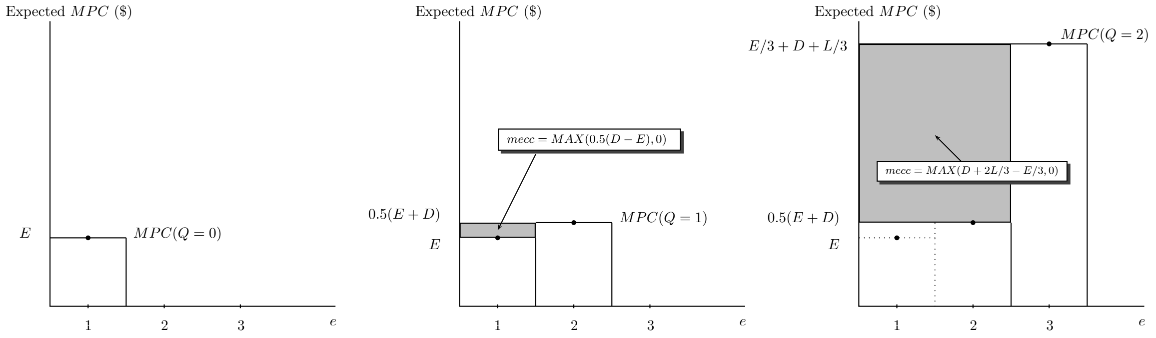
[24] It would be incorrect for the value to represent the difference between one and three entrants. The *mecc* should represent the change in costs of a single additional user. For games with N>3 the same properties hold when calculating the *mecc's* and resulting tolls of three-way congestion, four-way congestion, etc.

incurring a journey delay at the Early departure time results in the player not incurring any schedule delay by being bumped and arriving On-time. S/he will incur just the journey delay penalty, D. If $E > D$, then the *mecc* is negative since that player would prefer to be randomly be the player be bumped and incur a journey delay. The same properties do not hold for departure at or after the On-time departure time. Assuming positive parameters of E, D, and L, Very Early and Early departures could have negative *mecc* and a toll is not required, while times at or after the On-time departure will have positive *mecc* and will indeed require a toll (See Table 3.5).

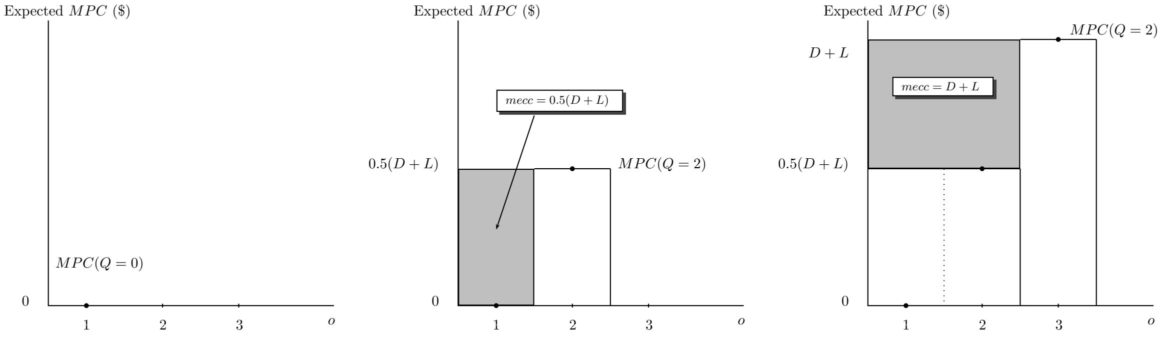
Conceptually, to solve the three-player game one must think of the game in a sequential manner. The four departure times illustrated in Figure 3.1 can be thought of as individual markets. Given the decision of a first player, the second player will make their decision on expected MPC with or without a toll of the four departure times (markets). The decision should differ between games with and without tolls. Observing the costs in Figure 3.1 motivates the need for efficient tolls. The inclusion of the toll will internalize the *mecc* and result in players making more socially optimal departure decisions by reducing congestion.



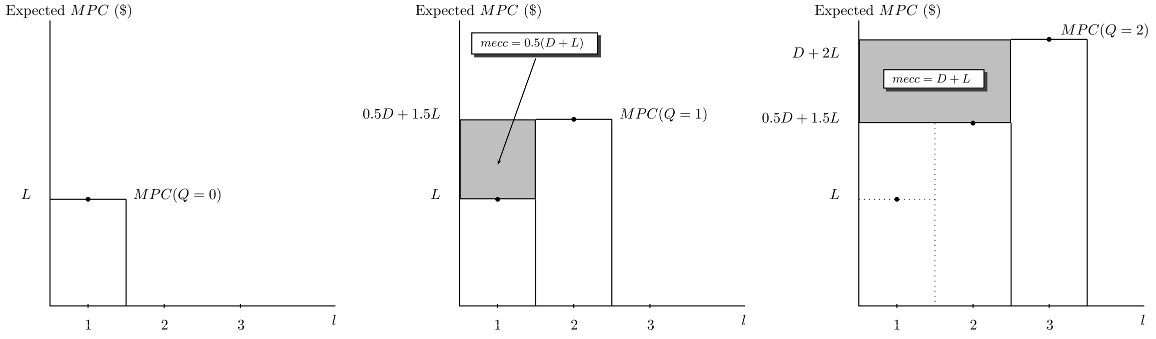
(A) One *Very Early* (B) Two *Very Early* (C) Three *Very Early*



(D) One *Early* (E) Two *Early* (F) Three *Early*



(G) One *On-time* (H) Two *On-time* (I) Three *On-time*



(J) One *Late* (K) Two *Late* (L) Three *Late*

Figure 3.1. The Incremental Costs Of Congestion Illustrated

3.5. A Discussion On Nash Equilibria And Model's Relevance

A simple closed-form method that solves Nash equilibria with and without tolls using parameters E, D, and L does not exist. The existence of PSNE depends on relative sizes of time cost parameters; if no PSNE exist then equilibria exist only in mixed strategies (MSNE). The PSNE of players departing at separate times typically exist when tolls are present. However, the PSNE are not unique since there are multiple PSNE of the same departure pattern when accounting for player identification. For example, if the predicted pure strategy equilibrium is Very Early, Early, and On-time then there exists six possible combinations of PSNE when accounting for player identification. The game then turns into a coordination game and players will employ mixed strategies since the socially-optimal PSNE is not unique. Players would randomize their departure decisions because of the uncertain nature of other players' decisions resulting in MSNE. A comparison of the MSNEs with and without toll can demonstrate that tolls provide an efficiency gain after toll revenues are redistributed.

To calculate all Nash equilibria including mixed strategies the open-sourced software Gambit is recommended (McKelvey et al., 2013). If PSNE exist, they can be found through an iterative process of players' best response using values from Table 3.4 and 3.6. An open question remains on how individuals base their decisions and whether learning and experience (hysteresis) affect their decisions (Roth and Erev, 1995; Ziegelmeyer et al., 2008). Players switching from a game with tolls to one without would revert back to a prisoner's dilemma.[25] Empirically observing the theoretical PSNE and MSNE predictions may take

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[25] Börjesson et al. (2012) did not observe people going back to their old habits immediately after the expiration of the six month congestion charge trial-period in Stockholm in 2006 and 2007.

several or multiple iterations of the game considering that this is a simultaneous game with 64 possible outcomes.[26]

The tolls do improve social welfare, but some players are definitely worse off. Some of the players are priced to a inferior departure time. A similar result is seen in the bottleneck model. Hau (1992) says that under "normal" traffic conditions and if the toll revenue is put aside, then an optimal toll achieves a socially efficient outcome, but would make society worse off because users' costs will increase. Only after the government spends the revenue will society be made better off. As mentioned in Levinson (2005), tolls are seen as a transfer and are assumed to be returned to the players (road users) in some form. A transfer needs to be assumed for any kind of efficient toll or Pigouvian policy to be welfare improving. However, methods of reducing users' costs through the handling of equity concerns and granting exemptions of certain groups from paying a toll can undermine efficiency (Anas and Lindsey, 2011). In a review of the literature on how to address equity concerns of road pricing, Levinson (2010) finds recycling collected toll revenues can address such concerns. Yet a tradeoff exists between alleviating fairness and equity concerns and improving system efficiency when considering or designing a pricing policy. Policymakers have to weigh the political feasibly of a congestion policy and whether it will be politically acceptable. Levinson (2010) remarks that the perception of equity is highly subjective and satisfying certain groups is necessary to obtain acceptability of congestion program.

In a small group environment, players would likely adjust their expected costs to account for the large revenue shares of any redistribution. Players would be aware that economically

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[26] Similarly, observing the MSNE in the classic "rock-paper-scissors" game (also called roshambo) observing the mixed strategy of every player randomizing their strategy by a third would take multiple observations. A player randomizes their strategies to keep the other players guessing so to not allow others to obtain advantage in the game.

significant shares of revenue recycling are likely because of the small N environment, the one-shot nature of the game, and the likely prompt timing of payouts of revenue shares. Players expecting revenue redistribution will discount the magnitude of the tolls which will degrade the objective effects and the efficiency of the tolls.[27] For example, a three-way congestion would no longer trigger a positive toll charge since if everyone pays the same toll and all revenue is redistributed back in lump-sum payments, then there is no additional cost for entering that scenario.[28] It is therefore important to consider when factoring in any type of redistribution the best response for a given departure pattern might change compared to a binding toll since players are considering the increased amount of toll revenue they will receive.

An example of a player accounting for revenue redistribution, where the toll incentivizes the player to make a Pareto inferior best-response decision, is the situation when the other two players are assumed to depart Early. Under standard assumptions for time cost values and with binding tolls, the best response for Player A to Players B and C both departing Early is to depart Very Early as can be shown in Table 3.6 (assuming $2E < L + D$). Yet full lump-sum redistribution of tolls complicates this best response. Player A will know that Players B and C will pay higher tolls, which increases toll revenues, if s/he chooses to depart On-time versus Very Early and thus will receive a larger compensation that will offset their expected costs. In Table 3.4, tolls for *eev* are less than *eeo*, which implies that the share of toll revenue will be greater if the player departs On-time. Therefore, the best response for Player A when the other two players depart Early is to depart On-time. An Early departure

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[27] An open question is how any redistribution will affect the performance of an omniscient pricing scheme.

[28] Such a departure decision may not be a best response *ex-post*.

minimizes their expected costs after adjusting for redistribution.[29] This shift of expected costs makes the outcome Pareto inferior since it increases TSC by increasing the amount of journey delays from one to two. Any proposed solution for this issue needs toll revenue to be allocated in such a way that it both improves social welfare and still achieves the social optimal in PSNE. This solution could be distributing a percentage of total revenues, the addition of third-party players that will spread and decrease the percentage of revenue allocation, or other methods that do not make the congestion policy Pareto inferior.

Note that this formal extension of the three-player game is not limited to making theoretical predictions, it can also be applied to laboratory experiments or classroom exercises.[30] The author has ran experiments of this game to investigate the performance and public acceptability of congestion tolls. The game was programmed and conducted with the software z-Tree (Fischbacher, 2007).[31] Classroom exercises using the same z-Tree code were conducted in Professor Levinson's Introduction to Traffic Engineering course at University of Minnesota in October 2013. Classroom experiments or similar hands-on approaches can provide an engaged learning tool for people (hopefully current and future policymakers) to understand congestion and congestion pricing.

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[29] From Table 3.5, total toll revenue (the toll multiplied by two) for the situation of *vee* is $MAX(D-E,0)$ while the total toll revenue for *eeo* is noticeably higher at $MAX(3D+2L-E,0)$. A full lump-sum redistribution of toll revenue (each player receives $MAX(D+\frac{2L}{3}-\frac{E}{3},0)$) implicitly subsidizes and incentivizes Player A to choose the socially inferior best response of departing On-time when the two other players are assumed to depart Early. An On-time departure will then, assuming a positive toll, have an adjusted expected cost of $\frac{E}{3}+\frac{L}{3}$ instead of the expected cost of $L+D$ of departing On-time without revenue redistribution. The adjusted expected costs are then $\frac{7E}{3}-D-\frac{2L}{3}$, $\frac{1}{3}E+D+\frac{1}{3}L$, $\frac{E}{3}+\frac{L}{3}$, and $\frac{E}{3}+\frac{L}{3}-D$ for departures of Very Early, Early, On-Time, and Late, respectively, given the other two players depart Early. The adjusted expected costs will most likely be less for On-time departure than the Very Early and Early departure if $6E > D+L$. It is up to the reader to modify the formal game and add a redistribution parameter that takes values 0-1 for collected toll revenue.

[30] See Ziegelmeyer et al. (2008). Using their own model based on the bottleneck model, they investigate the impact of public information and size of group on players' selection of scheduled discrete departure times. Their framework does not discuss the introduction of efficient tolls.

[31] A copy of the z-Tree code is available upon request

As with the case of including referendum votes, the game can be extended to test numerous theories in a laboratory environment. The provided formal framework of the congestion model can allow for relaxation of assumptions and further extensions to investigate congestion using game theory. Researchers applying the model must be aware that examining and testing MSNE in the laboratory is difficult and requires many observations.

3.6. CONCLUSION

This chapter corrects and further develops the discretized game-theoretic bottleneck model first introduced by Levinson (2005). This simplified and discretized version of the heavily discussed basic bottleneck model of users trading off travel time (journey delay) costs and schedule delay costs can illustrate the theoretical *ex-ante* and *ex-post* predictions and welfare implications of congestion with and without congestion pricing. The model assumes three players, but it can be expanded to more than three players. The inclusion of a third player introduces the problem of when a player enters behind an existing queue. Without congestion pricing and over a range of cost parameters, the game emulates a prisoner's dilemma. The predictions of the model indicate that congestion is an outcome of rational behavior. The inclusion of an efficient toll can lead to pure-strategy Nash Equilibria (PSNE) resulting in a socially optimal outcome or more efficient mixed-strategy Nash Equilibria (MSNE). However, some forms of revenue allocation can distort behavior yielding an inferior congestion policy that does not guarantee gains in efficiency. Through the understanding of simple interactions in a congestion context, policymakers exposed to such thinking can be made more informed of the congestion problem and the effects and necessity of congestion pricing.

The inclusion of an efficient toll equaling the marginal external congestion cost (*mecc*) of a player entering a departure time can lead to a socially optimal solution that may not be unique. The existence of multiple PSNE implies that equilibria exist in MSNE. The model confirms two troubling results mentioned in Silva et al. (2014) as they relate to the equilibrium solution in bottleneck model: the potential nonexistence and uniqueness of PSNE with or without tolls and that if PSNE do not exist, identical or homogeneous users can incur different equilibrium costs.

The existence of non-unique equilbria in pure strategies makes it difficult to observe any mixed strategies in a laboratory environment. The model can be extended to discuss methods of revenue allocation to generate a PSNE that obtains the socially optimal outcome unique. But any unique equilibrium solution will most likely have to have heterogeneous preferences among the three players or for the revenue allocation to create "winners" and "losers" *ad hoc* among homogeneous agents. The result in Levinson (2005) that tolls equaling a player's *mecc* act as an information signal and are not paid in the PSNE is important; however, since the optimal PSNE are not unique, there is still a need to design an effective toll revenue redistribution scheme while keeping the tolls efficient. The type of redistribution scheme is important when considering the public and political acceptability barriers of policymakers introducing congestion tolls. The hope is that this model can demonstrate to policymakers that congestion is a problem and such barriers are worth confronting. However, the model suggests that the public may not be persuaded to accept a congestion pricing institution where equity concerns are endogenous, the costs of traveling increase from tolls, and the existence of equilibria in mixed-strategies still creates potential congestion problems.

CHAPTER 4

PERFORMANCE AND ACCEPTABILITY OF CONGESTION PRICING OF A THREE-PLAYER BOTTLENECK GAME: EXPERIMENTAL EVIDENCE

4.1. INTRODUCTION

Traffic congestion generates costs to society in different ways–extra fuel is consumed, more vehicle miles are traveled, land-use decisions are distorted by the presence of congestion externalities, and commuters face time-delays. The Texas A&M Transportation Institute states in its 2012 Urban Mobility Report (Schrank et al., 2012) that United States traffic congestion costs are increasing and that in 2011 congestion generated additional carbon dioxide emissions of 56 billion pounds, about 2.9 billion gallons of fuel wasted, and $121 billion in total financial costs. These total financial costs translate to $818 per U.S. commuter in 2011. But the majority of the negative externality costs from urban transportation congestion stem from time-delay costs (Anas and Lindsey, 2011). These costs are cuased by road users even though many of these users make decisions of taking different modes of transportation, routes, or departing at different times, to avoid many of the costs of congestion.

When addressing traffic congestion, policy-makers face natural limitations of expanding road and parking capacity in urban areas and turn to demand management policies that use incentive-based mechanisms such as road pricing, cordon zone pricing, or demand-response pricing for parking. While economists recommend such theoretically efficient policies, policy-makers interested in mitigating the costs of negative externalities from traffic congestion are concerned with the actual efficiency and with political feasibility and public acceptability of incentive-based mechanisms. Plans to implement road congestion pricing in Hong Kong, Malaysia, the Netherlands, Scotland, and cities in the United States failed because of public opposition (Hau, 1990; Kallbecken, 2013). However, congestion pricing policies were successfully implemented and politically accepted, albeit disputed, in cities such as Stockholm, Singapore, London, and Milan (Anas and Lindsey, 2011; Winslott-Hiselius et al., 2009). Some of these schemes were successful in achieving their intended goals, others failed; partly because commuters did not respond to the incentives the way policy-makers expected, partly because the schemes, in an effort to increase acceptability, were not set up in a way economists would recommend. The public acceptability literature raises several questions on why some city congestion polices succeed while others do not. Yet as prefaced in much of the literature, each city's congestion policy experience has its unique circumstances on why a city's policy became a success or failure.

Two research questions then ensue, which motivated this chapter: how do individuals respond to different incentives in a congestion context when welfare effects are endogenous, and what factors influence the public acceptability of an incentive-based mechanism. By connecting the performance of individuals to their political worldviews on the acceptability of such a policy, we can elicit reasons why some incentive-based programs are successfully implemented while others fail. But since real-world data on individual congestion behavior are sparse and fraught with noise, we turn to laboratory experiments to investigate the performance and acceptability of revenue-neutral congestion tolls that are enacted by a series of referendum votes. Although observing a real-world experiment would be ideal, laboratory experiments allow for a low-cost setting to examine actual incentive-compatible behavior and can provide a guide of translating how policies would perform in the real world. I apply a three-player bottleneck congestion game that contains time-delay externalities and emulates a three-player prisoner's dilemma where the welfare effects are endogenous.

Despite theoretical predictions of efficiency improvements from revenue-neutral tolls, the results show varied performance and efficiency improvements. Congestion tolls appear to be most effective when there are higher schedule delay penalties (i.e., less schedule flexibility) yet the efficiency improvements from tolls did not automatically lead a group of individuals to the theoretically predicted socially optimal outcomes. Even with the evidence varied efficiency improvements from revenue-neutral tolls, public acceptability–measured by a series of referendum votes–did not increase over time. In this setting, political worldviews appear to have no strong effects on public acceptability.

The rest of this chapter is organized as follows. The next two sections present background information that reviews the literature and describes the three-player bottleneck congestion model used for this experiment. Section 4.4 presents the experiment design of the experiment. Section 4.5 presents the empirical results and discusses some implications of the results, and Section 4.6 concludes.

4.2. Review Of Literature

A plethora of literature exists that investigates congestion issues for different fields. Urban traffic congestion is one field that has interdisciplinary interest among urban planners, traffic engineers, economists, and others interested in the societal and environmental impacts from congestion. This chapter's focus on time-costs is a concept at the core of many issues related to congestion and queuing theory with many focusing on the allocation and value of time developed by Becker (1965). This chapter builds on the (endogenous) allocation and value of time concept by combining it with the observation by Anas and Lindsey (2011) that time-delay costs contribute to the majority of the negative externality costs from urban transportation congestion.

The theoretical discussions of traffic engineering by Wardrop (1952) in the 1950s paved the way for an enormous amount of literature in urban traffic congestion. Vickrey (1969) proposed a bottleneck theoretical model that uses a value of time metric to examine congestion problems. His model is used as the basis to many extensions that theoretically examines issues concerning traffic congestion such as number of routes, number of bottlenecks, preferences of motorists, parking availability, dynamic problems with congestion, and other related to transportation congestion issues (De Palma et al., 1983, 1997; Ben-Akiva et al., 1984, 1986; Arnott et al., 1990a,b, 1993; Arnott, 1994; Arnott et al., 1994; Arnott and Small, 1994; Arnott, 2006; De Palma and Fosgerau, 2010; Qian et al., 2011, 2012). These developed congestion models assume many individuals and motorists do not specifically examine congestion at the individual level. Levinson (2005) fills this gap by adapting Vickrey's model for a game-theoretical bottleneck congestion model with individual players. Levinson's model can examine congestion with just the simplest form of two players but can be expanded to multiple players. The model with three players is developed in Chapter 3 and is also described in the next section; it is useful for examining and predicting outcomes as well as calculating the optimal congestion tolls that make players internalize the social costs of increasing time-cost delays they impose on others when creating congestion.

Congestion and responsive pricing has been discussed since Vickrey (1971) as demand-management tool for congestion goods or goods having uncertain short-term demand. This type of pricing has been implemented for goods such as electricity, canal and airport slots, internet bandwidth at cafes, vending machines, and alcoholic beverages at bars.[1] The urban transportation literature has recently focused on pricing of roads and parking spaces (Lindsey and Verhoef, 2000; Anderson and De Palma, 2004; Shoup, 2005; Zou and Levinson, 2006; Borger, 2011).[2] Most of the literature examines the efficiency improvements and investigates the trade-offs stemming from equity concerns when responsive pricing is being used as a demand-management tool. Chapter 3 formally adapts the Levinson (2005) bottleneck congestion game, making it the most appropriate model for investigating the performance and acceptability of tolls that theoretically act as a responsive pricing mechanism that manages congestion.

Testing and investigating congestion theories in the real world is difficult. Because of the enormous costs and infeasibility of implementing policies and collecting data, laboratory experiments have recently provided a low-cost alternative of investigating bottleneck congestion models (Anderson et al., 2008; Hartman, 2007, 2012; Denant-Boemont et al., 2009; Ziegelmeyer et al., 2008). None of these experiments have incorporated voting behavior and investigated the trade-off between efficiency and equity concerns of congestion (Pigouvian) tolls. The Levinson (2005) bottleneck congestion game applied in this chapter does not have the exact properties as those in the previous literature. Such differences may prohibit the translation and comparison of results to previous congestion experiments, forms of the bottleneck congestion model, and three traffic paradoxes: Braess, Downs-Thomson, and Pigou-Knight-Downs. However, the objective of this chapter is to examine the performance and public acceptability of congestion tolls when welfare and equity concerns are

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[1] "A bar with changing prices" Freakonomics, April 13, 2012. http://www.freakonomics.com/2012/04/13/a-bar-with-changing-prices

[2] San Francisco is the first major city to experiment with responsive pricing for parking with their *SFpark* program (Chatman and Manville, 2014).

endogenous. The model in Chapter 3 provides a game-theoretical base to compare empirical outcomes to theoretical predictions. This chapter contributes to the literature by displaying the performance and acceptability of a Vickrey based bottleneck congestion model.

A range of literature examining the public acceptability of incentive-based mechanisms that deal with negative externalities exists with many studies focusing on the performance and acceptability of road policies (Schade and Schlag, 2003; Marcucci and Marini, 2001; Gaunt et al., 2007; Winslott-Hiselius et al., 2009; Larson and Sasanuma, 2010; Kallbecken, 2013). Schade and Schlag (2003) and Kallbecken (2013) identify and discuss factors that determine the public acceptability and political feasibility of incentive-based mechanisms. Even though pricing congestion can be seen as a mechanism to achieve cooperation and socially optimal outcomes, the public acceptability of any incentive-based mechanism is recognized as a main obstacle to the successful implementation of such a policy. Plans to implement road congestion pricing in Hong Kong, Malaysia, the Netherlands, Scotland, and the United States failed because of public opposition (Hau, 1990; Kallbecken, 2013). However, congestion pricing plans were successfully implemented and politically accepted in cities such as Stockholm, Singapore, London, and Milan. Yet each city has its own circumstances to explain the success or failure of congestion pricing policies. Eliasson (2009) comments that one of the issues related to urban road pricing is the imperfect nature of real-world pricing schemes. He argues that unlike predicted theoretical outcomes, these actual schemes do not guarantee that their benefits exceed their set-up and operation costs. This experiment examines if the endogenous welfare effects affect the success of a congestion toll policy.

The perceived effectiveness and efficiency of the congestion program assisted with the experience and eventual success in Stockholm. Furthermore, the implementation and positive experience of a trial run assisted and helped overcome the program's initial negative view resulting in a 51.3% referendum vote approval of keeping the policy permanent (Börjesson et al., 2012; Winslott-Hiselius et al., 2009). Such approval also overcame the perceived distributional and equity concerns of the regressive nature and punishing effects of road prices on society's poorer population (Karlström and Franklin, 2009). Yet Anas and Lindsey (2011) speculate that the voting behavior was influenced by political ideology (Hårsman and Quigley, 2010).

Yet pricing policies in cities like Hong Kong and Edinburgh, Scotland, failed. Distributional and equity concerns and the lack of understanding of the effectiveness of the program resulted in rational and self-interested people to vote down or discontinue these programs. Gaunt et al. (2007) reviewed self-completed questionnaires from voters in Edinburgh and found that the pricing scheme was too overly complex for people to understand and that car ownership was a principal determinant of voting behavior. This complexity did not allow car owners to fully appreciate the potential benefits and effectiveness of the scheme even though most knew that congestion was a significant and growing program. As such, this misunderstanding and Edinburgh's failure to expand transit opportunities as part of the program resulted in citizens in 2005 opposing and voting down the road pricing scheme (Anas and Lindsey, 2011).

Similarly, despite having a 21-month long trial run, Hong Kong had several contributing reasons for why their electronic road pricing system failed despite reports that the policy had an estimated benefit-cost ratio of 14 to 1 (Hau, 1990). Hau (1990) lists a few of the contributing reasons for why the policy was voted down: the income effects of a weakening economy at the time, the distributional concerns of motorists due to the exemptions of certain vehicles, the lack of public relations between the government and citizens, and the distrust people had on whether the government would follow through with their earmarking promises. So it appears that the circumstances for the acceptability of a congestion pricing scheme are sensitive to the perceived effectiveness and efficiency, the distributional concerns, and the rational self-interest and knowledge of voters of the policy. Experimental analysis thus seems to be an appropriate method to understand the significance of these reasons.

Motivated by the Stockholm experience in 2006, only recently has the public acceptability of Pigouvian like taxes been tested in a laboratory environment (Cherry et al., 2013, 2012; Kallbekken et al., 2011). Cherry et al. (2012) designed an externality-game experiment that includes treatments of a trial run with an efficient Pigouvian tax. They find that the experience of the trial run increases the acceptability of a tax, and that a positive experience of a trial run can overcome misperception and biases about an incentive based mechanisms tax policy. Yet unlike Stockholm, this evidence is not supported by what was observed with the experience in Hong Kong. Another experiment conducted by Kallbekken et al. (2011) found that a lack of understanding of the workings and effects of a Pigouvian tax instrument does not influence the opposition of such policies. So unlike the experimental designs of these experiments where subjects are maximizing profits with the presence of an externality, the experiment used in this chapter has subjects making cost-minimization decisions, which is more consistent with what is experienced in the real world.

This chapter touches on most of these factors that contribute to the public acceptability. But the chapter's focus is examining whether self-interest, distributional concerns, and the perceived effectiveness and efficiency of a policy when equity effects are endogeneous, are significant factors for determining the acceptability of a congestion toll policy. Such results will add to the literature and may highlight the factors that contribute (or not contribute) to the public acceptability of a congestion toll.

4.3. Three-Player Bottleneck Congestion Game

The bottleneck congestion game is derived from the game-theoretical model presented in Chapter 3 that emulates a three-player prisoner dilemma. In the game, all players have the same origin and decide when to depart to reach their (same) destination knowing that a bottleneck exists that restricts the arrival time so that a queue can develop. Introducing congestion pricing in the game can minimize total social costs if the revenue is returned to the participants (Levinson, 2005).

Each player has the discrete options of departing at one of four time slots: Very Early, Early, On-time, or Late. If two (three) players depart at the same time there will be congestion, and one (two) players will randomly arrive in the next (next and second to next) time slot. Six arrival outcomes are then possible: Very Early, Early, On-time, Late, Really Late, and Super Late. Players thus can depart at the same time slot, but because of the bottleneck will not arrive in the same time slot. If two players depart at the same time slot then randomly one will arrive at that time slot while the other incurs a journey delay and arrives at the next time slot. For the situation where all three players depart at the same time slot, then it is randomly determined that one player arrives at that time slot, another player incurs a journey delay and arrives at the next time slot, and the third person arrives two time slots later and incurs costs of being twice journey delayed. There exists 64 departure patterns with 20 distinct departure patterns if ignoring player identification. Players thus make cost-minimizing decisions and their costs (penalties) depend on their arrival time and the amount of journey delays.

Congestion created by players departing at the same time imposes a negative externality in the game and affects players that were never contributing to the congestion. Tolls are prescribed to mitigate this negative externality and reduce overall social costs. Tolls are only paid by a player that creates congestion. The congestion tolls are equal to the incremental (marginal) external congestion cost created by a player that enters and departs in a specific congestible scenario. It is the difference between the incremental social cost of entering a congestible scenario and the incremental private cost the user incurs by entering that scenario. For example, assume two players depart Early and On-time. A third player that also departs On-time increases the expected costs and imposes *ex-ante* an externality on that original individual that departed On-time since there is now a chance of that individual incurring a journey delay and arriving Late. The efficient toll is thus the incremental social costs (increased expected time costs borne by the other two player(s)) generated by the congestion from the third player's decision.

Out of the 64 possible departure patterns, there are 40 congestible scenarios when considering player identification and 16 congestible scenarios without considering player identification. Depending on the game's time-cost parameters, up to 16 non-zero valued tolls can be imposed for the 16 congestible scenarios without considering player identification. Each toll represents the externality that is incurred by the other player(s) by someone entering a congestible scenario and affects the other players' expected costs (the sum of journey and schedule delay costs). Please refer to Chapter 3 for the game-theoretical model and formal framework of the three-player game and the derivation of efficient congestion tolls. The tolls in this experiment are imposed only when congestion is created; tolls are revenue-neutral where toll revenue is redistributed lump-sum to all three players. The strategies and level of efficient tolls of the game depend on each individual's time-cost parameters. This game can be applied to where players have heterogeneous or homogeneous preferences. This chapter focuses on the case where players have known homogeneous preferences. A trade-off of fairness and efficiency among players may be elicited from having homogeneous preferences since subjects will observe and experience clear "winners" and "losers" from departure decisions and resulting arrival outcomes.[3]

4.4. EXPERIMENT DESIGN

The experiment is designed to elicit information to test the performance and acceptability of efficient tolls. In the experiment, the objective of each participant is to minimize travel costs. Participants are in groups of three and each participant decides when to depart while facing a bottleneck.

The experiment follows a 2×2 design that varies two treatments: sequencing of cost parameters (reference, low, and high costs) and whether a policy of congestion pricing (tolls) occurs in the first session of each round. The experiment consists of three rounds consisting of three sessions each. Each session consists of four periods where participants decide when to depart. Participants are randomly assigned into a group for each of the three rounds. After the first and second session (after the fourth and eighth period) of a round, a referendum vote occurs on whether to approve or disapprove a policy that introduces revenue-neutral tolls for the next 4-period session. A summary of the experiment is depicted in Table 4.1. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007).

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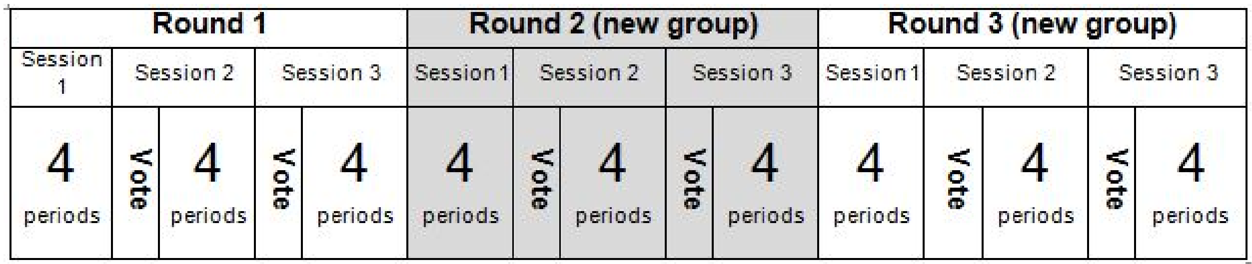
[3] See Chapter 3 for the Cheung (1983) boat tracker analogy.

Table 4.1. Summary Of The Experiment



Round 1					Round 2 (new group)					Round 3 (new group)				
Session 1	Session 2		Session 3		Session 1	Session 2		Session 3		Session 1	Session 2		Session 3	
4 periods	Vote	4 periods	Vote	4 periods	4 periods	Vote	4 periods	Vote	4 periods	4 periods	Vote	4 periods	Vote	4 periods

4.4.1. Experimental framework and parameters. Each round in Table 4.1 contains different time-cost preference parameters that yield different theoretical predictions. Parameters are based on the empirical estimates in Small (1982) and are homogeneous for a group.[4] Round 1 has parameters that are referred in this chapter as the "reference" cost case. The treatment effect for ordering of time-costs preferences occurs in rounds 2 and 3. Subjects have either "low" time-cost preferences in Round 2 and then "high" time-cost preferences in Round 3, or vice versa. Since subjects are making decisions over time, learning effects are likely. This treatment effect is then used to observe whether the ordering of cost time-preferences matters when examining the performance and acceptability of the congestion toll policy.

The second treatment effect is to test whether experience of the revenue-neutral pricing policy matters when examining performance and acceptability of such a policy. Similar to the experience in Stockholm, this is done by having a treatment where the first session of each round, as seen in Table 4.1, either have or do not have an institution with congestion

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[4] Small (1982) empirically estimated time preferences by worker type, family size, and type of commuter. Three of his estimates are employed in this experiment: "all drivers" "drivers that drive alone" and "drivers that drive alone, have a family and a white-collar job" for our reference, low, and high time-cost parameter cases, respectively. Small (1982) provides marginal rates of substitution of schedule arrivals by minutes of travel time for different subgroups of commuters. A minute of travel time is equivalent to one minute of journey delay. The values in the table were scaled up by four and rounded to get tractable parameter values for the experiment.

tolls before their first referendum vote. This effect will allow us to examine hypotheses related to how experience affects performance and acceptability of congestion tolls.

At the beginning of the experiment subjects are told that they are endowed with 400 laboratory tokens worth ten cents each. The time-cost preferences are thus measured in laboratory tokens. Thus cost-minimization is the objective of all subjects. As mentioned before, cost-minimization decisions in a context of congestion seem more consistent with real-world scenarios as well as being more tractable with the theoretical transportation congestion literature. Information on the toll values are disclosed before every decision is made. Subjects are updated on their individual cost outcomes, total toll payments, and share of toll revenue recycled at the end of every session and round. A general summary of individual and group outcomes are disclosed at the end of every period.[5]

Each subject experiences six referendum votes. The votes occur after the first and second session of each round (see Table 4.1).[6] Thus depending on the period and what treatment they are randomly placed in, subjects vote either to implement, not implement, continue, or dis-continue tolls for their group for the next four-period session.[7] They should vote for the policy if their welfare will improve from more reliable and lower cost outcomes. People

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[5] Each subject was provided a handout that had a period by period table so that they can keep track of their decisions and outcomes.

[6] I was cautious with the wording of the referendum vote in the experiment as to not influence the voting decisions of the subjects. Instead of describing the motivation of tolls of reducing congestion costs, rather the wording was kept more general. By keeping the wording general of stating that only those that create congestion are tolled and nothing to suggest welfare improvements, I did not want to prime subjects to vote a certain way. Additionally, I believed that subjects would have correctly rejected the tolls because of the additional negative welfare implications of creating congestion if the toll revenue was not redistributed. Thus the design of having total redistribution of tolls provides the best-case of a congestion demand-management policy. Real-world benefit-cost analysis of such congestion policy would have to consider other parts that affect the cost-benefit analysis of the program such as administrative costs, distributional concerns, and other alternatives to tolls.

[7] Such a design might make it difficult to make empirical cross-treatment comparisons since subjects are self-selecting their own treatment of experiencing the policy of tolls. Thus there exist multiple paths a subject can experience throughout the experiment on whether or not they participate with tolls. It is unlikely that one subject will have the same experience of having tolls or no tolls in each session as another subject.

should vote against the policy if they are averse to the possibility of paying tolls and/or having to depart at an undesirable costly time.

4.4.2. Theoretical predictions. The predicted outcomes depend on the time-cost parameters. Each parameter specification provide their own predicted outcomes. Table 4.2 summarizes the predicted Nash equilibria for the different cost parameters assuming no revenue redistribution.[8] Note that the reference and low-cost parameter cases yield no pure strategy Nash equilibria when no tolls are in place; only mixed-strategy Nash equilibria exist for these time-cost preferences.[9] In all three cases with tolls, three players departing separately at the earliest three time slots, *veo* (Very Early, Early, and On-time), is a pure strategy Nash equilibrium. In pure strategies, there are six possible sequences that this departure scenario occurs with player identification. All players depart at different times with this outcome, which results in no congestion and the lowest possible cost outcome for the group. In addition to this departure sequence, the low-cost case has an additional Nash equilibrium of *eol* (Early, On-time, and Late). Such a departure sequence yields the same minimum-cost outcome as the Very Early, Early, and On-time departure sequence, but only for the low-cost scenario.

Congestion tolls for each of the cost cases are depicted in Tables C.3.1 and C.3.2 in the Appendix.[10] The tolls act as a threat and are only paid by the players that create the particular congestion. The values in Table C.3.2 also show the marginal (incremental)

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[8] Recall that in the experiment revenue is redistributed at the end of stage. In my opinion, the uncertainty of the level of tolls and the lag in redistribution makes the tolls more binding.

[9] Mixed-strategy Nash equilibria were calculated using the software Gambit (McKelvey et al., 2013). Numerous mixed-strategy Nash equilibria exist for each time-cost case. This chapter reports only the symmetric equilbria. The non-symmetric mixed-strategy Nash equilbria can be made available by author upon request.

[10] After the experiment it was determined that the charges for the three-way congestion scenarios were originally overvalued. Referring to Table 3.5 in Chapter 3, the tolls used for *vvv, eee, ooo,* and *lll* were $2D-2E$, $2D+\frac{2L}{3}-\frac{4E}{3}$, $2L+2D$, and $2L+2D$, respectively. The error did not affect pure-strategy Nash equilibria (assuming no toll revenue is redistributed.)

Table 4.2. Predicted Pure Strategy Nash Equilibria Solutions

				No Tolls		**With Tolls (Optimal)**	
Parameters	***E***	***D***	***L***	***# N.E.***	***Solutions****	***# N.E.***	***Solutions****
Reference	3	4	8	13 (4)**	mixed N.E.	49 (12)	*veo*
Low	2	4	4	52 (13)	mixed N.E.	28 (7)	*veo*, *eol*
High	5	4	12	1	*eee*	49 (12)	*veo*

*Symmetric Mixed Nash equilibrium for reference cost case with no tolls: $v = 19.82\%, e = 80.18\%, o = 0\%, l = 0\%$; with tolls: $v = 42.3\%, e = 36\%, o = 21.7\%, l = 0\%$.. Symmetric Mixed Nash equilibrium for low-cost case with no tolls: $v = 19.38\%, e = 68.58\%, o = 7.8\%, l = 4.23\%$; with tolls $v = 31.83\%, e = 34.20\%, o = 25.67\%, l = 8.3\%$. Symmetric Mixed-strategy Nash equilibrium for high-cost case with tolls: $v = 38.56\%, e = 42.13\%, o = 19.31, l = 0\%$.

**For count of mixed-strategy Nash equilibria, the number in parentheses ignores player identification.

external congestion cost a single player creates by entering in a particular congestion scenario. This cost is the increased expected journey and schedule delay incurred by the other players. For the three cost cases, the tolls should have a noticeable behavioral effect of the best responses of the player when they assume that the other players depart Early and/or one departs Early and the other On-time.

The socially optimal outcome of players departing at separate times is analogous to the Chapter 2 two-route congestion game socially optimal outcome of three of the lowest value of time players taking the slower uncongested route, Route B. Both outcomes minimize total social costs. However, the social optimum in Chapter 2 is a unique pure-strategy equilibrium while here it is not unique. Multiple pure-strategy equilibria exist and in mixed strategies as well. Hence the equity effects in this experiment are unstable and endogenous while in Chapter 2 they were exogenous and predicted to be stable.

Note in Table C.3.2 in the reference and low-cost cases that the optimal level of congestion is zero. Zero congestion can be socially acceptable in some cases in the high-cost case. For example, assume player 1 departs Very Early and player 2 departs On-time in the high-cost case. If Player 2 departs early, then Player 1 would incur a cost of 12 and player 3 a cost of 0. But if Player 2 departs the same time as player 1, Very Early, and if Player 1 is delayed to the Early time slot, then player 1 suffers a journey delay cost of 4 and a schedule delay cost of 5 (total cost of 9). Congestion at Very Early *ex-ante* actually reduced player 1's (expected) costs! So although congestion in the high-cost case creates journey delays, congestion in the Very Early time period does not create positive marginal social costs thus is socially acceptable and optimal only if it occurs in the Very Early time period. But the optimal amount of congestion evaluated at the Nash equilibrium with tolls is no congestion occurring across all cost-cases. Therefore congestion is still socially acceptable only when it occurs in the Very Early time slot for the high-cost case.[11]

Tables C.1.1, C.1.2, and C.1.3 in the Appendix are the normal-form representation of the games for each cost case, with and without tolls, for a given player. The expected costs for each departure scenario is the sum of the expected journey delay and expected schedule delay given the departure strategies of the other two players. Chapter 3 provides more detail on how these values are created. The best response for every player is the departure decision that minimizes expected costs (see Table 4.2) for equilibria for each cost case and toll scenario. All games with no tolls represent a prisoner's dilemma where the decisions of self-interested individuals lead to a sub-optimal group outcome that increases total group costs.

The high-cost case best illustrates the prisoner's dilemma of the congestion game (refer to Table C.1.3). Without tolls, risk-neutral individuals ought to depart early since this decision minimizes expected individual costs at $\frac{29}{3}$ and no other decision could make the individual better off. Such an outcome represents a unique pure-strategy Nash equilibrium as reported

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[11] Other time-cost parameter values may also result in some congestion being socially acceptable and even socially optimal. Moreover, the real world will most definitely have some non-zero level of congestion be socially acceptable and optimal.

in Table 4.2. Yet if all depart Early, then randomly one person arrives early and incurs a cost of 5, another is delayed to the On-time slot and incurs a cost of 4, while another person is delayed twice, arrives Late, and incurs a cost of 20. This pure-strategy equilibrium leads to a total group cost of 29 where individuals have a 33% probability of incurring the highest individual cost of 20. But the group can be made better off if they have a departure pattern of *veo* which achieves the lowest and optimal group cost of 15. Yet *veo* is not stable without tolls and individuals have the incentive return to the strategy of departing Early.

In the high-cost case, consider an individual that deviates (assuming the other two players depart Early) and instead of departing Early she departs Very Early. Such a deviation yields an expected cost of 10 for the individual, which is half the amount of cost if the individual ended up arriving Late, but 10 is greater than the expected cost of $\frac{29}{3}$ from departing Early. Moreover, departing Early allows a two-thirds chance to obtain a lower individual cost of 5 or 4 compared to the expected cost of $\frac{29}{3}$. As such, a Pareto improvement, based on arrival outcomes, is possible if two of the three players deviate with one departing Very Early and the other On-time. Yet the context and institution of the game from the randomness of who actually gets congested and when they arrive does not allow for such coordination to happen. However, when tolls are in place then individuals can cooperate and obtain the efficient minimal-cost outcome of *veo* for the high-cost case. Like the high-cost case, a similar story can be told regarding the prisoner's dilemma faced in the reference and low-cost cases but with the presence of mixed strategies without tolls.

4.5. Empirical Analysis

Using undergraduates from Colorado State University, 2880 total individual observations and 940 group observations were collected.[12] The average age was 19.3 with a third of the subjects being female. Each subject participated in 3 groups, thus with 84 subjects there were 84 total unique groups (28 for each cost scenario). Observations between institutions with tolls and without tolls across all cost scenarios are not evenly split because of varied populations across treatments and voting behaviors.[13] Below is the empirical analysis of the data collected from the experiment that examines group performance and voting behavior. Inferences about the public acceptability of a policy must also include whether people behaved according to theory.

4.5.1. Group performance and effectiveness of tolls.

Group performance and efficiency improvements from tolls are examined by comparing outcomes of departure decisions, total group costs, amount of journey delays occurred and likelihood of congestion, likelihood a group achieves the optimal departure pattern (or the likelihood of not obtaining a sub-optimal departure pattern like the high-cost case), and the difference in an efficiency metric that measures a group's performance of a period compared to the optimal outcome. The frequency of the 20 various departure patterns (ignoring player identification) reveals the uncertain behavior of individuals. Tables C.1.4, C.1.5, and C.1.6 in the Appendix report

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[12] Subjects were paid based on their performance with average earnings of $20. The no-policy-first treatment had 21 subjects in the reference-low-high cost sequence and 18 in the reference-high-low cost sequence. The policy-first treatment had 24 subjects in the reference-high-low cost sequence and 21 subjects in the reference-low-high cost sequence.

[13] After completion of the experiment a bug in the z-Tree code was discovered and it affected two of the treatments. The parameters for three of the subjects in two groups in round 2 in each treatment were not correct. The error only affects the low and high-cost scenarios. Of the 1008 group observations which had 3024 individual observations, four groups with twelve observations each were dropped from the empirical analysis. Future analysis will be conducted to see how this decision affects the outcomes of the final round, but I currently assume that there is no effect from the error in round 3.

the group departure decisions for the each cost case for periods with and without tolls. The frequencies reveal a variety of departure patterns that occurred, and most notably that the presence of tolls created a greater dispersion of different departure patterns for a given cost case. Note also in the high-cost case in Table C.1.6 that, as predicted by the Nash equilibria predictions reported in Table 4.2, everyone appears to depart early with no tolls. The frequency noticeably drops when tolls are in place. The presence of tolls appear to change group behavior by allowing for greater dispersion in frequency of other departure patterns.

4.5.1.1. *Question 1: Do revenue-neutral tolls reduce total group costs and improve efficiency?* The presence of tolls appears to change group departure patterns, yet the question is whether the change results in improvement in group welfare and efficiency. Table C.1.7 reports average group costs by cost scenario and treatment type. It is exclusively in the high-cost case that appears a noticeable difference in average group costs between situations with and without tolls.[14] Improvements from the tolls appear to vary across the cost cases.

The effectiveness in the reduction of group costs from tolls are empirically estimated using a random effects panel data model specification (Cameron and Trivedi, 2005). Since each group is unique per cost setting and makes twelve group decisions over time, the random-effects specification provides structure to these repeated decisions. The effect of tolls on

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[14] Using the Wilcoxon rank-sum test for each cost case to compare group costs with and without tolls yields z-scores of 1.56, 3.43, 5.69, for the reference, low, and high-cost cases. Tolls have no statistically significant difference on group costs for the reference cost case and have a 1% statistical significant difference for the low and high-cost cases.

group i total group costs ($GroupCost_{i,t}$) for period t is represented in equations 9 and 10:

$$\begin{aligned} GroupCost_{i,t} = {} & \beta_0 + \beta_1 Low_t + \beta_2 High_t + \beta_3 (Low_t \times Rd2_t) + \beta_4 (High_t \times Rd2_t) \\ & + \beta_5 (Reference_t \times Tolls_{i,t}) + \beta_6 (Low_t \times Tolls_{i,t}) + \beta_7 (High_t \times Tolls_{i,t}) \\ & + \beta_8 (Tolls1stTrmt_i) + \beta_9 (Ref - High - LowTrmt_i) \\ & + \beta_{10} (Tolls1st_i \times Ref - High - Low_i) + \varepsilon_{it} \end{aligned} \tag{9}$$

$$\varepsilon_{it} = \eta_i + \mu_{it} \tag{10}$$

where ε_{it} represents unobserved factors that influence total group costs. As seen in equation (10) this term has two components where μ_{it} represents the random unobserved influences, where the mean of μ_{it} is assumed to be zero and η_i reflects the unobserved differences among the groups.

Equation (9) strictly uses binary independent variables and thus provides a basic method of estimating the effectiveness of tolls by cost scenario. The interaction terms $Low_t \times Rd2_t$ and $High_t \times Rd2_t$ are invariant variables that control for the design of the experiment where subjects experienced the high and low-cost cases at either round two or three of the experiment. The "$Tolls1stTrmt$" treatment variable represent whether groups started a stage of a round with tolls (1=yes, 0=no), "$Ref - High - LowTrmt$" represents the ordering treatment (1=yes, 0=no), and "$Tolls1st \times Ref - High - Low$" is the interaction of the two treatments.

In Equation 9, the effectiveness of the toll is β_5 for the reference case, β_6 for low-cost case, and β_7 for the high-cost case. The expected signs of these estimated coefficients (marginal effects of tolls for a given cost scenario) regarding group costs are negative. This introduces the Hypothesis 1a:

- Hypothesis 1a: For each cost scenario, tolls do not decrease group costs. ($H_0 : \beta_5 \geq 0$; $H_0 : \beta_6 \geq 0$; $H_0 : \beta_7 \geq 0$ when dependent variable is group costs)

As shown in the first column of Table 4.3, tolls do reduce total group costs. But when examining across all the cost cases in columns 2 and 3, only for the high-cost case is the reduction in group costs significantly different compared to without a toll (1% significance). Therefore just one of the three null hypotheses is rejected: tolls do not decrease group costs in the high-cost case. Treatment effects of ordering of cost cases or having tolls occur in the first session of a round appear to not have any significant effect on group cost outcomes.

However, instead of looking at group costs, another way of examining the welfare improvement is using a metric of efficiency by comparing how a group did compared to the optimal rate. Recall that the optimal group cost is the cost associated for when the group separately depart at the three earliest time slots. Thus $(1 - (GroupCost_{i,t} - 9)/(51))$, $(1 - (GroupCost_{i,t} - 6)/(30))$, $(1 - (GroupCost_{i,t} - 15)/(69))$ provide a formula for efficiency percentages bounded by zero and one for the reference, low-cost, and high-cost cases, respectively.[15] Such a metric can allow for a normalized comparison across the three cost cases.

In the Appendix, Figures C.1a, C.1b, and C.1c illustrate the average efficiency per period for the different cost scenarios with and without the presence of tolls. The Appendix also shows the percentage frequency groups obtained the socially efficient outcome for each period

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[15] The general formula for calculating group efficiency is: $Efficiency = 1 - \frac{GroupCost_{i,t} - LowestGroupCostPossible}{HighestGroupCostPossible - LowestGroupCostPossible}$ where the lowest group cost possible is the optimal outcome and the highest group possible is self-explanatory and is associated with the outcome where everyone departs late. It can be seen that the optimal outcome results in a zero numerator resulting in 100% while the worst results in in an outcome of 1 resulting in 0%.

in a round (see Figures C.2a, C.2b, and C.2c). Tolls in the high-cost case in Figure C.1c appear to have the most noticeable efficiency improvement. Tolls in the low-cost case in Figure C.1b might have some improvement, but the lines in Table C.1a for the reference-cost case do not suggest any difference. One distinct observation for the high-cost case is how all the outcomes with the exception of period 10 appear above 51.7% (the efficiency measurement for the Nash equilibrium when all players depart early). Indeed, as shown in Table C.1.6 many groups in the high-cost case without tolls did play the Nash equilibrium, but the average suggests that not all individuals behaved according to theoretical predictions preventing efficiency gains. Also, there are no noticeable improvements or learning in any of the cost cases apparent when looking at the figures. To examine if efficiency improves with tolls, Hypothesis 1b is tested:

- Hypothesis 1b: For each cost-scenario, tolls do not increase efficiency. ($H_0 : \beta_5 \geq 0$; $H_0 : \beta_6 \geq 0$; $H_0 : \beta_7 \geq 0$ when dependent variable is efficiency)

Applying Equation 9 and random effects panel model specification, but with group efficiency as the dependent variable, Table 4.3 reports coefficient estimates. The tolls appear to have a significant effect of improving efficiency by roughly 2% across all cost cases. But when examining the effect of the toll by each cost case, no statistically significant effects are observed for the reference or low-cost cases. And as expected from Figure C.1c, the high-cost case had the largest efficiency improvement of 3.3%. The results suggest that individuals to not converge to the optimal departure pattern and that the effectiveness of tolls depend on individuals' time-cost preferences. Similar to the tests of Hypothesis 1a, the null hypothesis in Hypothesis 1b of tolls not increasing efficiency is rejected just for the high-cost case (5% significance). Failure to reject both hypotheses from Hypothesis 1 for the reference and

TABLE 4.3. Estimates On Effectiveness Of Tolls On Group Costs And Efficiency

Dependent variable:	(1) Group Cost	(2) Group Cost	(3) Group Cost	(4) Efficiency	(5) Efficiency	(6) Efficiency
Tolls	-0.9105*			0.0196**		
	(0.4800)			(0.0087)		
High× Rd2		0.5041	1.6422		-0.0073	-0.0295
		(0.8573)	(1.2010)		(0.0176)	(0.0247)
Low× Rd2		-0.2376	-1.3807		0.0079	0.0307
		(0.8817)	(1.2203)		(0.0181)	(0.0251)
Low		-4.9569***	-4.4366***		-0.0396**	-0.0500***
		(0.8213)	(0.9103)		(0.0168)	(0.0187)
High		7.6111***	7.0234***		0.0156	0.0270
		(0.8889)	(1.0021)		(0.0182)	(0.0206)
Reference× Tolls		-0.0229	0.0352		0.0003	-0.0015
		(0.7118)	(0.7333)		(0.0145)	(0.0149)
Low× Tolls		-0.6827	-0.6165		0.0228	0.0212
		(0.7582)	(0.7728)		(0.0155)	(0.0157)
High× Tolls		-2.3634***	-2.3246***		0.0343**	0.0332**
		(0.7280)	(0.7359)		(0.0148)	(0.0150)
Tolls1st Trmt			-0.2014			0.0078
			(0.7533)			(0.0155)
Ref-High-Low Trmt			-1.0675			0.0236
			(0.9887)			(0.0204)
Tolls1st× Ref-High-Low			-0.0847			-0.0034
			(0.9969)			(0.0205)
Constant	17.5020***	16.6329***	17.3092***	0.8420***	0.8504***	0.8354***
	(0.6431)	(0.5337)	(0.7758)	(0.0068)	(0.0109)	(0.0160)
N	960	960	960	960	960	960
p-value	0.0579	0.0000	0.0000	0.0249	0.0003	0.0012
χ^2	3.5971	414.5689	410.7500	5.0288	27.4093	29.0103

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

low-cost cases suggest the mixed Nash equilibria predictions and endogenous welfare effects creates unstable outcomes (or at least the tolls make the outcomes in the high-cost case more noticeably stable).

Answer to Research Question 1: Revenue-neutral tolls reduced group costs and improved group welfare and efficiency for the high-cost case (i.e., inflexible scheduling preferences) and not for the reference or low-cost cases.

The observed improvement from the toll does suggest something about the economic significant about the effects of the tolls. Keeping in mind that these are upper-bound welfare estimates, tolls indeed provide efficiency improvement depending on the cost case, but the magnitude might not be enough when policymakers consider a benefit-cost analysis of recommending such a policy. Moreover, voting behavior for each scenario ought to be consistent with efficiency improvements. Regardless, as will be seen in addressing the next research questions, tolls had various specific performance improvements with group outcomes across all cost cases that must also be considered. As expected, the result highlights the difficulty of examining outcomes when mixed strategies exist and welfare effects are endogenous.

4.5.1.2. *Question 2: Do subjects behave according to theoretical predictions such that the presence of revenue-neutral tolls reduce congestion and journey delays?* The reduction in journey delays, reduction in types of congestion, and the improvement in a group's coordination to achieve optimal departure patterns can explain the gains in group efficiency for a respective cost case.[16] Equation 9 is again used to estimate the effect of tolls on the following dependent variables: frequency of journey delays, whether congestion occurs, whether three-way congestion occurs, whether two-way congestion occurs, whether a queue (player is delayed without causing congestion) occurs, whether the social optimal (minimal cost) outcome occurs, whether the departure pattern *veo* occurs, and whether the departure pattern *eee* occurs. Equation 9 is again used to estimate the effect of tolls on the above performance measures. The following hypotheses are tested:

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[16] Using the Wilcoxon rank-sum test for each cost case to compare journey delays of a group with and without tolls yields z-scores of 1.68, 2.79, 4.74, for the reference, low-cost, and high-cost cases, respectively. Tolls have a 10% statistically significant difference for the reference case while the low-cost and high-cost cases have a 1% statistically significant difference.

- Hypothesis 2a: For each cost-scenario, tolls do not reduce the frequency of journey delays. ($H_0 : \beta_5 \geq 0$; $H_0 : \beta_6 \geq 0$; $H_0 : \beta_7 \geq 0$; when dependent variable is number of journey delays)
- Hypothesis 2b: For each cost-scenario, tolls do not change the probability of any type of congestion occurring. ($H_0 : \beta_5 = 0$; $H_0 : \beta_6 = 0$; $H_0 : \beta_7 = 0$; when dependent variable is whether congestion occurs)
- Hypothesis 2c: For each cost-scenario, tolls do not change the probability of three-way congestion occurring. ($H_0 : \beta_5 = 0$; $H_0 : \beta_6 = 0$; $H_0 : \beta_7 = 0$; when dependent variable is whether three-way congestion occurs)
- Hypothesis 2d: For each cost-scenario, tolls do not change the probability of two-way congestion occurring. ($H_0 : \beta_5 = 0$; $H_0 : \beta_6 = 0$; $H_0 : \beta_7 = 0$; when dependent variable is whether two-way congestion occurs)
- Hypothesis 2e: For each cost-scenario, tolls do not change the probability of a queue developing. ($H_0 : \beta_5 = 0$; $H_0 : \beta_6 = 0$; $H_0 : \beta_7 = 0$; when dependent variable is whether a queue occurs)
- Hypothesis 2f: For each cost-scenario, tolls do not change the probability of a groups obtaining social optimal (lowest cost) departure decisions. ($H_0 : \beta_5 = 0$; $H_0 : \beta_6 = 0$; $H_0 : \beta_7 = 0$; when dependent variable is whether a the social optimal departure pattern occurs)
- Hypothesis 2g: For each cost-scenario, tolls do not change the probability of a groups obtaining a *veo* departure pattern. ($H_0 : \beta_5 = 0$; $H_0 : \beta_6 = 0$; $H_0 : \beta_7 = 0$; when dependent variable is whether a *veo* departure pattern occurs)
- Hypothesis 2h: For each cost-scenario, tolls do not change the probability of a groups obtaining a *eee* departure pattern. ($H_0 : \beta_5 = 0$; $H_0 : \beta_6 = 0$; $H_0 : \beta_7 = 0$; when dependent variable is whether a *eee* departure pattern occurs)

Regression (1) in Table C.1.8 provides negative binomial estimates for frequency of journey delays by applying a random effects specification for Equation 9. The count data generation makes the negative binomial specification appropriate for estimating journey delays. Looking at Hypothesis 2a, the null hypothesis of journey delays not being reduced from tolls is rejected for the high (1% significance) and low (5% significance) cost cases when a one-sided test is implemented. Journey delays are economically significantly reduced more in the high-cost case. This observation is helpful when thinking of costs that might occur to parties outside of the three players. A reduction of congestion or cars cruising to find parking can have external benefits like the reduction of accidents, reduction pollution and other environmental benefits. Such benefits are not included in the costs of experiments but should be considered by policymakers. Yet these benefits are assumed to not be considered when an individual votes since they are outside of the context of the experiment.

Estimating the likelihood of congestion outcomes and departure patterns using a logit specification reveals that tolls do not absolutely guarantee a reduction in congestion nor guarantees groups coordinating to and achieve socially optimal outcomes. Regressions (2) through (5) in Table C.1.8 reports the logit coefficient estimates of the likelihood of various types of congestion occurring with and without tolls. Three-way congestion is when all groups depart at the same time, two-way congestion is when only two subjects depart at the same time, while a queue is a form of two-way congestion where one player departs at the time immediately after the two-way congestion occurs.[17] "Any Congestion" is if either two-way or three-way congestion occurs. Tolls appear to reduce any type of congestion for the low-cost case, yet only for the high-cost case do tolls reduce the likelihood of obtaining

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[17] Recall that three-way congestion results in three total journey delays, two-way congestion results in one journey delay, and a queue results in two journey delays.

three-way congestion. This latter result is consistent with theoretical predictions for the high-cost case (see Table 4.2). Furthermore, the estimates suggest that tolls *increase* the likelihood of two-way congestion for the high-cost case despite the reduction of three-way congestion. Tolls do reduce the likelihood of a queue developing in the reference cost case. When these mixed outcomes are applied to the hypothesis tests, the majority of the null hypotheses stated in Hypotheses 2b to 2e failed to be rejected. The most notable result is from Hypothesis 2c where the likelihood of three-way congestion is reduced and is negative at 1% significance; it follows that tolls are forcing players to deviate from the no-toll pure-strategy Nash equilibria, *eee*.

Table C.1.8 reports regressions (6) to (8) which estimate the logit coefficients and likelihood of achieving socially optimal departure patterns, the occurrence when a groups departs *veo*, and if all depart early (*eee*). Again, a random effects panel model with a logit specification is used for these estimations. Consistent with theoretical predictions, the likelihood of all individuals departing early increases in the high-cost case without tolls, and tolls reduce the likelihood of obtaining that outcome. Notice too that the likelihood of this same undesirable departure pattern is reduced for the low-cost case. Further, tolls increase the likelihood that *veo* is observed in the high-cost case. Tables C.1.5 and C.1.6 also support the finding that the toll reduces everyone from all departing early in the low and high-cost cases. Of the nine null hypotheses listed under Hypotheses 2f, 2g, and 2h, six cannot be rejected. However, consistent with the efficiency gains observed in the high-cost case, the null hypothesis that tolls do not affect the probability of all group members departing early is rejected at 1% significance.

Answer to research question 2: Improvements in measures of coordination from revenue-neutral tolls varies and are mixed across time-cost preferences. Tolls appear to be most helpful in improving outcomes when groups have high value of times.

The existence of endogenous welfare effects reveals that curbing congestion with a pricing mechanism may not be straightforward. The varied welfare gains from tolls are noticeable when observing the impacts on journey delays, type of congestion, and likelihood of certain departure patterns. In the high-cost case, the significant reduction of everyone departing Early explains why tolls had a superior effect on that specific cost case. Congestion still persisted with tolls across cost cases. Yet, although varied, the tolls did help coordination and reduced types of congestion and journey delays. The experiment's referendum votes ought to reveal that the high-cost case should be the most publicly acceptable of the three cost cases since this improved total group welfare. The tolls should still be acceptable for the reference and low-cost cases since tolls also had socially improving outcomes. Despite groups not coordinating and converging to the minimal-cost level with tolls, a policymaker should consider any third-party effects and environmental benefits from the reduction of congestion before advocating for congestion pricing unilaterally.

4.5.2. Public acceptability of tolls. Improved performance from revenue-neutral tolls in the form of improved cooperation and coordination ought to result in more favorable public acceptability when observing referendum voting approval, especially for the high-cost case. Yet an individual's political worldview on role of government intervention and equality might also dictate public acceptability. Moreover, the experimental treatment of having previous experience with tolls may also influence public acceptability. Subjects should have a better understanding of the policy from their prior experiences. The experimental data can help determine voting behavior.

Generally, as seen in Table C.2.1 and when looking at all individuals in Table 4.4, despite the enhanced performance in the high-cost case, no voting patterns across cost treatments appear to exist. Recall each subject participated in three different groups were each group had a referendum vote during the fifth and ninth period of each round resulting in each having six voting opportunities (see Table 4.1). The referendum vote passes 42-45% of the time across the cost scenarios. Table C.2.1 shows that some groups approved or rejected tolls unanimously. Seven subjects always voted in favor of tolls while fifteen always rejected the referendum. Such consistent individual voting and unanimous group voting might be explained by idiosyncratic worldview preferences, experiences from the congestion game, or a combination of both.

4.5.2.1. *Question #3: Do individual worldviews strictly affect the public acceptability of revenue-neutral tolls regardless of performance?* Similar to Chapter 2, at the end of the experiment participants answer a survey that elicits their worldviews. Statements from Kahan et al. (2011) are used to measure an individual's worldview across two dimensions: hierarchy-egalitarianism and individualism-communitarianism. Unlike Chapter 2, these were the only beliefs elicited from the subjects (See Table C.2.2 in the Appendix for statements). Six individuals statements (individualism-communitarianism) focus on the "attitudes toward social orderings that expect individuals to secure their own well-being without assistance or interference from society versus those that assign society the obligation to secure collective welfare and power to override competing individuals interest" (Kahan et al., 2011). And six hierarchical statements (hierarchy-egalitarianism) capture the "attitudes toward social orderings that connect authority to stratified social roles based on highly conspicuous and largely fixed characters such as gender, race, and class" (Kahan et al., 2011). Subjects indicate the extent that they agree with each of the statements using a six-level Likert scale which are translated to a score of 1 to 6 on their level of agreement (1 = strongly disagree to 6 = strongly agree). The sum of scores for each set of statements places their views on the respective hierarchy-egalitarianism and individualism-communitarianism spectrums (6 to 36). These two worldview measures ought to assist in the examination of individual voting behavior.

Figure C.3 illustrates the scores of all 84 individuals. Table 4.4 shows the amount of people that fit in specific worldview categories. Kahan et al. (2011) combines the two dimensions and defines people that score above the median in both dimensions as Hierarchical-Individualist and those that scored below the median in both dimensions as Egalitarian-Communitarian. Following their definitions as well as the definitional extensions by Cherry et al. (2013), subjects that scored in the top quartile of the Hierarchy and Individualism measures are additionally defined as Hierarchical and Individualist, respectively, while those that scored in the bottom quartile of each measure are defined as Egalitarian and Communitarian.[18]

Table 4.4 details the voting behavior of the defined individuals based on worldview and their gender. Everyone appears to vote similarly and no noticeable pattern emerges on acceptability of policies. Communitarian individuals ought to be more favorable to tolls while Egalitarian individuals are argued to be against such incentive-based policies. Several critics of congestion pricing argue that such policies are regressive and result in inequitable

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[18] The Individualism measure has a mean of 24 and standard deviation of 4.4, and the 25th, 50th (median) and 75th percentiles are 20.75, 24, and 26. The Hierachry measure has a mean of 18.3 and standard deviation of 5.3 and the 25th, 50th, and 75th percentiles are 14, 18.5, 21.

Table 4.4. Counts Of Individuals And Percentage Of Votes In Favor Of Referendum For Each Type Of Individual By Cost Scenario

Type of Individual	***N***	**All**	**Reference**	**Low**	**High**
All	84	44%	45%	43%	43%
Hierarchical-Individualist	17	45%	53%	38%	44%
Egalitarian-Communitarian	17	37%	41%	32%	38%
Hierarchical	20	43%	48%	38%	43%
Egalitarian	19	41%	42%	47%	34%
Individualist	19	46%	50%	39%	47%
Communitarian	21	42%	38%	48%	40%
Male	56	45%	46%	45%	45%
Female	28	42%	45%	41%	39%

outcomes. These summary statistics do not show how an individual's or group performance influence voting decisions. An individual's desire of obtaining the optimal On-time time slot rather than have an intervention where there will be clear winners and losers, may be more of a factor in voting decisions than just strictly an individual's worldview. Such an egalitarian concern appears to be reflected in the high-cost case by the noticeably low acceptability of 34% by members that identify with the egalitarian worldview in Table 4.4.

Since each individual makes multiple votes, a first step is to see if worldviews can predict how individuals vote initially after just four periods. The first vote ought to elicit the most out of a person's worldview since this voting decision would rely most on heavily on a person's idiosyncratic preferences that dictate their political worldviews. However, no such significant result was observed when the initial vote was examined in Chapter 2.

Unlike the previous estimates in the chapter that utilized a random effects approach, just a logit specification is required when examining the first vote and individual observations (84 observations) are observed and not group observations. The following model is estimated:

$$Vote_{i,1} = \beta_0 + \beta_1(Tolls1stTrmt_i) + \beta_n(BeliefMeasure_i) + +\mu_i \tag{11}$$

Explanatory variables specifying the type of individual by worldview ($BeliefMeasure_i$) and the treatment effect of tolls ($Tolls1stTrmt$) occurring in the first four periods are used. Controlling for the ordering treatment is not necessary since all individuals are in the reference cost case. Using Equation 11, the following hypothesis is tested:

- Hypothesis 3a: For the first vote, worldviews have no effect on voting behavior. ($H_0 : \beta_n = 0$; for all belief measures)

In addition to grouping individuals by the Kahan et al. (2011) worldview measures, an alternative is added to examine whether some common patterns on worldviews can be established in the Likert-scale responses. Table C.2.2 summarizes the subjects responses as well as dissects the full matrix of answers into its principal components and determines whether political worldviews vary systematically.

There exists five principal components of interest. The first principal component accounts 24% of the variation about the mean response and could be labeled agreement as a "Communitarian-Egalitarian agreement" variable. The second principal component accounts for 17% of the variation suggests that those that want the government to do more in advancing society's goals also think government intervenes too much. This component is labeled "quasi-dictator" since it suggests that one thinks that government could be run more effectively if they were in charge. The third principal component accounts for 13% of variation and can be labeled as preference for "equity concerns" over discrimination concerns. The fourth principal component can be labeled as "overreaching government" and can be thought of as a view that government currently does too much (accounts for 10% of variation). The fifth principal component which accounts for 8% of variation is labeled as a “nanny state” worldview which measures an individuals distaste for current government intervention. The five components are incorporated in Equation 11 to add robustness for testing Hypothesis 3a.

Table C.2.3 shows four columns of logit coefficient estimates of various specifications of worldviews. No model specification is statistically significant nor are any of the coefficients. The fourth column in Table C.2.3 shows estimates of voting behavior of the first of six votes when incorporating the principal component analysis. And just like the worldview characterizations, the model specification is not significant nor are the coefficients. The statistical power of only observing the first vote is obviously restrictive because of the small sample size. As such, the null hypothesis of worldviews not contributing to initial voting behavior fails to be rejected. This is consistent with the observation of Chapter 2 where beliefs had no influence on initial voting behavior. The difference in this experiment is that players experience the problem before their initial vote unlike Chapter 2 where players voted before experiencing the congestion problem. However, experiencing just 4 periods may not be enough for individuals to confidently vote in favor of a congestion policy since they may be still learning the problem and how the congestion policy works. But observing no effects of worldviews on initial feelings of a toll policy is a surprising finding, and suggests that individuals may need to understand the severity of a congestion problem before relying on their beliefs.

Even though there is no robust inference on worldview behavior on the first vote, an examination on how worldview affects the other five as well as the first vote is necessary.

Equation 12 is used to estimate the likelihood of voting for the policy:

(12)

$$Vote_{i,t} = \beta_0 + \beta_1(Low_t \times Rd2_t) + \beta_2(High_t \times Rd2_t) + \beta_3 Low_t + \beta_4 High_t + \beta_5(Tolls1stTrmt_t)$$

$$+ \beta_6(Ref - High - LowTrmt_t) + \beta_7(Tolls1st_t \times Ref - High - Low_t)$$

$$+ \beta_8(2ndVoteinRound_t) + \beta_n(BeliefMeasure_i) + \eta_i + \mu_{it}$$

Equation 12 uses similar controls as in the previous equations, but an additional control, $2ndVoteinRound_t$, is used to indicate if the vote is the second of two votes of the round.[19] The marginal effect of the worldview variable tells us how much worldviews affect the likelihood of voting for all six votes controlling for the design of the experiment. The hypothesis that is tested is:

- Hypothesis 3b: For the all votes, worldviews have no effect on voting behavior. ($H_0 : \beta_n = 0$; for all belief measures)

Table C.2.4 reports logit coefficient estimates with a random effects specification on the effects of worldviews on the likelihood of voting for the policy. The model is specified similarly to the models estimating the effectiveness of tolls on performance with the exception of the inclusion of a control for the timing of the second vote in each session. Similar to the examination of just the first vote, no statistical statistical inferences can be made on the Kahan et al. (2011) worldview measures. Yet note in the fourth column in Table C.2.4 that despite the model lacking statistical significance, the ”nanny state” variable does have statistical significance and has an expected negative effect on public acceptability. And

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[19] An obvious endogeneity problem exists in the current equation since individuals get to vote for their own treatment. To try to tease out the learning and experience effects, several other specifications were considered than Equation 12 including linear and non-linear measures of an individual's share of the total costs of the previous session or period and a group's average efficiency of the previous session or period. Specifying an appropriate instrumental variable for the complex design of the experiment proved difficult. Estimates from Equation 12 are reported instead of the other specifications to suggest that there are no satisfying robust patterns or results to report on how worldviews affect voting.

despite its superior performance, there is no clear increase in public acceptability for the high-cost case. These results suggest that experience in the game itself, and not just worldviews, probably can better explain voting behavior in the experiment.

Thus for almost all the worldview measures, the null hypothesis in Hypothesis 3b fails to be rejected expect when the principal components are used. And it is just the "nanny state" component that is rejected with 5% significance. The results from testing Hypotheses 3a and 3b suggest that the congestion game created no robust pattern of outcomes for individuals to confidently vote for or against a policy. However, despite the noise, those individuals that with high "nanny state" measures prefer the randomness from the bottleneck and are less likely to prefer government intervening and implementing a congestion pricing policy.

Answer to research question 3: No robust inferences can be made that can predict an individual's likelihood of voting for a revenue-neutral incentive-based policy based on worldviews: attitudes on hierarchy-egalitarianism and individualism-communitarianism.

Recall that the experiment's votes are without real-world context. Subjects might vote differently in a real referendum vote if they had more emotional feelings and attachments such as the proposal of tolls of a regularly driven road or parking spaces, knowledge of a local politician's support or disapproval of tolls, or exemptions of a particular groups from tolling. The results may also suggest that without context and in a controlled environment that worldviews can not solely predict the public acceptability of incentive-based policies.

4.6. CONCLUSION

Congestion creates social costs, and the objective of incentive-based mechanisms like congestion pricing is to improve social welfare. Using a simplified version of a congestion problem, efficiency improvements from revenue-neutral tolls are observed in a laboratory environment when welfare effects are endogenous. The observed improvements from congestion tolls appear to depend on the individual schedule delay penalties relative to the individual's cost of traveling (journey delay). When schedule delay costs are relatively high, the results suggest that individuals do deviate away from sub-optimal group departure patterns to lower cost departure patterns.

An examination of voting behavior yielded mixed outcomes and no strong patterns of the acceptability of congestion tolls. The efficiency improvements are not directly related to public acceptability of such policy. When comparing the performance of tolls on different time-cost preferences cases, the relatively superior performance of tolls in one cost case did not yield increased acceptability for that cost case. the results found that political worldviews do not solely predict acceptability of tolls. Yet our principal component analysis showed that some predictions can still be made.

The conduction of this experiment provides many lessons learned. One lesson is that the revenue-neutral aspect of the game with having lump-sum redistribution of the tolls is a concern in this small-group environment. The perception of full redistribution of tolls by the subjects may make the tolls no longer effective. A second lesson is that there was no measure of risk taking since some individuals may prefer the randomness of the bottleneck. Future experiments using this three-player game should measure risk preferences using measures from Holt and Laury (2002). A third lesson is that observing effectiveness with mixed strategies is difficult, and even more difficult when subjects can vote for treatment effects. Future experiments should follow designs similar to Chapter 2 and not have subjects experience multiple cost cases. Furthermore, mixed strategies would be best examined over multiple iterations without voting interruptions (or at least not have votes determining the next immediate institutional environment). The last lesson is that future experiments examining voting acceptably should already have possible instrumental variable(s) specified before conducting an experiment.

The above results provide an upper-bound of welfare improvements since it is assumes a 100% pass-through of revenue back to all individuals. Any up-front fixed costs or administrative costs will likely decrease welfare improvements. However, policymakers ought to consider third-party environmental or other benefits from the reduction of congestion. Thus a policymaker's benefit-cost analysis must consider these additional costs and benefits as well as be aware that the performance of congestion tolls depend on time-cost preferences. Moreover, the acceptability of the policy may be driven more by loss aversion and not necessarily worldviews. Altogether, this chapter and the design of the experiment revealed that observing the effectiveness and acceptability of a congestion policy when welfare effects are endogenous is an ambitious endeavor. As seen in Chapter 2, policymakers would have an easier time predicting acceptability when individual welfare effects are more predictable.

CHAPTER 5

CONCLUSIONS

Urban congestion is widely reported as a growing problem that creates many external costs. Congestion pricing is seen as an efficient solution in urban areas and has been successful in some places like London, Stockholm, and Singapore. In many other areas, however, congestion pricing proposals are sometimes considered but abandoned. Equity and fairness concerns, as well as the uncertainty of congestion pricing programs, are often blamed for the lack of public acceptability and political feasibility of congestion pricing policies. However, the experience in Stockholm of voters overcoming their initial aversion of congestion pricing after experiencing a trial run of the policy is encouraging for environmental economists advocating for incentive-based mechanisms to mitigate environmental problems.

The experience in Stockholm, and the lack of widespread implementation of congestion pricing despite the growing external costs stemming from congestion, raises three primary research questions. Does experience of congestion pricing predict acceptability or do personal traits predict acceptability? What makes congestion pricing effective and why would anyone be opposed to such an efficiency-enhancing policy? What motivates an individual to want to opt in or opt out of a congestion pricing policy when equity effects are endogenously determined? These questions were examined theoretically and/or empirically using laboratory experiments.

Chapter 2 examines how the combination of personal beliefs and experience (accustomation of problem and policy and the welfare effect of the policy) affect the evolution of acceptability. Data is generated using a laboratory experiment where the policy has inequitable affects and users have three votes: before being accustomed to the congestion problem, after being accustomed to the congestion problem, and then after being accustomed to the policy and disclosure of the nature of the welfare impact from congestion pricing. Voting measures the acceptability of a policy, and the design of the experiment make all votes incentive compatible. The experimental design best emulates the Stockholm experience. Unlike Chapters 3 and 4, the welfare effects that generate inequities among users are imposed exogenously. The hypotheses tested the effectiveness of the toll policy and addressed the primary research question of what determines the acceptability of congestion pricing: experience versus beliefs.

A survey at the end of the experiment collected demographic information as well as responses to sensitive questions that determines their worldview (Kahan et al., 2011), feelings toward the environment measured on the New Ecological Paradigm scale, altruism (Kotchen and Moore, 2007), and political ideology. A probit model estimated the likelihood of voting over the course of the experiment and the relationship between these measures of beliefs and accustomation. This model was also estimated by sub-samples based on the theoretical predictions of the welfare effects of individuals. Surprisingly, across all samples, neither beliefs nor the the redistribution rate of the policy were significant in determining initial acceptability of congestion pricing. Only after being accustomed to the problem did certain beliefs influence acceptability, suggesting that some individuals rely on his or her worldviews in determining the severity of the congestion problem. This result is consistent with the need of having a sympathetic local environment that is identified by Ison and Rye (2005) as an issue influencing the implementation of congestion pricing. Similar to the situation in Stockholm, experience appeared to matter. An additional finding showed that accustomation and the nature of the experience matter the most to those individuals with intermediate value of times and are likely to be made worse off by incentivizing them to use an inferior substitute. This group may be sympathetic of the need of a congestion pricing policy, but would oppose congestion pricing mostly based on self-interest. Although beliefs matter, policymakers may be averse to introducing congestion pricing fearing a groups of individuals made worse off from the policies (i.e., individuals with intermediate value of time preferences) may make the majority of their constituents and threaten any successful implementation of an efficiency-improving policy. Self-interested equity concerns matter.

Chapters 3 and 4 examine a congestion problem where, unlike the problem in Chapter 2, the equity effects are endogenously determined. And unlike Chapter 2, users make departure decisions to use the same route that has a bottleneck rather than make route-choices in a two-route network. Chapter 3 formally develops a three-player bottleneck congestion game and examines the *ex-ante* and *ex-post* strategies and welfare effects with and without congestion pricing. The model is a discretized version of the basic bottleneck model and illustrates the tradeoff between schedule delay and travel time. By expanding to three players, the model where individuals make simultaneous departure decisions can predict pure-strategy Nash equilibria with and without congestion pricing, but equilibria also exist in mixed strategies. Congestion tolls help facilitate departure times to avoid congestion. The game endogenously creates “winners” and “losers,” depending on the departure time of individuals. The model can show that people can be incentivized to make socially inferior decisions when a majority of the toll revenues are redistributed. Individuals have an incentive to select departure times that increase the congestion pricing charge of the other individuals, thus compensating themselves for making a socially poor decision. The game represents a prisoner’s dilemma and a situation where some individuals might find the *ex-ante* randomness of the bottleneck sorting mechanism preferable and more equitable than a congestion pricing mechanism.

Chapter 4 examines the theoretical model developed in Chapter 3 under different cost settings and institutional structures. The experimental design tests what motivates users to opt in or opt out of a congestion policy. Similar to Chapter 2, demographics and world-view measures from Kahan et al. (2011) are matched to voting behavior. The other belief measures from Chapter 2 were not collected. Several hypotheses on the effectiveness and acceptability of congestion pricing were tested. Unlike Chapter 2, since equilibria exist in mixed strategies, the effectiveness of the pricing policy for the various cost scenarios was difficult to examine, the results, however, show that congestion pricing was most effective when homogeneous users had high schedule delay costs. Estimates on predicting voting behavior yielded mixed outcomes, and when a principal component analysis was applied on belief measures, some significant predictions could be made. The lack of robust results suggest that congestion pricing policies can be contentious when inequities are endogenously determined. The data did not show an evolution of voting behavior after different accustomation and group experiences where individuals voted for the efficiency-enhancing policy.

Although efficiency improving, congestion pricing may be hindered by the inequitable effects it creates; this is true whether these effects are exogenous or endogenous. Policy-makers are recommended to take special care of understanding what the *ex-ante* and *ex-post* outcomes of congestion pricing are and to be able to identify the magnitude of the welfare effects of the various populations affected by the policy. Moreover, some populations will be sensitive to how toll revenue is redistributed. Beliefs matter in determining acceptability, but only after being accustomed to a congestion problem. Surprisingly, the expectations based on the definitions were not observed in the laboratory. For example, those with strong anti-government-intervention views were not shown to initially oppose congestion pricing. This body of research displayed that carefully implemented trial or pilot programs could positively affect the likelihood of making congestion pricing programs permanent, and that, in addition to welfare predictions on individuals' travel time preferences, individual characteristics and beliefs affect attitudes toward congestion pricing policies.

Future research needs to be conducted to measure the validity of the worldview measures in relationship to market outcomes. Moreover, the experimental design in Chapter 2 provides multiple opportunities to examine different contexts of the congestion problem. Several modifications are suggested for future research where there is a third option for abstaining from voting and/or having a monetary cost for a vote. Further research in this field will provide a better understanding of the difference between worldview and self-interest motivations for acceptability of congestion pricing. Equity concerns on the outcomes of congestion pricing have heavily been cited as barriers to implementation, but understanding the perceptions of these concerns may allow for more effective communication to introducing successful policies. Such findings may also improve the likelihood of implementing Pigouvian policies that deal with environmental problems such as climate change.

BIBLIOGRAPHY

Anas, A. and Lindsey, R. (2011). Reducing urban road transportation externalities: Road pricing in theory and in practice. *Review of Environmental Economics and Policy*, 5(1):66–88.

Anderson, L., Holt, C. A., and Reiley, D. (2008). Congestion pricing and welfare. In *Environmental Economics, Experimental Methods*, chapter 15, pages 280–292. Routledge.

Anderson, S. P. and De Palma, A. (2004). The economics of pricing parking. *Journal of Urban Economics*, 55(1):1–20.

Arnott, R. (1994). Alleviating traffic congestion: alternatives to road pricing. In *Proceedings of the Taxation, Resources and Economic Development (TRED) Conference on "Alternative Strategies for Managing Externalities.*

Arnott, R. (2006). Spatial competition between parking garages and downtown parking policy. *Transport Policy*, 13(6):458–469.

Arnott, R., de Palma, A., and Lindsey, R. (1990a). Departure time and route choice for the morning commute. *Transportation Research Part B: Methodological*, 24(3):209–228.

Arnott, R., De Palma, A., and Lindsey, R. (1990b). Economics of a bottleneck. *Journal of Urban Economics*, 27(1):111–130.

Arnott, R., De Palma, A., and Lindsey, R. (1993). A structural model of peak-period congestion: A traffic bottleneck with elastic demand. *The American Economic Review*, 83(1):161–179.

Arnott, R., De Palma, A., and Lindsey, R. (1994). The welfare effects of congestion tolls with heterogeneous commuters. *Journal of Transport Economics and Policy*, 28(2):139–161.

Arnott, R. and Small, K. (1994). The economics of traffic congestion. *American Scientist*, 82(5):446–455.

Becker, G. S. (1965). A theory of the allocation of time. *The Economic Journal*, 75(299):493–517.

Ben-Akiva, M., Cyna, M., and De Palma, A. (1984). Dynamic model of peak period congestion. *Transportation Research Part B: Methodological*, 18(4):339–355.

Ben-Akiva, M., De Palma, A., and Kanaroglou, P. (1986). Dynamic model of peak period traffic congestion with elastic arrival rates. *Transportation Science*, 20(3):164–181.

Borger, B. D. (2011). Optimal congestion taxes in a time allocation model. *Transportation Research Part B: Methodological*, 45(1):79–95.

Börjesson, M., Eliasson, J., Hugosson, M. B., and Brundell-Freij, K. (2012). The Stockholm congestion charges—5 years on. Effects, acceptability and lessons learnt. *Transport Policy*, 20:1–12.

Breinbjerg, J. N., Sebald, A., and Østerdal, L. P. (2014). Strategic behavior and social outcomes in a bottleneck queue: Experimental evidence. *Discussion Papers on Business and Economics, University of Southern Denmark*, 12.

Cameron, A. C. and Trivedi, P. K. (2005). *Microeconometrics: Methods and Applications*. Cambridge University Press.

Chatman, D. G. and Manville, M. (2014). Theory versus implementation in congestion-priced parking: An evaluation of sfpark, 2011–2012. *Research in Transportation Economics*, 44:52–60.

Cherry, T. L., Kallbekken, S., and Kroll, S. (2012). The acceptability of efficiency-enhancing environmental taxes, subsidies and regulation: An experimental investigation. *Environmental Science & Policy*, 16:90–96.

Cherry, T. L., Kallbekken, S., and Kroll, S. (2013). Does your cultural worldview make you dislike pigouian policies? a laboratory investigation of taxes, subsides and regulation. *Working Paper*.

Cheung, S. N. (1983). The contractual nature of the firm. *Journal of Law and Economics*, 26(1):1–21.

De Palma, A., Ben-Akiva, M., Lefevre, C., and Litinas, N. (1983). Stochastic equilibrium model of peak period traffic congestion. *Transportation Science*, 17(4):430–453.

De Palma, A. and Fosgerau, M. (2010). Dynamic and static congestion models: A review. *HAL Working Papers*.

De Palma, A., Marchal, F., and Nesterov, Y. (1997). METROPOLIS: modular system for dynamic traffic simulation. *Transportation Research Record: Journal of the Transportation Research Board*, 1607(1):178–184.

Dechenaux, E., Mago, S. D., and Razzolini, L. (2013). Traffic congestion: an experimental study of the downs-thomson paradox. *Experimental Economics*, pages 1–27.

Denant-Boemont, L., Hammiche, S., et al. (2009). Public transit capacity and users' choice: An experiment on Downs-Thomson paradox. In *4th Kuhmo-Nectar Conference "Transport and Urban Economics"*.

Eliasson, J. (2009). A cost–benefit analysis of the Stockholm congestion charging system. *Transportation Research Part A: Policy and Practice*, 43(4):468–480.

Falk, A. and Heckman, J. J. (2009). Lab experiments are a major source of knowledge in the social sciences. *Science*, 326(5952):535–538.

Fischbacher, U. (2007). z-Tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics*, 10(2):171–178.

Gaunt, M., Rye, T., and Allen, S. (2007). Public acceptability of road user charging: the case of Edinburgh and the 2005 referendum. *Transport Reviews*, 27(1):85–102.

Hall, J. D. (2013). Pareto improvements from lexus lanes: the case for pricing a portion of the lanes on congested highways. In *proceedings of the Kuhmo NECTAR Conference on Transportation Economics: Annual Conference of the International Transportation Economics Association*.

Hårsman, B. and Quigley, J. M. (2010). Political and public acceptability of congestion pricing: Ideology and self-interest. *Journal of Policy Analysis and Management*, 29(4):854–874.

Hartman, J. L. (2006). A route choice experiment involving monetary payouts and actual waiting times. *mimeo, Department of Economics, University of California Santa Barbara, Santa Barbara, CA 93106*.

Hartman, J. L. (2007). A route choice experiment with an efficient toll. *mimeo, Department of Economics, University of California Santa Barbara, Santa Barbara, CA 93106*.

Hartman, J. L. (2012). Special issue on transport infrastructure: A route choice experiment with an efficient toll. *Networks and Spatial Economics*, 12(2):205–222.

Hau, T. D. (1990). Electronic road pricing: developments in Hong Kong 1983-1989. *Journal of Transport Economics and Policy*, 24(2):203–214.

Hau, T. D. (1992). Economic fundamentals of road pricing: a diagrammatic analysis. Technical report, The World Bank.

Holt, C. A. and Laury, S. K. (2002). Risk aversion and incentive effects. *American economic review*, 92(5):1644–1655.

Ison, S. and Rye, T. (2005). Implementing road user charging: the lessons learnt from hong kong, cambridge and central london. *Transport Reviews*, 25(4):451–465.

Kahan, D. M., Jenkins-Smith, H., and Braman, D. (2011). Cultural cognition of scientific consensus. *Journal of Risk Research*, 14(2):147–174.

Kahan, D. M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L. L., Braman, D., and Mandel, G. (2012). The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Climate Change*, 2(10):732–735.

Kallbecken, S. (2013). Public acceptability of incentive-based mechanisms. In *Encyclopedia of Energy, Natural Resource, and Environmental Economics, 1st Edition*, chapter Forthcoming chapter. Elsevier.

Kallbekken, S., Kroll, S., and Cherry, T. L. (2011). Do you not like Pigou, or do you not understand him? tax aversion and revenue recycling in the lab. *Journal of Environmental Economics and Management*, 62(1):53–64.

Karlström, A. and Franklin, J. P. (2009). Behavioral adjustments and equity effects of congestion pricing: Analysis of morning commutes during the Stockholm trial. *Transportation Research Part A: Policy and Practice*, 43(3):283–296.

King, D., Manville, M., and Shoup, D. (2007). For whom the road tolls: The politics of congestion pricing. *Access*, (31).

Kotchen, M. J. and Moore, M. R. (2007). Private provision of environmental public goods: Household participation in green-electricity programs. *Journal of Environmental Economics and Management*, 53(1):1–16.

Larson, R. C. and Sasanuma, K. (2010). Urban vehicle congestion pricing: A review. *Journal of Industrial and Systems Engineering*, 3(4):227–242.

Levinson, D. (2005). Micro-foundations of congestion and pricing: A game theory perspective. *Transportation Research Part A: Policy and Practice*, 39(7):691–704.

Levinson, D. (2010). Equity effects of road pricing: A review. *Transport Reviews*, 30(1):33–57.

Lindsey, C. R. and Verhoef, E. T. (2000). Traffic congestion and congestion pricing. *Tinbergen Institute Discussion Papers*.

Maddala, G. S. (1983). *Limited-dependent and qualitative variables in econometrics*. Number 3. Cambridge university press.

Mahendra, A., Grant, M., and Swisher, M. (2012). Effective approaches for advancing congestion pricing in a metropolitan region–a primer on lessons learned and best practices. No. FHWA-HOP-12-030. Technical report.

Marcucci, E. and Marini, M. (2001). Individual uncertainty and the political acceptability of road pricing policies. Technical report, University Library of Munich, Germany.

McKelvey, R. D., McLennan, A. M., and Turocy, T. L. (2013). Gambit: Software tools for game theory, version 13.0.2.

Morgan, J., Orzen, H., and Sefton, M. (2009). Network architecture and traffic flows: Experiments on the Pigou–Knight–Downs and Braess Paradoxes. *Games and Economic Behavior*, 66(1):348–372.

Pigou, A. C. (1924). *The Economics of Welfare*. Transaction Publishers.

Qian, Z. S., Xiao, F. E., and Zhang, H. (2011). The economics of parking provision for the morning commute. *Procedia-Social and Behavioral Sciences*, 17:612–633.

Qian, Z. S., Xiao, F. E., and Zhang, H. (2012). Managing morning commute traffic with parking. *Transportation Research Part B: Methodological*, 46(7):894–916.

Roth, A. E. and Erev, I. (1995). Learning in extensive-form games: Experimental data and simple dynamic models in the intermediate term. *Games and Economic Behavior*, 8(1):164–212.

Schade, J. and Schlag, B. (2003). Acceptability of urban transport pricing strategies. *Transportation Research Part F: Traffic Psychology and Behaviour*, 6(1):45–61.

Schrank, D., Eisele, B., and Lomax, T. (2012). TTI's 2012 urban mobility report. *Proceedings of the 2012 Annual Urban Mobility Report. Texas A&M Transportation Institute, Texas, USA*.

Selten, R., Chmura, T., Pitz, T., Kube, S., and Schreckenberg, M. (2007). Commuters route choice behaviour. *Games and Economic Behavior*, 58(2):394–406.

Shoup, D. C. (2005). *The High Cost of Free Parking*. Planners Press, American Planning Association.

Silva, H. E., Lindsey, R., and de Palma, A. (2014). On the existence and uniqueness of equilibrium in the bottleneck model with atomic users. *Econometrica*, 82(2):705–30.

Skinner, B. and Carlin, B. (2013). The price of anarchy—on the roads and in football. *Significance*, 10(3):25–30.

Small, K. A. (1982). The scheduling of consumer activities: Work trips. *American Economic Review*, 72(3):467–479.

Small, K. A. and Verhoef, E. T. (2007). *The Economics of Urban Transportation*. Routledge.

van den Berg, V. and Verhoef, E. T. (2011). Winning or losing from dynamic bottleneck congestion pricing?: The distributional effects of road pricing with heterogeneity in values of time and schedule delay. *Journal of Public Economics*, 95(7):983–992.

Vickrey, W. (1971). Responsive pricing of public utility services. *The Bell Journal of Economics and Management Science*, 2(1):337–346.

Vickrey, W. S. (1969). Congestion theory and transport investment. *The American Economic Review*, 59(2):251–260.

Walters, A. A. (1961). The theory and measurement of private and social cost of highway congestion. *Econometrica: Journal of the Econometric Society*, pages 676–699.

Wardrop, J. (1952). Some theoretical aspects of road traffic research. *Proceedings of the Institution of Civil Engineers*, 1(3):325–378.

Winslott-Hiselius, L., Brundell-Freij, K., Åsa Vagland, and Byström, C. (2009). The development of public attitudes towards the Stockholm congestion trial. *Transportation Research Part A: Policy and Practice*, 43(3):269–282.

Xin, W. and Levinson, D. M. (2007). Stochastic congestion and pricing model with endogenous departure time selection and heterogeneous travelers. In *Transportation Research Board 86th Annual Meeting*, number 07-1035.

Ziegelmeyer, A., Koessler, F., and Denant-Boemont, L. (2008). Road traffic congestion and public information: an experimental investigation. *Journal of Transport Economics and Policy (JTEP)*, 42(1):43–82.

Zou, X. and Levinson, D. (2006). A multi-agent congestion and pricing model. *Transportmetrica*, 2(3):237–249.

APPENDIX A

SUPPLEMENTARY MATERIAL FOR CHAPTER 2

A.1. SUPPLEMENTARY THEORY TABLES FOR TWO-ROUTE CONGESTION GAME

TABLE A.1. User Equilibria Predictions

Predicted effect of toll on **users' costs** by redistribution rate relative to no toll equilibrium			
Value (Route)	**No Toll** **(Endowment - Cost)**	**Toll w/ 100% Redistribution**	**Toll w/ 40% Redistribution**
12 (Route A)	145 - **120** = 25	-21.3%	-16.0%
11 (Route A)	135- **110** = 25	-20.5%	-14.7%
10 (Route A)	125 - **100** = 25	-19.5%	-13.2%
4 (Route B)	65 - **40** = 25	-6.3%	+9.5%
3 (Route B)	55 - **30** = 25	-15.0%	+6.0%
2 (Route B)	45 - **20** = 25	-32.5%	-1.0%

Note: All six individuals use Route A with no toll; with a toll the three lower value of time individuals switch to Route B.

A.2. CULTURAL WORLDVIEW, NEP, ALTRUISM, AND POLITICAL IDEOLOGY STATEMENTS

Similar cultural worldview measures as Kahan et al. (2011) were used. These two sets of questions are shown below.

People in our society often disagree about how far to let individuals go in making decisions for themselves. How strongly do you agree or disagree with each of these statements? [strongly disagree, moderately disagree, slightly disagree, slightly agree, moderately agree, strongly agree; items prefixed by 'S' were reversed coded]

IINTRSTS. The government interferes far too much in our everyday lives.

SHARM. Sometimes government needs to make laws that keep people from hurting themselves.

IPROTECT. It's not the government's business to try to protect people from themselves.

IPRIVACY. The government should stop telling people how to live their lives.

SPROTECT. The government should do more to advance society's goals, even if that means limiting the freedom and choices of individuals.

SLIMCHOI. Government should put limits on the choices individuals can make so they don't get in the way of what's good for society.

People in our society often disagree about issues of equality and discrimination. How strongly do you agree or disagree with each of these statements? [strongly disagree, moderately disagree, slightly disagree, slightly agree, moderately agree, strongly agree; items prefixed by 'E' were reversed coded]

HEQUAL. We have gone too far in pushing equal rights in this country.

EWEALTH. Our society would be better off if the distribution of wealth was more equal.

ERADEQ. We need to dramatically reduce inequalities between the rich and the poor, whites and people of color, and men and women.

EDISCRIM. Discrimination against minorities is still a very serious problem in our society.

HREVDIS2. It seems like minority groups don't want equal rights, they want special rights just for them.

HFEMININ. Society as a whole has become too soft.

Similar beliefs of New Ecological Paradigm (NEP), Schwartz altruism measures as Kotchen and Moore (2007) were used. These statements are shown below.

People in our society often disagree about issues on how human actions affect the environment. How strongly do you agree or disagree with each of these statements? [strongly disagree, disagree, neutral, agree, strongly agree; items prefixed in "Na" were reversed coded]
HuCRISIS. The so-called "ecological crisis" facing humankind has been greatly exaggerated. NaLIMITED. The earth is like a spaceship with limited room and resources.
NaMAJOR. If things continue on their present course, we will soon experience a major ecological catastrophe.
HuCOPE. The balance of nature is strong enough to cope with the impacts of modern industrial nations.
NaABUSE. Humans are severely abusing the environment.

People in our society often disagree about issues regarding altruism. How strongly do you agree or disagree with each of these statements? [strongly disagree, disagree, neutral, agree, strongly agree; items prefixed in "A" were reversed coded]
SCONTRIB. Contributions to community organizations rarely improve the lives of others.
SRESPONSI. The individual alone is responsible for his or her well-being in life.
ADUTY. It is my duty to help other people when they are unable to help themselves.
SPROVIDE. My responsibility is to provide only for my family and myself.
AACTIONS. My personal actions can greatly improve the well-being of people I don't know.

Questions of political ideology followed the phrasing and possible responses used by Gallup, Inc. [very liberal, liberal, moderate, conservative, very conservative]

ConservECON. Thinking about economic issues, would you say your views on economic issues are –

ConservSOC. Thinking about social issues, would you say your views on social issues are –

A.3. SUMMARY STATISTICS – DECISION TREES OF VOTING BEHAVIOR BY SAMPLE

Below are the voting decision trees for various samples. The first value is the number of observations, the second value is the percentage of the entire sample making that sequence of voting decision(s), and the third value is the percentage making the voting decision of the number of observations from the previous node.

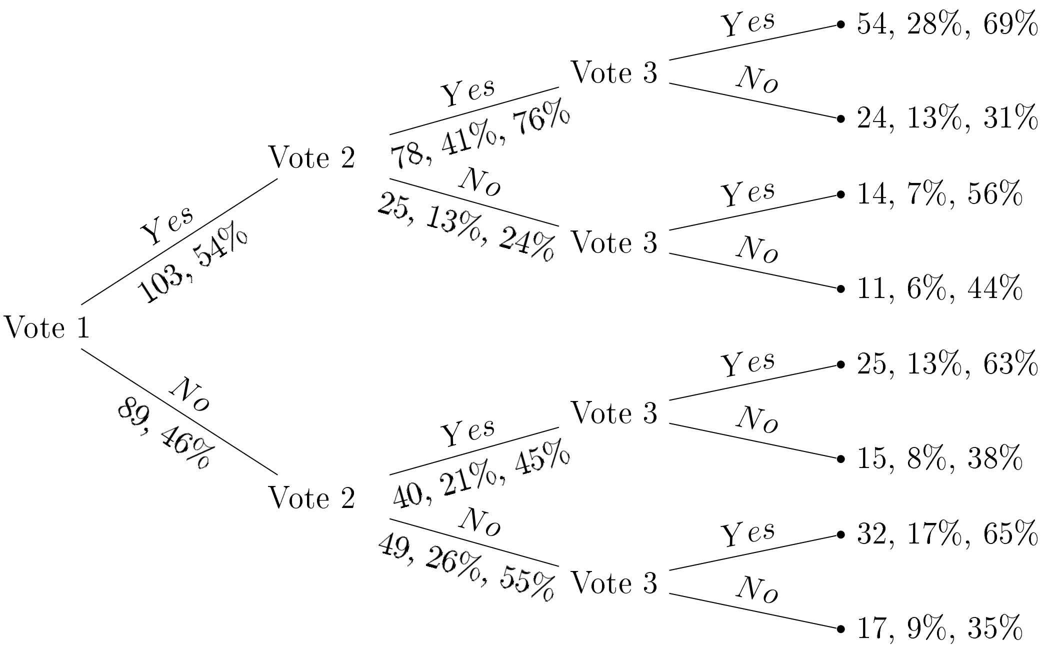


FIGURE A.1. Decision Tree For Full Sample

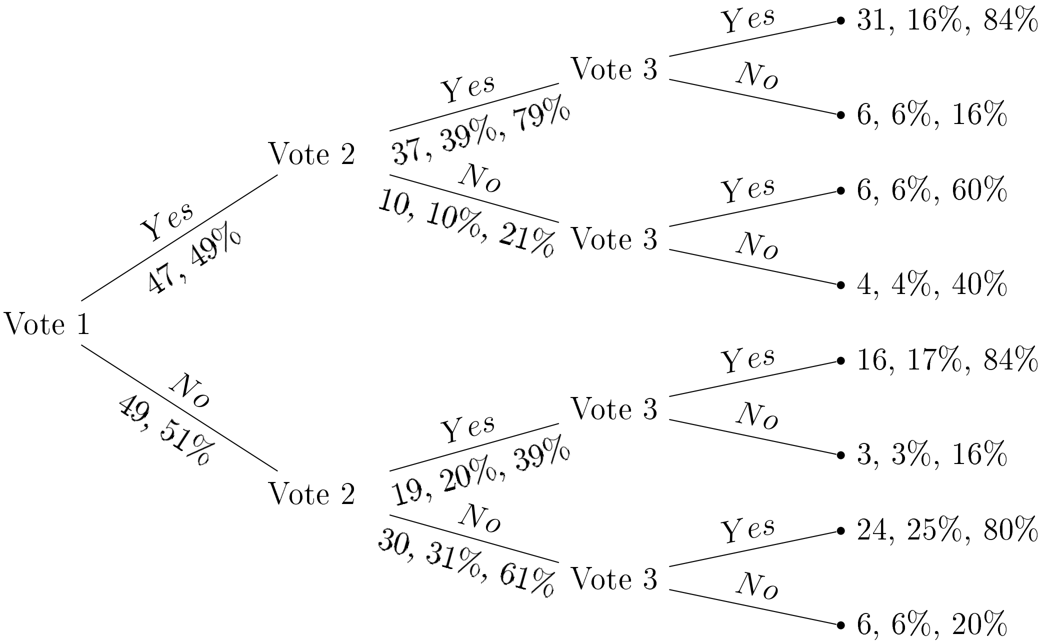


FIGURE A.2. Decision Tree For Sub-Sample – 100% Redistribution Treatment

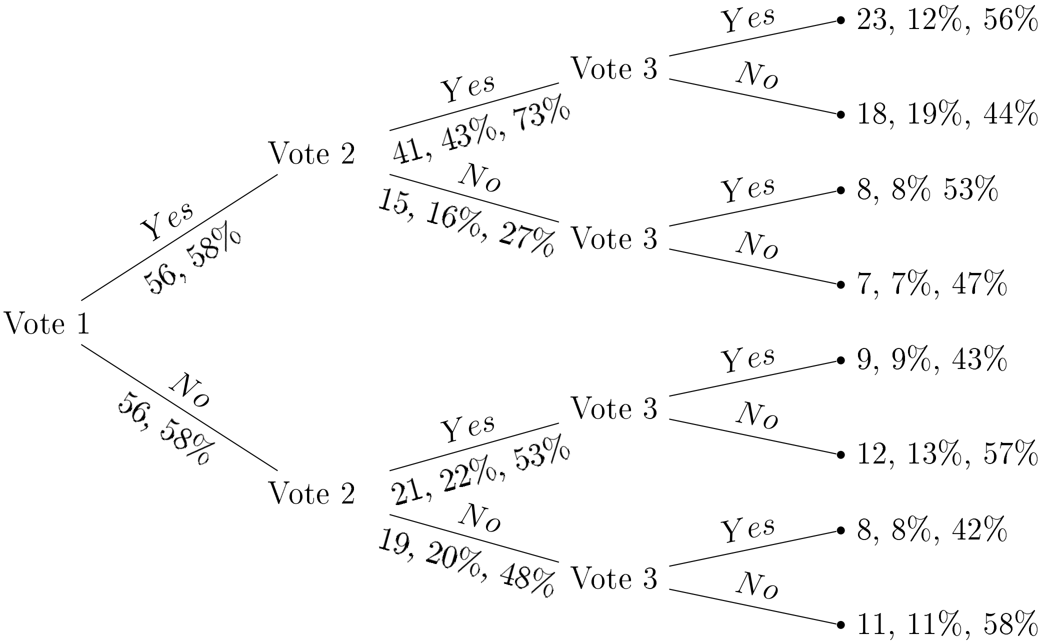


FIGURE A.3. Decision Tree For Sub-Sample – 40% Redistribution Treatment

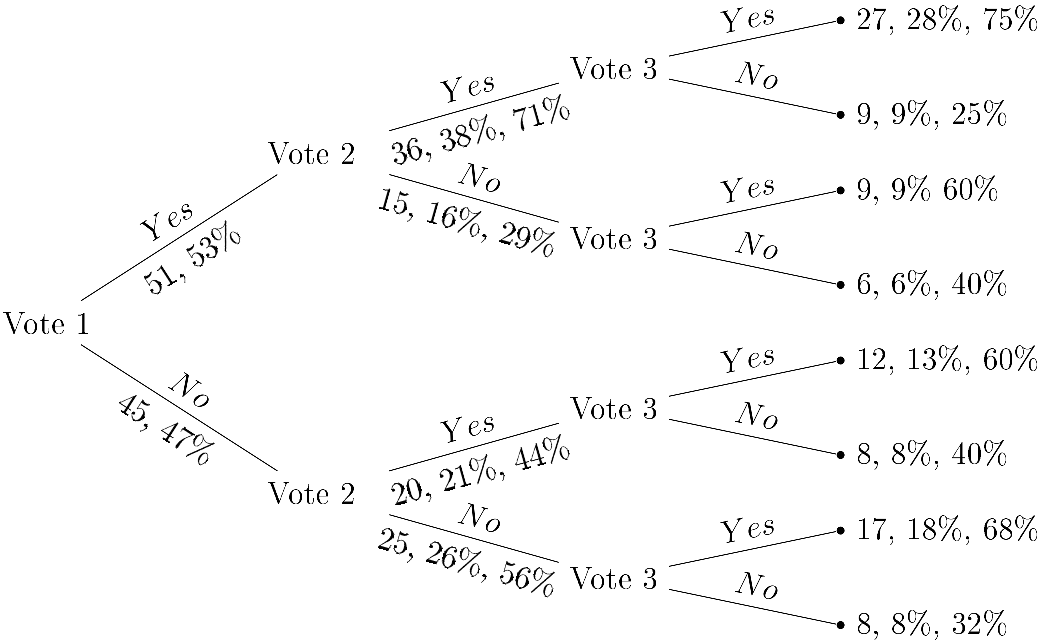


FIGURE A.4. Decision Tree For Sub-Sample – No Ranked Grouped Information Disclosure Treatment

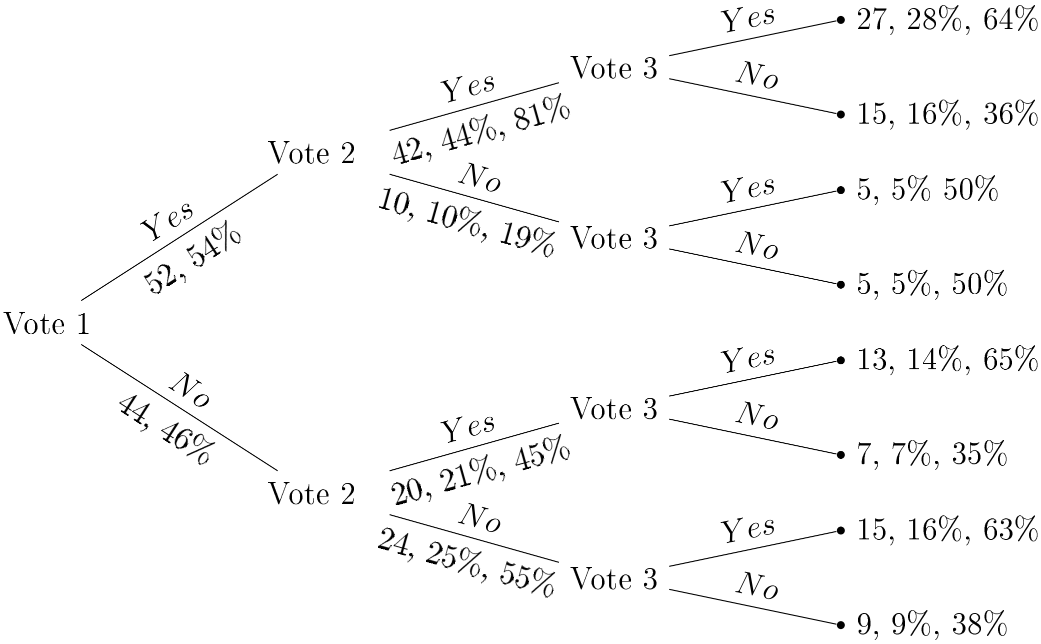


FIGURE A.5. Decision Tree For Sub-Sample – Disclosure Of Ranked Grouped Information Treatment

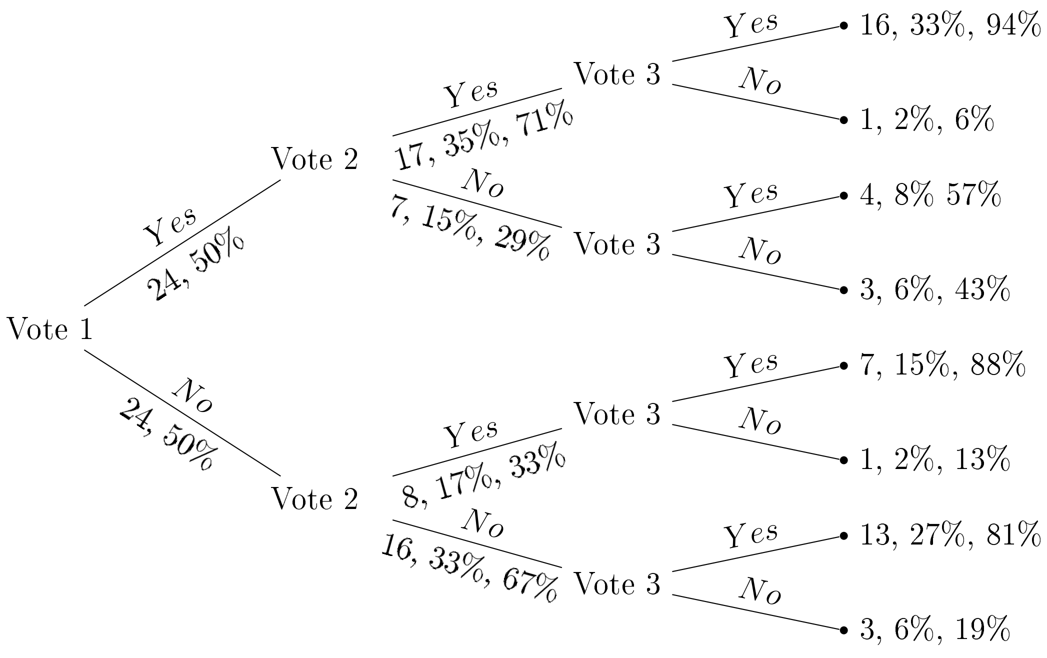


Figure A.6. Decision Tree For Sub-Sample – 100% Redistribution Treatment And No Disclosure Of Ranked Grouped Information Treatment

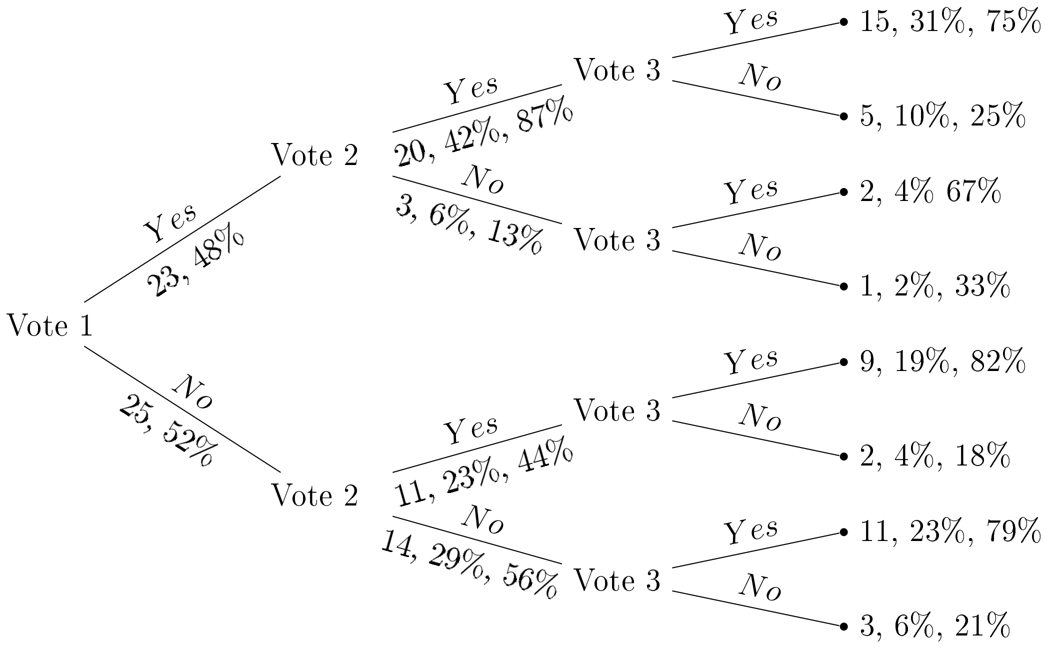


Figure A.7. Decision Tree For Sub-Sample – 100% Redistribution Treatment And Disclosure Of Ranked Grouped Information Treatment

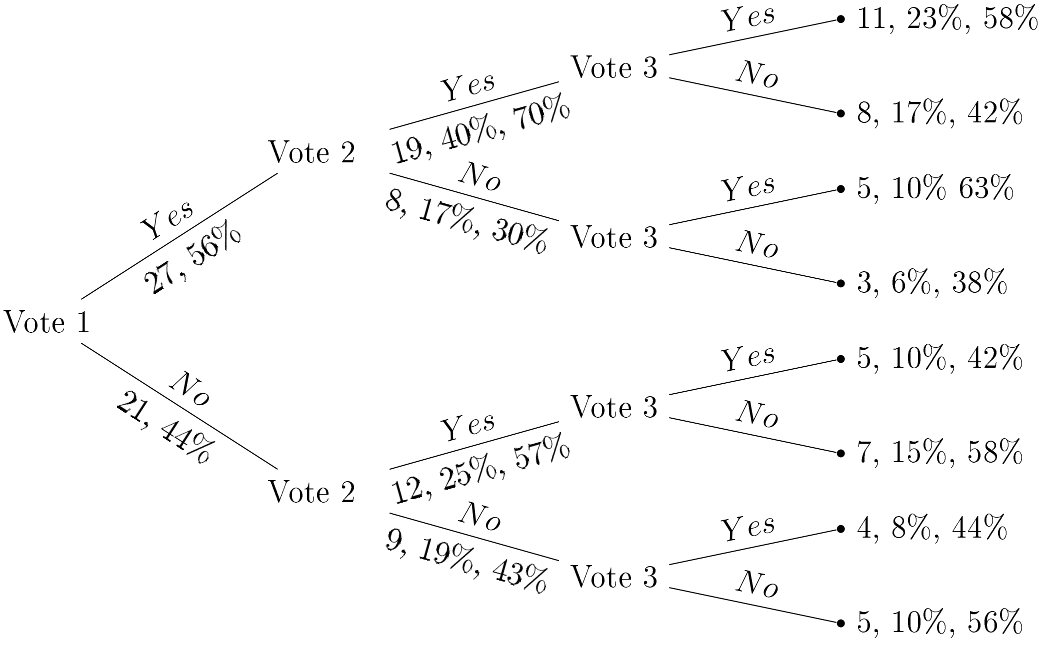


FIGURE A.8. Decision Tree For Sub-Sample – 40% Redistribution Treatment And No Disclosure Of Ranked Grouped Information Treatment

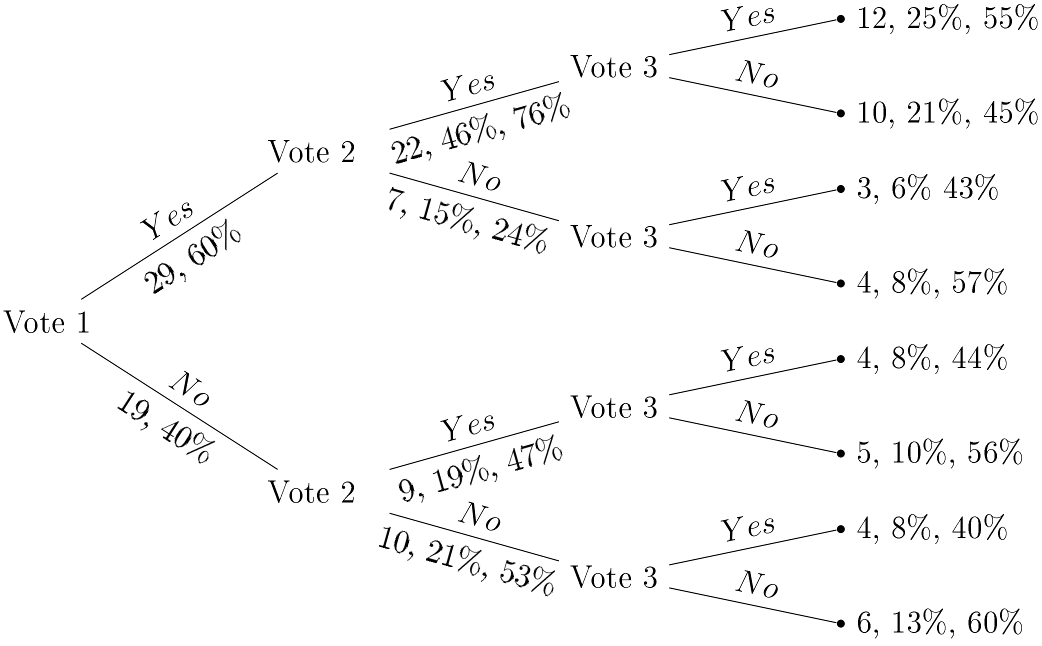


FIGURE A.9. Decision Tree For Sub-Sample – 40% Redistribution Treatment And Disclosure Of Ranked Grouped Information Treatment

A.4. Experiment Instructions (100% Redistribution)

Instructions

You are about to participate in an experiment on decision making. Please read these instructions carefully. You will earn money, which will be paid to you in cash at the end of the experiment. Your payoff will depend on your choices and the choices of other participants. All transactions in this experiment will be done in “tokens,” with 1 token = $0.06.

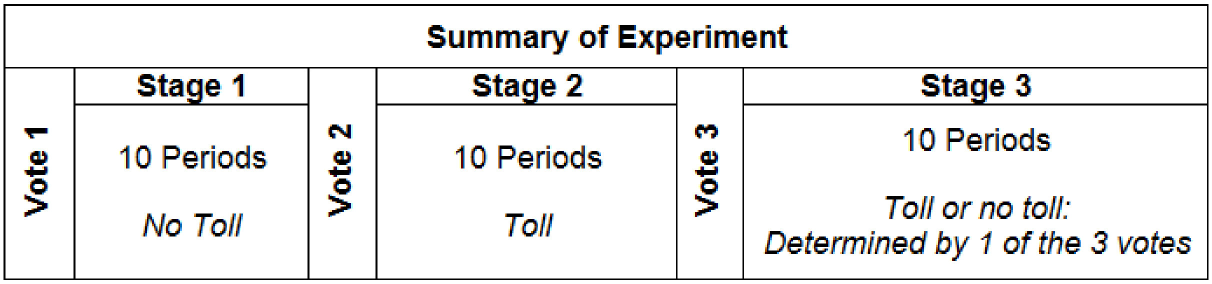
During the entire experiment communication of any kind is strictly prohibited. Communication between participants will lead to your exclusion from the experiment and the forfeiture of all earnings. Please raise your hand if you have any questions and a member of the research team will come to you and answer your questions privately. Also, please turn off your cell phones!

Note you must complete the entire experiment to be eligible to be paid. The experiment will last roughly 60 minutes.

Summary of the Experiment

As shown in Table 1 you will participate in three independent stages; each stage consists of 10 independent periods making the experiment 30 periods long. You will also participate in three referendum votes. You will first start the experiment with a referendum vote before starting Stage 1. Only one of the three 10-period stages will count towards your earnings.

Table 1



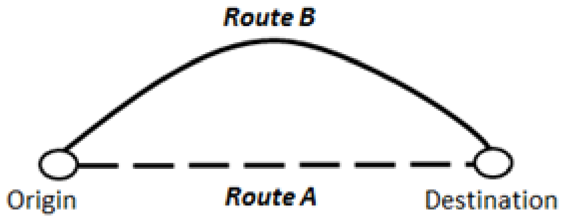
Summary of Experiment					
	Stage 1		Stage 2		Stage 3
Vote 1	10 Periods *No Toll*	Vote 2	10 Periods *Toll*	Vote 3	10 Periods *Toll or no toll: Determined by 1 of the 3 votes*

The votes are important. One of the three votes will be used to determine the nature of the third stage. Before we explain the votes and the toll, we first introduce how the experiment works.

Basic Overview

You and the other participants will be randomly assigned to groups of six (you will stay in the same group of 6 for the entire experiment). In each period you and the other group members must decide individually which route you will like to take to get from the same origin to the same destination. Each person has the option of one of two routes: Route A or Route B:

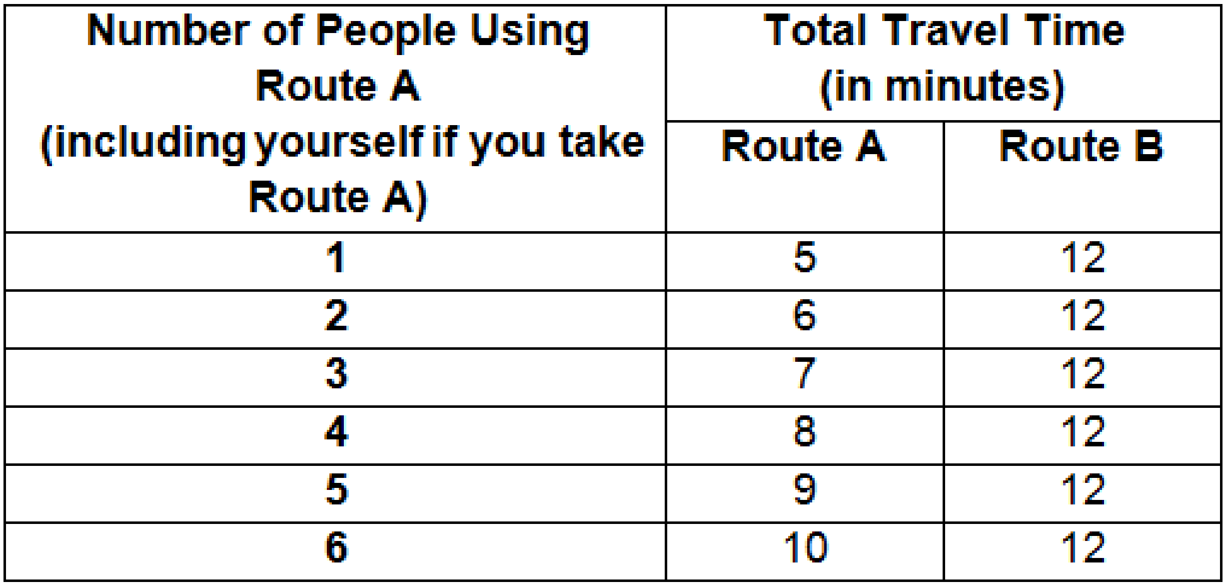
Figure 1



For Route A, the amount of time it takes to arrive at your destination depends on the amount of traffic. The amount of traffic on Route A is equal to the number of people in your group using this route. Travel time on Route A is higher with more traffic and lower with less traffic. The travel time for Route B is always constant and does not depend on traffic in Route A or Route B.

Consider Table 2: if, for example, three people use Route A, the travel time of those three is 7 minutes per person, and if four people use Route A, then the travel time of those four is 8 minutes per person. In both cases, the other three or two users of Route B have a travel time of 12 minutes per person.

Table 2



Number of People Using Route A (including yourself if you take Route A)	Total Travel Time (in minutes)	
	Route A	Route B
1	5	12
2	6	12
3	7	12
4	8	12
5	9	12
6	10	12

Determining your payoffs

Your payoffs are calculated using the following:

- **Value of time**: Each group member has a value of travel time (= your cost of time), which is measured in tokens per minute.
- **Per-period endowment**: Each group member starts with an amount of tokens at the beginning of each period.

Each group member's value of time and per-period endowment will not change in the course of the experiment. Your value of time and per-period endowments will be different from those of the other members in your group. In each period your value of time and your per-period endowment as well as the value of times of other members of your group will be shown on the top of your computer screen.

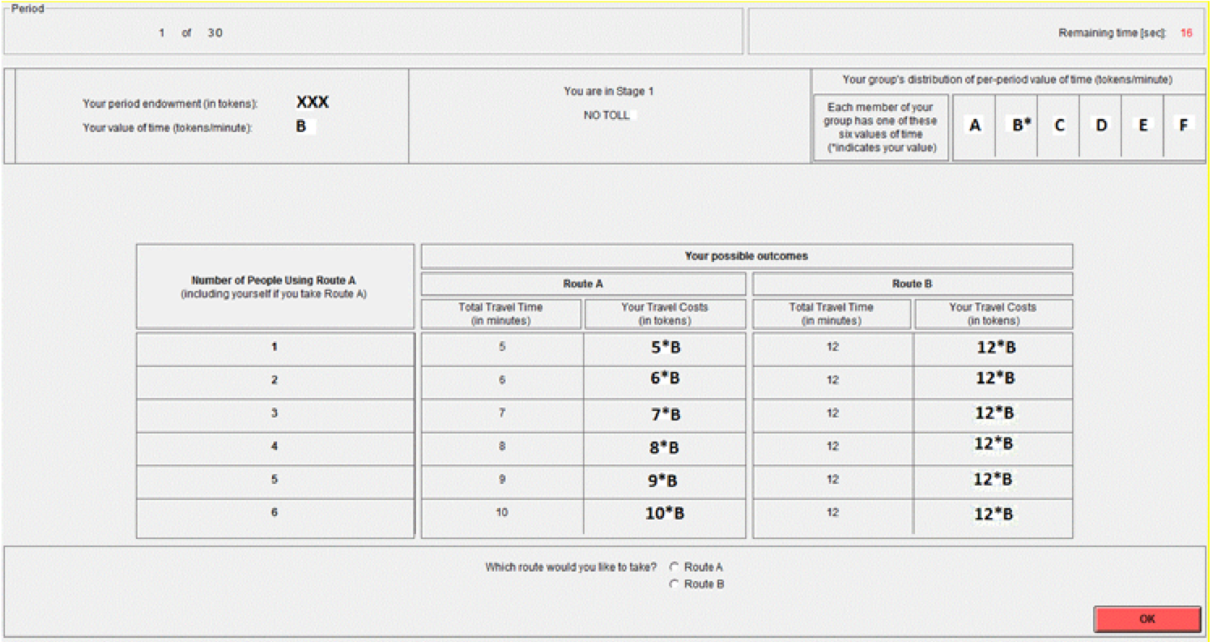
Your travel cost is equal to the time it takes to reach the destination multiplied by your value of time. For example, if it takes you 10 minutes to reach the destination and your value of time is 5 tokens per minute then your travel costs are 50 tokens (10 x 5 = 50). This travel cost will be subtracted from your per-period endowment to obtain your earnings for that period. For example, if your period endowment is 60 tokens and your travel costs are 50 tokens, then you earned 10 tokens for that period. Your final earnings will be your total earnings from all periods in one of the three stages. The stage that will determine your final earnings will be randomly chosen at the end of the experiment.

At the end of each period you will be provided feedback on which route you took, your travel time, travel time cost, your earnings for the period, the number of people using Route A, and, if applicable, the implications from the payment and collection of toll revenue, which will be explained later. After each decision you will have the option to see a summary of your previous decisions.

What will you see on your screen?

Figure 2 is a screenshot of what you will see before you make your route choice decision. As you can see, the top box shows your endowment, your value of time, and the value of times of other members of your group. The table in the center shows the same information as Table 2 except that there are additional columns that show your calculated travel time costs for both routes by multiplying your value of time with the number of minutes for each possible outcome.

Figure 2



1 of 30

Remaining time [sec]: 16

Your period endowment (in tokens): XXX
Your value of time (tokens/minute): B

You are in Stage 1
NO TOLL

Your group's distribution of per-period value of time (tokens/minute)

Each member of your group has one of these six values of time (*indicates your value)	A	B*	C	D	E	F

Number of People Using Route A (including yourself if you take Route A)	Your possible outcomes			
	Route A		Route B	
	Total Travel Time (in minutes)	Your Travel Costs (in tokens)	Total Travel Time (in minutes)	Your Travel Costs (in tokens)
1	5	5*B	12	12*B
2	6	6*B	12	12*B
3	7	7*B	12	12*B
4	8	8*B	12	12*B
5	9	9*B	12	12*B
6	10	10*B	12	12*B

Which route would you like to take? ○ Route A
○ Route B

The Toll for using Route A

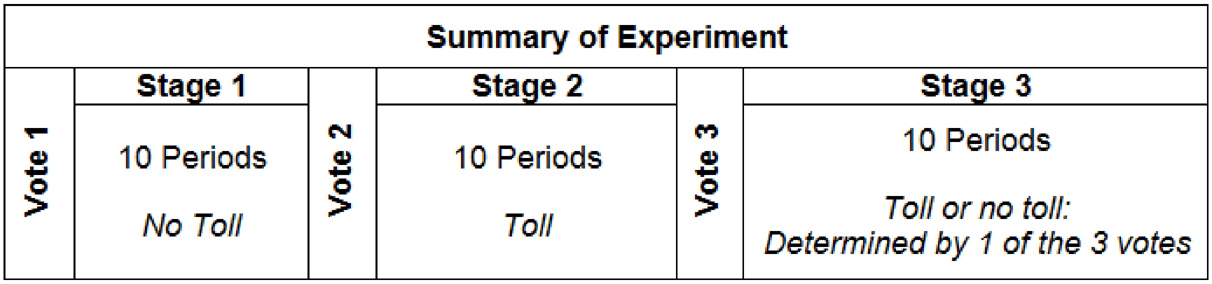
In Stage 2 and potentially in Stage 3 anyone using Route A will pay a toll that will be displayed on the computer screen before a route decision is made. The toll will be the same for everyone that is using Route A and will be the same throughout the experiment. The toll will be an additional cost to your travel costs. However, 100% of the collected toll revenues for a period will be redistributed back in equal shares to everyone in your group including those that use Route B. That is, your share of the toll revenues is equal to all of the total toll revenue divided by six (number of people in your group). The size of your share depends on the amount of people using Route A. In a stage with a toll the information in the center table in Figure 2 will be exactly the same. Please remember that the size and redistribution of the toll will also impact your per-period costs and resulting earnings.

How is the size of the toll determined? As was shown in Table 2, each additional user of Route A increases the travel time for everyone else using Route A. For example, the travel time for everybody when three people use Route A is 7 minutes per person. If instead four people use Route A, then the fourth person increases the travel time for each of the original three people from 7 minutes per person to 8 minutes per person (and this fourth person also has a travel time of 8 minutes). In other words, by choosing Route A instead of Route B, this individual increases the total travel time of those three people in Route A by 3 minutes (1 minute each).

With the toll in place, each user who chooses Route A faces now the increased total travel costs they impose on the other users of Route A. The purpose of the toll is to get some people to their destination faster, and the toll is charged like a fee for this service. The toll reduces the number of users in Route A, reducing the travel time of users already in Route A. Based on the group's average value of time, the size of the toll is set to optimize the use of Route A.

Voting

Table 1



Summary of Experiment					
Vote 1	**Stage 1**	**Vote 2**	**Stage 2**	**Vote 3**	**Stage 3**
	10 Periods *No Toll*		10 Periods *Toll*		10 Periods *Toll or no toll: Determined by 1 of the 3 votes*

As shown in Table 1 above (copied from page 1), Stage 1 will not have a toll and Stage 2 will have a toll. Whether Stage 3 will have a toll is based on how your group votes. In each of the three votes your group will be voting on whether to impose tolls for Stage 3. You will not learn your group's voting outcomes until after the third and final vote. The vote that counts will be determined randomly at the conclusion of the third referendum vote; so each one of the three votes can be decisive with a 1/3 chance. In the case of a 3-3 tie in the decisive referendum vote, the tiebreaker will be randomly determined using a deck of cards. At the end of the experiment, the stage that will determine your monetary earnings will also be chosen through a similar random process.

You will start the experiment with the first referendum vote. You will see your value of time, your per-period endowment, and the group's value of time distribution for the 30-period experiment before you cast your first vote. We suggest you refer to Table 2 for your possible travel time outcomes before you cast your first vote.

Are there any questions?

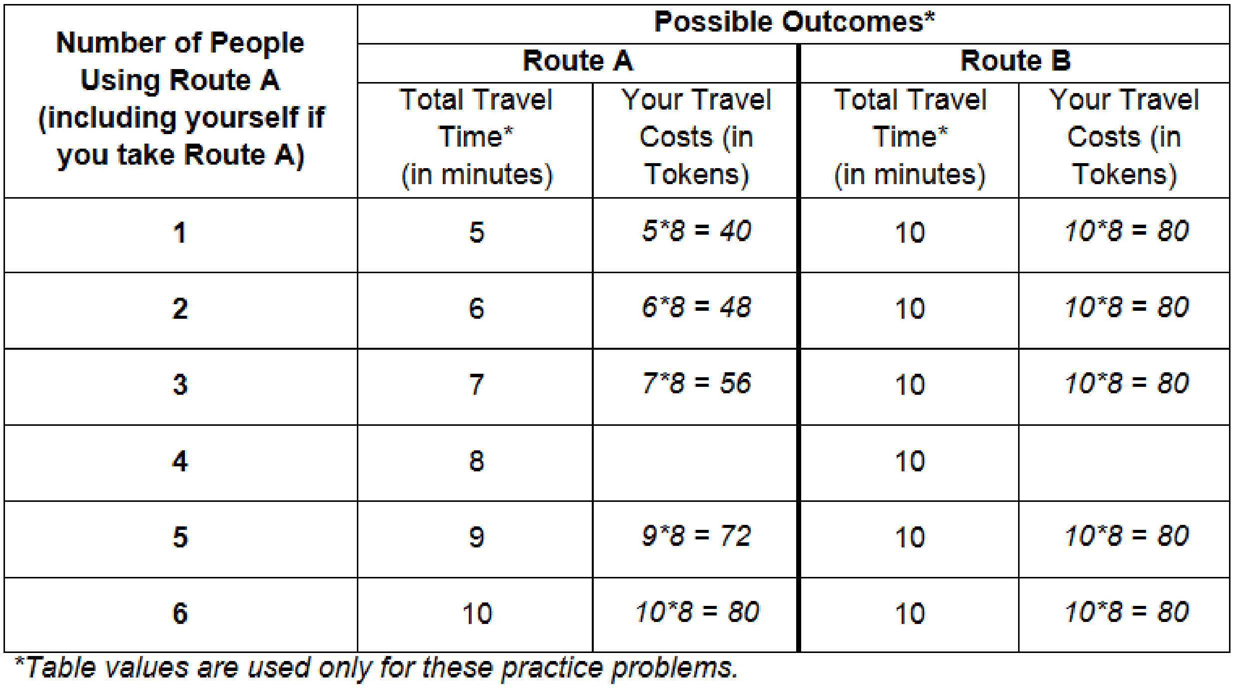
Practice Problems

Please use the following information to answer the following practice problems:

(Values used are only for these practice problems)

Your value of time = 8 tokens/minute Your period endowment = 90 tokens

For questions 1-4 assume that there are no tolls



Number of People Using Route A (including yourself if you take Route A)	**Possible Outcomes***			
	Route A		**Route B**	
	Total Travel Time* (in minutes)	Your Travel Costs (in Tokens)	Total Travel Time* (in minutes)	Your Travel Costs (in Tokens)
1	5	5*8 = 40	10	10*8 = 80
2	6	6*8 = 48	10	10*8 = 80
3	7	7*8 = 56	10	10*8 = 80
4	8		10	
5	9	9*8 = 72	10	10*8 = 80
6	10	10*8 = 80	10	10*8 = 80

Table values are used only for these practice problems.

1) If 4 people including you take Route A, what is your total travel time? _______ minutes. How much travel cost would you incur? _______ tokens. What would be your earnings for this period? _______ tokens.

2) What would your travel time be if you instead chose Route B? _______ minutes. What would your travel cost be for choosing Route B? _______ tokens. What would be your earnings for this period? _______ tokens.

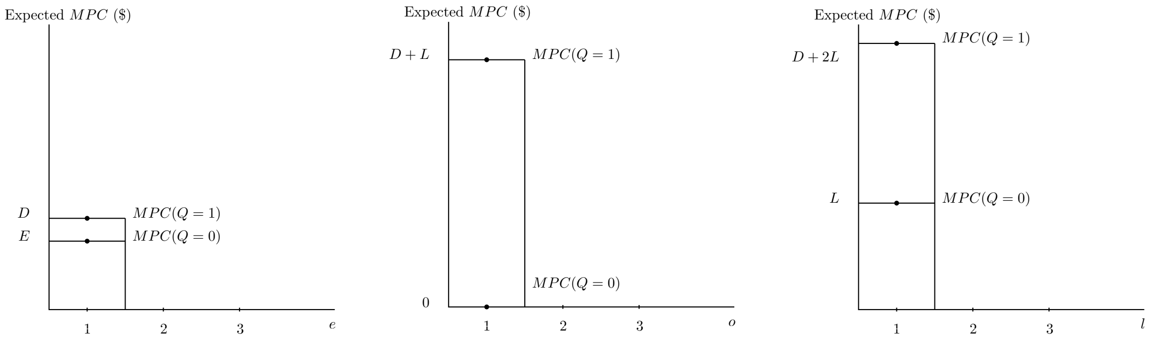
3) True or False? Without tolls my travel cost using Route B depends on the number of users on Route A. _______.

4) If you are the 5th person entering Route A, how much will the per-person travel time increase for the other Route A users? _______ minute(s) per person. By how much will aggregate total travel time of that group of 4 Route A users increase? _______ minutes.

APPENDIX B

SUPPLEMENTARY MATERIAL FOR CHAPTER 3

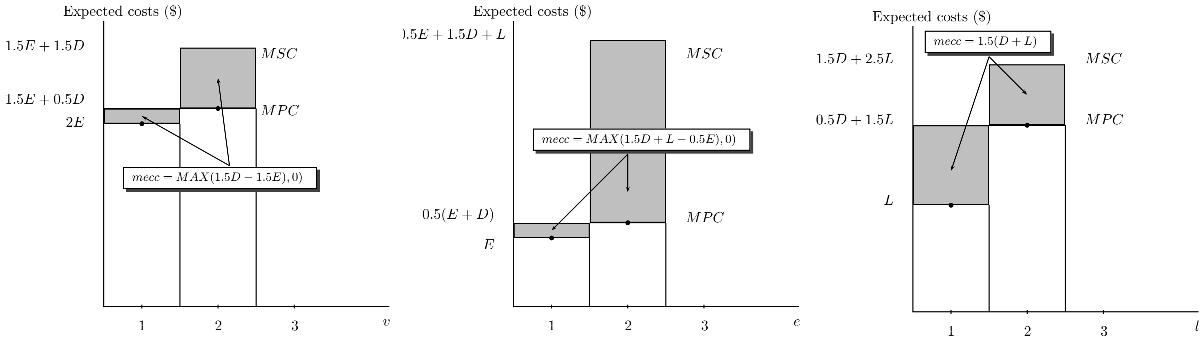
B.1. SUPPLEMENTAL EXPECTED COSTS FIGURES OF THREE-PLAYER CONGESTION GAME



(A) Entering a Queue (*Early*) *evv*

(B) Entering a Queue (*On-time*) *ooe*

(C) Entering a Queue (*Late*) *loo*



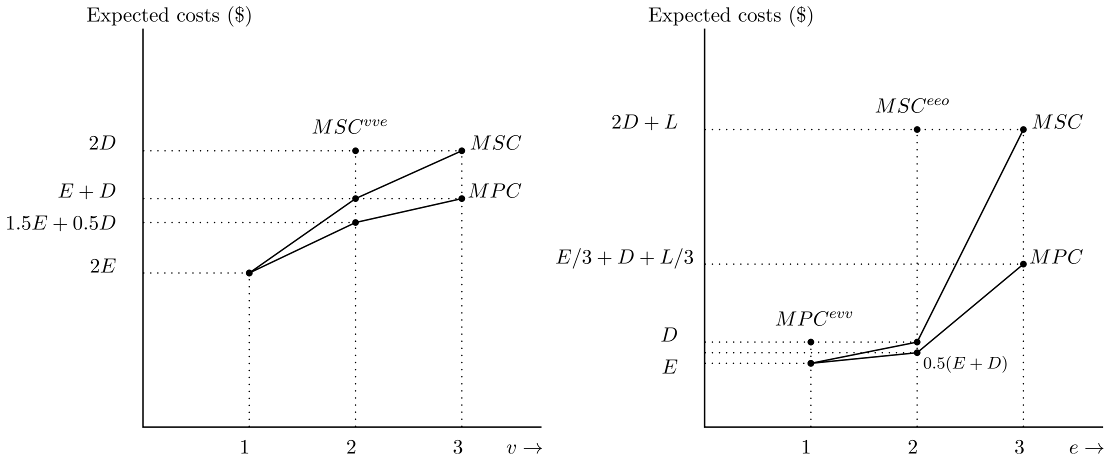
(D) Creating a Queue (*Very Early*) *vve*

(E) Creating a Queue (*Early*) *eeo*

(F) Creating a Queue (*On-Time*) *ool*

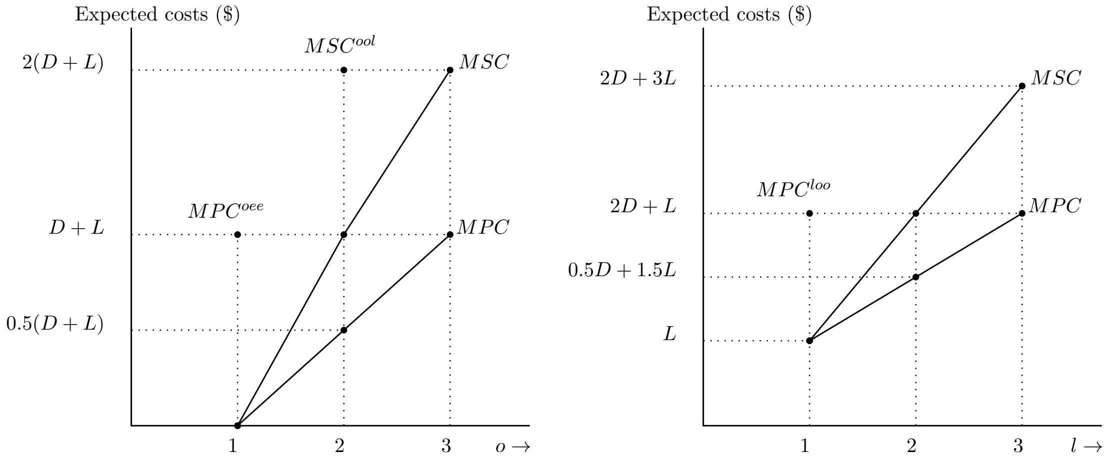
*Note the relative sizes of boxes representing *mecc* within figures d, c, and f are not drawn to scale. The *mecc* created by second departure is much larger. Figures B.1a, B.1b, and B.1c represent a player entering a queuing scenario for congestion scenarios *evv*, *ooe*, and *oee*, respectively ($mecc = 0$) .
Figures B.1d, B.1e, B.1f represent a player creating a queuing scenario and *mecc* ($mecc \geq 0$) for congestion scenarios *vve*, *eeo*, and *ool*, respectively.

FIGURE B.1. The Incremental Costs Of Congestion If Entering Or Creating A Queue Illustrated*



(A) *Very Early*

(B) *Early*



(C) *On-time*

(D) *Late*

FIGURE B.2. Cost Curves For Each Departure Time

B.2. TABLE OF NOMENCLATURE

TABLE B.2.1. Table of Nomenclature

Variable	Description
t_i	Individual departure time
t_{-i}	Departure times of all other individuals
E	Early penalty
D	Delay penalty
L	Late penalty
v; $\overline{v}$	Very early departure time; very early arrival time
e; $\overline{e}$	Early departure time; early arrival time
o; $\overline{o}$	On-time departure time; on-time arrival time
l; $\overline{l}$	Late departure time; late arrival time
$\overline{r}$	Really late arrival time
$\overline{s}$	Super late arrival time
d_t	Time of player's journey delay
$\varepsilon(d_t)$	Expected journey delay
Q_t	Standing queue at time t
A_t	Total departure at time t
$C(d_t)$	Expected costs from a journey delay
S_i	Schedule delay
t_a	Player's departure time
t_o	Player's desired arrival time
$C(S_i)$	Cost of a schedule delay
$\theta(S_i)$	Expected cost of a schedule delay

B.3. CORRIGENDUM TO “MICRO-FOUNDATIONS OF CONGESTION AND PRICING: A GAME THEORY PERSPECTIVE”

The following are corrections to Levinson (2005) and not the full text of the corrigendum. In December 2014, the corrigendum co-authored with David Levinson was sent to the editor of Transportation Research A: Policy and Practice.

In reviewing and extending “Micro-foundations of Congestion and Pricing: A Game Theory Perspective” Levinson [2005], Nicholas Janusch identified several errors in the original manuscript due to a spreadsheet error. The following are corrections to Levinson [2005]:

The original author regrets the error.

- p700: Probabilities in Table 10 for Player A departing Late (l) given Players B and C departing Early and Late (el) are incorrect. $P(\bar{r}) = 0.5$ not 0 for this scenario.
- p700: In the sentence “To illustrate the gains from pricing, for instance, in the case: $E = 3$,D= 1, $L = 4$, the unpriced equilibrium solution eee has a total cost of 10, compared with the priced equilibria of eoo, oeo, ooe which have a total cost of 7.” The total cost is 8 not 7 ($3 + 0 + 1 + 4 = 8$).
- p701 Corrections to several predicted pure strategy Nash equilibria (PSNE) reported in Table 11 using this paper’s three-player game methodology. Notice that unlike Table 11, many of the corrected PSNE with congestion pricing shown below have departure patterns where players depart at separate times. These corrected results are more consistent with the objective of congestion pricing. ($\#,\#,\# = E, D, L$)

Table B.3.1. Corrected Table 11 From Levinson (2005) Of Results From Three-player Game

E, D, L	Number of Nash equilibria (unpriced)	Solutions (Unpriced)	Number of Nash equilibria (priced)	Solutions (priced)	Lowest total cost
0, 0, 0	64	all	64	all	0
0, 1, 0	24	*veo, …, vel ,…, vol, …, eol , …*	24	*veo, …, vel ,…, vol, …, eol , …*	0
0, 0, 1	**16**	*vvv,* ***vve, …****, vvo, …, vee, …, veo, …*	**16**	*vvv,* ***vve, …****, vvo, …, vee, …, veo, …*	0
0, 1, 1	6	*veo, …*	6	*veo, …*	0
1, 0, 0	8	*ooo, lll, ool, … , oll, …*	8	*ooo, lll, ool, …, oll, …*	0
1, 1, 0	7	*ooo, ool, …, oll, …*	**9**	*oll, …,* ***eol, …***	1
1, 0, 1	5	*ooo, eee,* ***eoo, …***	**10**	*eee, eeo, …,* ***eol, …***	2
1, 1, 1	9	*eol, …, eoo, …*	6	*eol, …*	2
3, 1, 4	1	*eee*	**6**	***eol, …***	7
4, 0, 3	2	*ooo, eee*	**10**	*eee, eoo, …,* ***eol, …***	7
4, 1, 3	4	*ooo, eoo, …*	**6**	***eol, …***	7
3, 0, 4	1	*eee*	**13**	*eee,* ***eeo, …, eoo, …, eol, …***	7

Corrections in **Bold**. Note: Column 1 gives the penalty for arriving early, suffering journey delay, or arriving late. The characterization of solutions identifies which patterns are Nash equilibria, *v* indicates vehicles arrive very early, *e* early, *o* on-time, *l* late.

APPENDIX C

Supplementary Material For Chapter 4

C.1. Tables And Figures Of Timing Decisions

Table C.1.1. Expected Total Costs With And Without Tolls With Reference Case Parameters ($E = 3, D = 4, L = 8$) And Given Departure Strategies, Three-player Game

(a) Reference Cost Case: Expected Total Costs Without Tolls

	Player B	v	v	v	v	e	e	e	o	o	l
	Player C	v	e	o	l	e	o	l	o	l	l
Player A	v	7	6.5	6.5	6.5	6*	6	6	6	6	6
	e	4	3.5	3*	3	23/3	3.5*	3.5	3*	3*	3
	o	0*	0*	6	0*	12	6	0*	12	6	0*
	l	8	8	8	14	8	8	14	20	14	20

*indicates best response cost-minimizing strategy given other players' departure decisions.

(b) Reference Cost Case: Expected Total Costs With Tolls

	Player B	v	v	v	v	e	e	e	o	o	l
	Player C	v	e	o	l	e	o	l	o	l	l
Player A	v	9	8	7	7	6*	6*	6	6	6	6
	e	4	4	3*	3	17	16	4	3*	3*	3
	o	0*	0*	12	0*	12	12	0*	36	24	0*
	l	8	8	8	20	8	8	20	20	20	44

*indicates best response cost-minimizing strategy given other players' departure decisions.

TABLE C.1.2. Expected Total Costs With And Without Tolls With Low Case Parameters ($E = 2, D = 4, L = 4$) And Given Departure Strategies, Three-player Game

(A) Low-Cost Case: Expected Total Costs Without Tolls

	Player B	v	v	v	v	e	e	e	o	o	l
	Player C	v	e	o	l	e	o	l	o	l	l
Player A	v	6	5	5	5	4*	4	4	4	4	4
	e	4	3	2*	2	6	3*	3	2*	2*	2
	o	0*	0*	4	0*	8	4	0*	8	4	0*
	l	4	4	4	8	4*	4	8	12	8	12

*indicates best response cost-minimizing strategy given other players' departure decisions.

(B) Low-Cost Case: Expected Total Costs With Tolls

	Player B	v	v	v	v	e	e	e	o	o	l
	Player C	v	e	o	l	e	o	l	o	l	l
Player A	v	10	8	6	6	4*	4*	4	4	4	4
	e	4	4	2*	2	14	12	4	2*	2*	2
	o	0*	0*	8	0*	8	8	0*	24	16	0*
	l	4	4	4	12	4*	4*	12	12	12	28

*indicates best response cost-minimizing strategy given other players' departure decisions.

Table C.1.3. Expected Total Costs With And Without Tolls With High Case Parameters ($E = 5, D = 4, L = 12$) And Given Departure Strategies, Three-player Game

(a) High-Cost Case: Expected Total Costs Without Tolls

	Player B	v	v	v	v	e	e	e	o	o	l
	Player C	v	e	o	l	e	o	l	o	l	l
Player A	v	9	9.5	9.5	9.5	10	10	10	10	10	10
	e	4	4.5	5*	5	29/3*	4.5*	4.5	5*	5*	5
	o	0*	0*	8	0*	16	8	0*	16	8	0*
	l	12	12	12	20	12	12	20	28	20	28

*indicates best response cost-minimizing strategy given other players' departure decisions.

(b) High-Cost Case: Expected Total Costs With Tolls

	Player B	v	v	v	v	e	e	e	o	o	l
	Player C	v	e	o	l	e	o	l	o	l	l
Player A	v	9	9.5	9.5	9.5	10*	10*	10	10	10	10
	e	4	4.5	5*	5	19	20	4.5	5*	5*	5
	o	0*	0*	16	0*	16	16	0*	48	32	0*
	l	12	12	12	28	12	12	28	28	28	60

*indicates best response cost-minimizing strategy given other players' departure decisions.

Table C.1.4. Departure Frequencies: Reference Cost Case

(a) All Treatments – Without Tolls

	Player B	***v***	***e***	***o***	***l***	***e***	***v***
176 obs.	**Player C**	***v***	***e***	***o***	***l***	***o***	***l***
Player A	***v***	0	16	6	0	41	-
	e	5	13	28	0	-	1
	o	3	45	11	0	-	1
	l	0	2	3	0	2	-

(b) All Treatments – With Tolls

	Player B	***v***	***e***	***o***	***l***	***e***	***v***
160 obs.	**Player C**	***v***	***e***	***o***	***l***	***o***	***l***
Player A	***v***	2	12	16	1	34	-
	e	11	12	10	0	-	7
	o	12	15	10	0	-	4
	l	1	5	2	0	6	-

Table C.1.5. Departure Frequencies: Low-Cost Case

(a) All Treatments – Without Tolls

	Player B	***v***	***e***	***o***	***l***	***e***	***v***
172 obs.	**Player C**	***v***	***e***	***o***	***l***	***o***	***l***
Player A	***v***	1	34	15	0	29	-
	e	3	19	28	0	-	1
	o	1	40	2	0	-	1
	l	0	2	1	0	2	-

(b) All Treatments – With Tolls

	Player B	***v***	***e***	***o***	***l***	***e***	***v***
140 obs.	**Player C**	***v***	***e***	***o***	***l***	***o***	***l***
Player A	***v***	1	9	12	0	26	-
	e	10	5	14	0	-	8
	o	12	19	5	1	-	1
	l	3	2	0	0	12	-

Table C.1.6. Departure Frequencies: High-Cost Case

(a) All Treatments – Without Tolls

	Player B	***v***	***e***	***o***	***l***	***e***	***v***
164 obs.	**Player C**	***v***	***e***	***o***	***l***	***o***	***l***
Player A	***v***	0	11	4	0	23	-
	e	1	40	23	0	-	1
	o	0	50	7	0	-	0
	l	0	3	0	0	1	-

(b) All Treatments – With Tolls

	Player B	***v***	***e***	***o***	***l***	***e***	***v***
148 obs.	**Player C**	***v***	***e***	***o***	***l***	***o***	***l***
Player A	***v***	0	23	11	0	33	-
	e	4	8	26	0	-	0
	o	6	28	7	0	-	0
	l	0	1	0	0	1	-

Table C.1.7. Average Group Cost Comparison With And Without Tolls By Experimental Treatment

(a) Reference Cost Case: Average Group Costs And Group Efficiency

Reference Cost Scenario (Lowest Group Cost – 9)		
Treatment	w/o tolls	w/ tolls
No Policy First – Ref-High-Low	17.3 (85%)	16.4 (85%)
No Policy First – Ref-Low-High	17.5 (84%)	17.9 (86%)
Policy First – Ref-High-Low	15.1 (83%)	15.5 (83%)
Policy First – Ref-Low-High	16.2 (86%)	17.2 (84%)
All Treatments	16.7 (85%)	16.5 (85%)

(b) Low-Cost Case: Average Group Costs And Group Efficiency

Low-Cost Scenario (Lowest Cost – 6)		
Treatment	w/o tolls	w/ tolls
No Policy First – Ref-High-Low	11.4 (82%)	11.0 (83%)
No Policy First – Ref-Low-High	12.1 (80%)	10.5 (85%)
Policy First – Ref-High-Low	11.8 (81%)	11.3 (82%)
Policy First – Ref-Low-High	10.3 (86%)	10.7 (85%)
All Treatments	11.6 (81%)	10.9 (84%)

(c) High-Cost Case: Average Group Costs And Group Efficiency

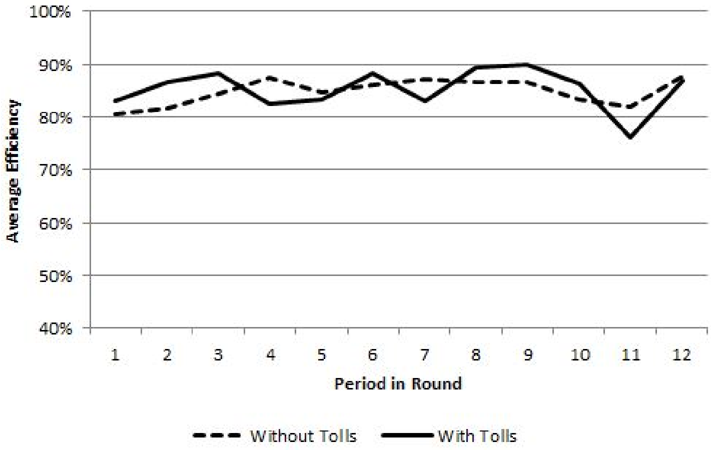
High-Cost Scenario (Lowest Group Cost – 15)		
Treatment	w/o tolls	w/ tolls
No Policy First – Ref-High-Low	24.1 (87%)	22.7 (89%)
No Policy First – Ref-Low-High	24.1 (87%)	21.2 (91%)
Policy First – Ref-High-Low	25.8 (84%)	21.8 (90%)
Policy First – Ref-Low-High	23.6 (88%)	22.7 (89%)
All Treatments	24.5 (86%)	22.1 (90%)

Table C.1.8. Negative Binomial Coefficient Random Effects Estimates Of Journey Delays and Logit Coefficients Estimates Of Particular Type Of Congestion Occurring And Of Specific Group Departure Patterns

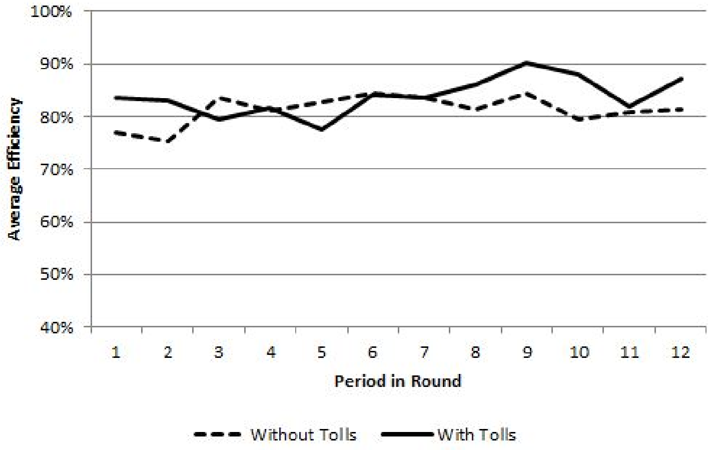
Dependent Variable:	(1) Journey Delay	(2) Any Congestion	(3) 3-way Congestion	(4) 2-Way Congestion	(5) Queue	(6) Lowest Cost	(7) veo	(8) eee
High*Rd2	0.0624	0.2004	0.5450	-0.1498	-0.4950	-0.4374	-0.4473	-0.0157
	(0.1521)	(0.4889)	(0.5569)	(0.3545)	(0.3904)	(0.5080)	(0.4813)	(0.6589)
Low*Rd2	-0.1295	-0.0518	-0.7274	0.2448	0.0813	0.1190	-0.2916	0.1643
	(0.1626)	(0.4781)	(0.6230)	(0.3633)	(0.4077)	(0.5014)	(0.4944)	(0.7377)
Low	0.0499	0.3787	0.2254	0.1971	-0.2929	-0.3877	-0.3761	0.3758
	(0.1196)	(0.3677)	(0.4538)	(0.2807)	(0.2917)	(0.3764)	(0.3630)	(0.5196)
High	0.2488*	0.5737	0.6998	-0.1184	0.3606	-0.4214	-0.4041	1.4201***
	(0.1270)	(0.4161)	(0.4515)	(0.3027)	(0.3289)	(0.4307)	(0.4115)	(0.5474)
Reference*Tolls	-0.0946	-0.2225	0.1972	-0.2813	-0.5969**	-0.1861	-0.1234	0.0536
	(0.1065)	(0.2812)	(0.3633)	(0.2394)	(0.2800)	(0.3005)	(0.2958)	(0.4622)
Low*Tolls	-0.2060*	-0.7029**	-0.4900	-0.3833	-0.1353	0.5100	0.2684	-1.2073**
	(0.1149)	(0.3051)	(0.4298)	(0.2575)	(0.2922)	(0.3191)	(0.3351)	(0.5657)
High*Tolls	-0.3507***	-0.4295	-1.2650***	0.4957**	-0.4365	0.4982	0.5423*	-1.6950***
	(0.1008)	(0.3190)	(0.3527)	(0.2465)	(0.2712)	(0.3272)	(0.3228)	(0.4398)
Tolls1st Trmt	-0.0491	-0.0722	-0.0279	-0.0750	-0.3031	-0.0139	-0.2908	0.2051
	(0.0990)	(0.3004)	(0.3681)	(0.2251)	(0.2549)	(0.3140)	(0.3085)	(0.4342)
Ref-High-Low Trmt	0.0112	0.1508	-0.3211	0.2379	0.3938	-0.0196	-0.1677	0.4991
	(0.1269)	(0.3954)	(0.4714)	(0.2924)	(0.3171)	(0.4124)	(0.3909)	(0.5768)
Tolls1st*Ref-Low-High	-0.0449	-0.2783	-0.0899	-0.1150	0.1055	0.3925	0.6767*	-0.7580
	(0.1286)	(0.4022)	(0.4819)	(0.2964)	(0.3261)	(0.4180)	(0.4052)	(0.5622)
Constant	16.0698	1.1481***	-1.7950***	0.3877*	-1.0030***	-1.3433***	-1.2101***	-2.8649***
	(132.7705)	(0.3067)	(0.3662)	(0.2310)	(0.2553)	(0.3196)	(0.3026)	(0.4796)
N	960	960	960	960	960	960	960	960
p-value	0.0004	0.0742	0.0049	0.2637	0.0675	0.4317	0.3856	0.0002
χ^2	31.9360	17.0079	25.2358	12.3284	17.3221	10.1011	10.6479	33.4501

Standard errors in parentheses

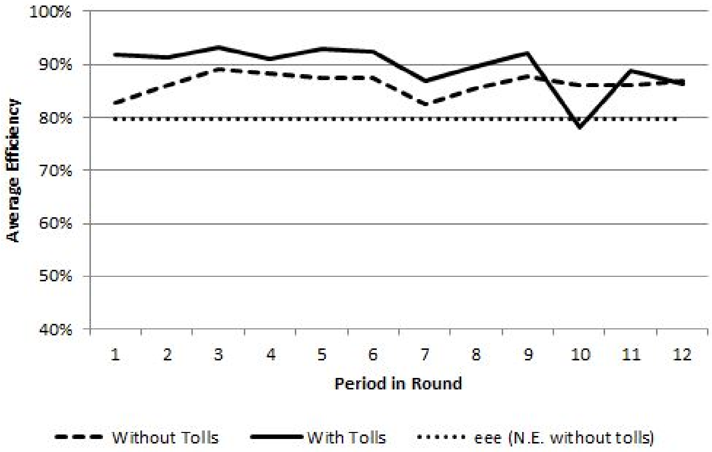
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$



(A) Average Group Efficiency With And Without Tolls By Period For Reference Cost Case

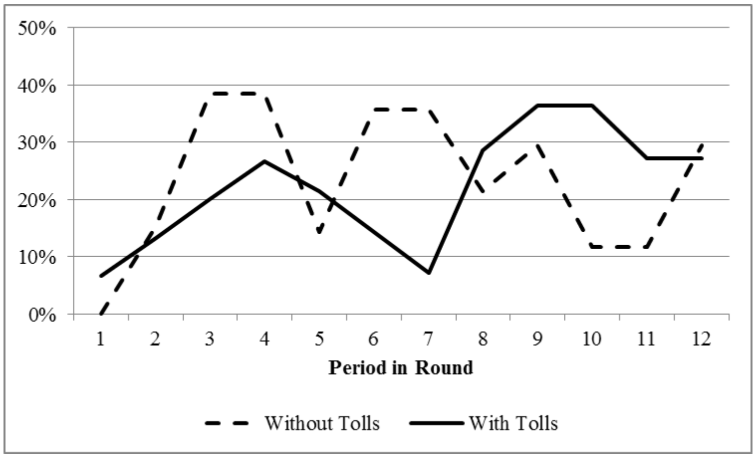


(B) Average Group Efficiency With And Without Tolls By Period For Low-Cost Case

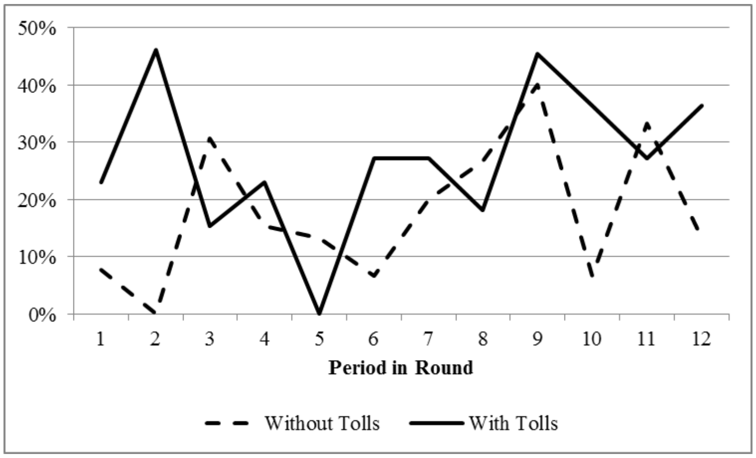


(C) Average Group Efficiency With And Without Tolls By Period For High-Cost Case

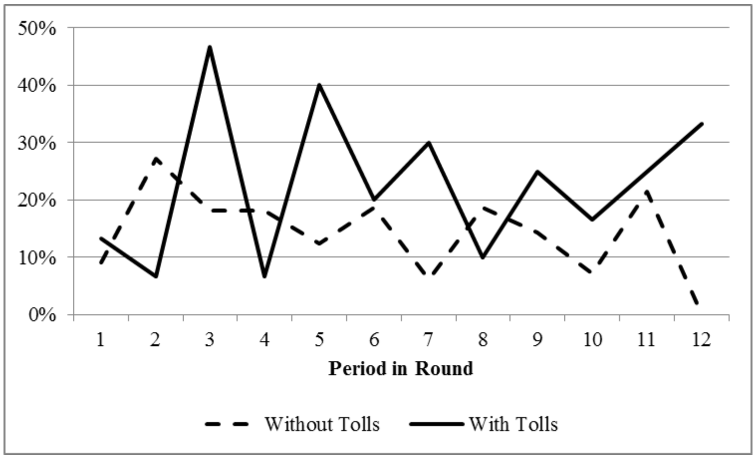
Figure C.1. Average Group Efficiency With And Without Tolls By Period And Cost Case



(A) Percentage Of Groups In Reference Cost Scenario Obtaining Socially Efficient Departure Pattern



(B) Percentage Of Groups In Low-Cost Scenario Obtaining Socially Efficient Departure Pattern



(C) Percentage Of Groups In High-Cost Scenario Obtaining Socially Efficient Departure Pattern

FIGURE C.2. Percentage Frequencies Of Groups Obtaining Socially Efficient Departure Patterns

C.2. Tables And Figures From Voting Analysis

Table C.2.1. Frequency Of Total Group Votes By Cost Case And Period Of A Group's Round

	Reference		Low		High	
Period	5th	9th	5th	9th	5th	9th
3 votes	1 (4%)	2 (7%)	4 (15%)	1 (4%)	2 (8%)	2 (8%)
2 votes	13 (46%)	9 (32%)	7 (27%)	10 (38%)	8 (31%)	10 (38%)
1 vote	7 (25%)	16 (57%)	12 (46%)	12 (46%)	12 (46%)	12 (46%)
0 vote	7 (25%)	1 (4%)	3 (12%)	3 (12%)	4 (15%)	2 (8%)

Table C.2.2. Worldview Questions (1 = Strongly Disagree; 6 = Strongly Agree) And Principal Component Analysis

Statement	Definition	Mean	Principal Components[a,b]											
			1	2	3	4	5	6	7	8	9	10	11	12
1	The government interferes far too much in our everyday lives.	4.04 (1.15)[a]	-0.36	-0.22	0.12	**0.42**	-0.12	-0.24	0.36	0.03	0.25	0.33	**0.50**	-0.08
2	Sometimes government needs to make laws that keep people from hurting themselves.	3.80 (1.35)	0.20	0.35	-0.06	**0.44**	-0.16	**0.43**	0.12	**-0.46**	-0.36	0.24	0.07	0.02
3	It's not the government's business to try to protect people from themselves.	3.52 (1.19)	-0.21	-0.18	-0.06	-0.001	**0.83**	0.17	-0.25	-0.14	-0.16	0.26	0.16	0.00
4	The government should stop telling people how to live their lives.	4.30 (1.18)	-0.26	-0.24	0.04	**0.63**	0.05	0.24	-0.05	0.30	-0.11	**-0.44**	-0.33	0.11
5	The government should do more to advance society's goals, even if that means limiting the freedom and choices of individuals.	2.45 (1.27)	0.29	**0.40**	0.20	0.05	0.34	0.09	0.24	0.20	0.12	**-0.48**	**0.49**	0.03
6	Government should put limits on the choices individuals can make so they don't get in the way of what's good for society.	2.61 (1.11)	0.26	0.28	0.28	0.29	0.27	**-0.58**	0.09	0.17	-0.17	0.28	-0.39	-0.02
7	We have gone too far in pushing equal rights in this country.	2.61 (1.25)	-0.31	0.33	0.30	-0.06	0.13	0.28	0.16	-0.22	**0.61**	0.09	-0.39	0.04
8	Our society would be better if the distribution of wealth was more equal.	3.58 (1.52)	0.25	-0.36	**0.55**	-0.05	-0.07	0.04	-0.09	-0.17	0.00	0.05	0.08	**0.67**
9	We need to dramatically reduce inequalities between the rich and the poor, whites and people of color, and men and women.	3.95 (1.41)	0.34	-0.37	**0.44**	0.02	0.00	0.21	-0.02	-0.06	0.05	0.00	-0.06	**-0.71**
10	Discrimination against minorities is still a very serious problem in our society.	4.17 (1.36)	**0.40**	-0.04	-0.27	0.11	0.00	0.34	-0.08	**0.54**	0.35	**0.45**	-0.02	0.13
11	It seems like minority groups don't want equal rights, they want special rights just for them.	2.83 (1.36)	-0.31	0.11	0.33	-0.33	-0.09	0.29	0.30	0.46	**-0.48**	0.21	0.00	0.01
12	Society as a whole has become too soft.	3.57 (1.48)	-0.19	0.34	0.30	0.13	-0.21	-0.03	**-0.78**	0.15	0.04	0.07	0.24	0.10
	Percent Variation		0.24	0.17	0.13	0.10	0.08	0.06	0.06	0.05	0.04	0.04	0.03	0.01
	Eigenvalue		2.87	2.07	1.53	1.17	0.98	0.76	0.70	0.61	0.48	0.43	0.31	0.12

[a] Numbers in parentheses are standard deviations.

[b] Coefficients with absolute values greater than 0.4 are in bold.

Table C.2.3. Logit Coefficient Estimates Of Individual Worldview Effects On The First Of Six Votes

Dependent variable:	(1) 1st Vote	(2) 1st Vote	(3) 1st Vote	(4) 1st Vote	(5) 1st Vote
Tolls1st Trmt	-0.4631	-0.4554	-0.4969	-0.4982	-0.4310
	(0.4514)	(0.4475)	(0.4527)	(0.4551)	(0.4677)
Hierarchical-Individualist	0.4361				
	(0.5742)				
Egalitarian-Communitarian	0.5923				
	(0.5703)				
Individualist		0.1106		-0.0952	
		(0.5635)		(0.6007)	
Communitarian		0.2868		0.3047	
		(0.5375)		(0.5467)	
Hierarchical			0.5762	0.6643	
			(0.5522)	(0.5931)	
Egalitarian			0.3808	0.3541	
			(0.5571)	(0.5618)	
“Communitarian-Egalitarian”					0.0935
					(0.1391)
“Quasi-Dictator”					0.0183
					(0.1623)
“Equity concerns”					-0.1156
					(0.1861)
“Overreaching government”					0.2929
					(0.2195)
“Nanny state”					-0.3237
					(0.2353)
Constant	-0.2551	-0.1448	-0.2526	-0.3229	-0.0749
	(0.3679)	(0.3757)	(0.3785)	(0.4178)	(0.3344)
N	84	84	84	84	84
p-value	0.5001	0.7274	0.5195	0.7494	0.4745
χ^2	2.3653	1.3073	2.2638	2.6784	5.5575

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

TABLE C.2.4. Logit Coefficient Estimates On The Effects Of Worldview On Voting Behavior

Dependent variable:	(1) Vote	(2) Vote	(3) Vote	(4) Vote
Low× Rd2	0.6309	0.6233	0.6321	0.6383
	(0.5425)	(0.5426)	(0.5424)	(0.5429)
High× Rd2	0.2142	0.2081	0.2133	0.2133
	(0.5344)	(0.5344)	(0.5345)	(0.5342)
Low	-0.1282	-0.1281	-0.1283	-0.1286
	(0.3582)	(0.3580)	(0.3583)	(0.3588)
High	-0.0717	-0.0717	-0.0717	-0.0713
	(0.3787)	(0.3787)	(0.3787)	(0.3777)
Policy1st Trmt	0.4807	0.4772	0.4266	0.5894
	(0.5756)	(0.5740)	(0.5789)	(0.5581)
Ref-High-Low Trmt	0.0095	-0.0222	-0.1241	0.1478
	(0.6437)	(0.6443)	(0.6716)	(0.6471)
Policy1st× Ref-High-Low	-0.9317	-0.9603	-0.8564	-0.9471
	(0.7885)	(0.7891)	(0.7981)	(0.7705)
2nd Vote in Round	0.1191	0.1191	0.1191	0.1192
	(0.2184)	(0.2184)	(0.2184)	(0.2185)
Hierarchical-Individualist		-0.0129		
		(0.5050)		
Egalitarian-Communitarian		-0.2922		
		(0.5164)		
Individualist			0.0855	
			(0.5347)	
Communitarian			0.1051	
			(0.4773)	
Hierarchical			-0.2244	
			(0.5200)	
Egalitarian			-0.5134	
			(0.5207)	
“Communitarian-Egalitarian”				0.0608
				(0.1192)
“Quasi-Dictator”				0.0618
				(0.1364)
“Equity concerns”				-0.1627
				(0.1594)
“Overreaching government”				-0.1953
				(0.1748)
“Nanny state”				-0.4252**
				(0.1979)
Constant	-0.3398	-0.2495	-0.1392	-0.4785
	(0.4853)	(0.5183)	(0.5785)	(0.4874)
N	480	480	480	480
p-value	0.5889	0.7404	0.8218	0.4111
χ^2	6.5224	6.8404	7.5146	13.4848

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

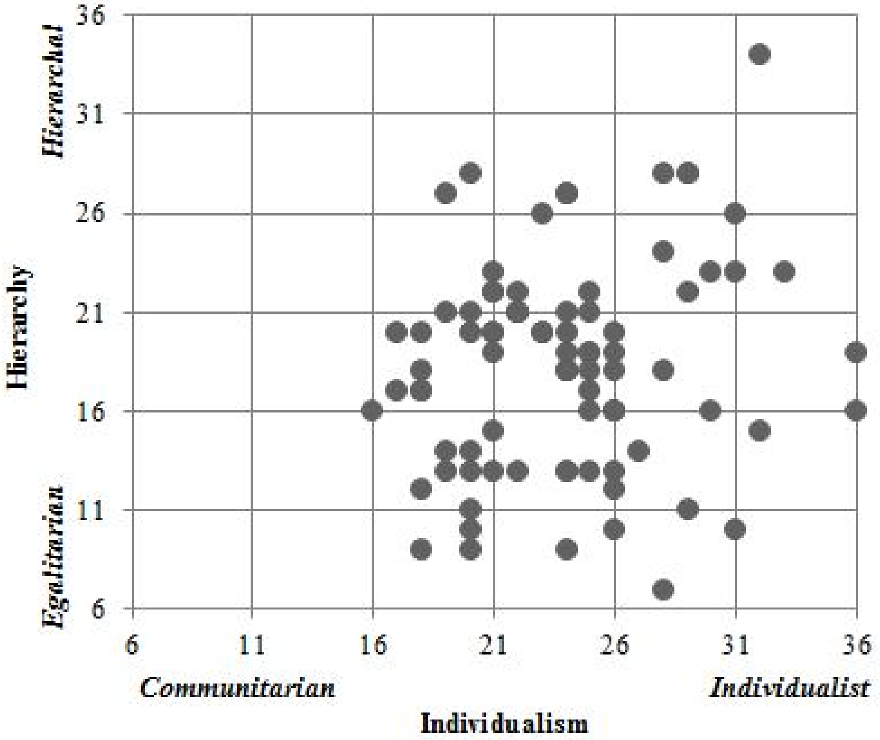


Figure C.3. Correlation Of Worldview Scores

C.3. Tolls Used

Table C.3.1. Tolls For A Three-player Game

Congestion Scenario	$Toll = ISC - IPC$	Toll Symbol
vvv	$MAX(2D - 2E, 0)$	τ_α
vve	$MAX(1.5D - 1.5E, 0)$	τ_β
vvo	$MAX(0.5D - 0.5E, 0)$	τ_δ
vee	$MAX(0.5D - 0.5E, 0)$	τ_δ
vvl	$MAX(0.5D - 0.5E, 0)$	τ_δ
eee	$MAX(2D + \frac{2}{3}L - \frac{4}{3}E, 0)$	τ_Θ
voo	$0.5L + 0.5D$	τ_μ
eeo	$MAX(1.5D + L - 0.5E, 0)$	τ_ε
eel	$MAX(0.5D - 0.5E, 0)$	τ_δ
eoo	$0.5L + 0.5D$	τ_μ
vll	$0.5L + 0.5D$	τ_μ
ooo	$2L + 2D$	τ_λ
ell	$0.5L + 0.5D$	τ_μ
ool	$1.5L + 1.5D$	τ_σ
oll	$0.5L + 0.5D$	τ_μ
lll	$2L + 2D$	τ_λ

Table C.3.2. Tolls For The Experiment's Three Cost Parameter Scenarios: Reference, Low, and High

Toll Symbol	Congestion Scenario(s)	Reference	Low	High
τ_α	vvv	2	4	0
τ_β	vve	1.5	3	0
τ_δ	vvo, vee, vvl, eel	0.5	1	0
τ_Θ	eee	28/3	8	28/3
τ_ε	eeo	13	9	15.5
τ_λ	ooo, lll	24	16	32
τ_σ	ool	18	12	24
τ_μ	voo, eoo, vll, ell, oll	6	4	8

C.4. Cultural Worldview Measures

We used similar cultural world view measures as Kahan et al. (2011). These questions are shown below.

People in our society often disagree about how far to let individuals go in making decisions for themselves. How strongly do you agree or disagree with each of these statements? [strongly disagree, moderately disagree, slightly disagree, slightly agree, moderately agree, strongly agree; items prefixed by 'S' were reversed coded]

IINTRSTS. The government interferes far too much in our everyday lives.

SHARM. Sometimes government needs to make laws that keep people from hurting themselves.

IPROTECT. It's not the government's business to try to protect people from themselves.

IPRIVACY. The government should stop telling people how to live their lives.

SPROTECT. The government should do more to advance society's goals, even if that means limiting the freedom and choices of individuals.

SLIMCHOI. Government should put limits on the choices individuals can make so they don't get in the way of what's good for society.

People in our society often disagree about issues of equality and discrimination. How strongly do you agree or disagree with each of these statements? [strongly disagree, moderately disagree, slightly disagree, slightly agree, moderately agree, strongly agree; items prefixed by 'E' were reversed coded]

HEQUAL. We have gone too far in pushing equal rights in this country.

EWEALTH. Our society would be better off if the distribution of wealth was more equal.

ERADEQ. We need to dramatically reduce inequalities between the rich and the poor, whites and people of color, and men and women.

EDISCRIM. Discrimination against minorities is still a very serious problem in our society.

HREVDIS2. It seems like minority groups don't want equal rights, they want special rights just for them.

HFEMININ. Society as a whole has become too soft.

C.5. Experiment Instructions (No Policy First)

Instructions

You are about to participate in an experiment on decision making in markets. Please read these instructions carefully. You will earn money, which will be paid to you in cash at the end of the experiment. Your payoff will depend on your choices and the choices of other participants. All transactions in this market will be done in "tokens," with 1 token = $0.10.

During the entire experiment communication of any kind is strictly prohibited. Communication between participants will lead to your exclusion from the experiment and the forfeiture of all earnings. Please raise your hand if you have any questions and a member of the research team will come to you and answer your questions privately. Also, please silent your cell phones to minimize disruption during the experiment.

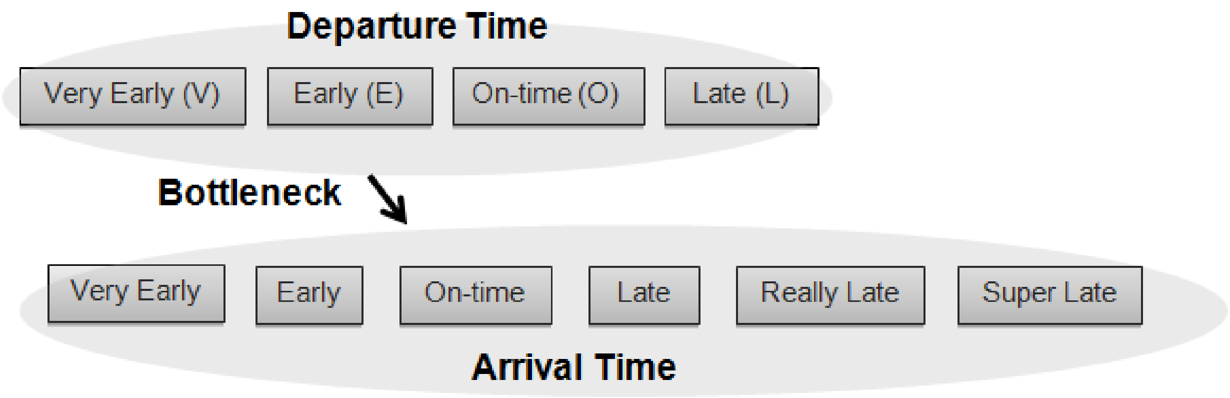
Market Sessions

The experiment consists of a series of market sessions of four period sets. You and the other participants will be randomly assigned to groups of three. In each market session, you and the other people in your group will be deciding when to depart to reach the same destination that has a bottleneck. This bottleneck restricts people to arriving only one-at-a-time.

You have the option to depart Very Early, Early, On-time, or Late. In the case that two people happen to decide to depart at the same time, then it is determined randomly that one of the two people arrives at their intended time while the other person is bumped and arrives at the next time slot and incurs an extra cost of being Delayed.

Further, if it so happens that all three depart at the same time, then again it is randomly determined that one of the three people will arrive at their intended time. A second person will thus incur a cost of being delayed and be bumped and arrive at the next time slot. The third person will then be bumped twice and arrive two slots after their intended time of departure and incur the delay costs of being twice Delayed.

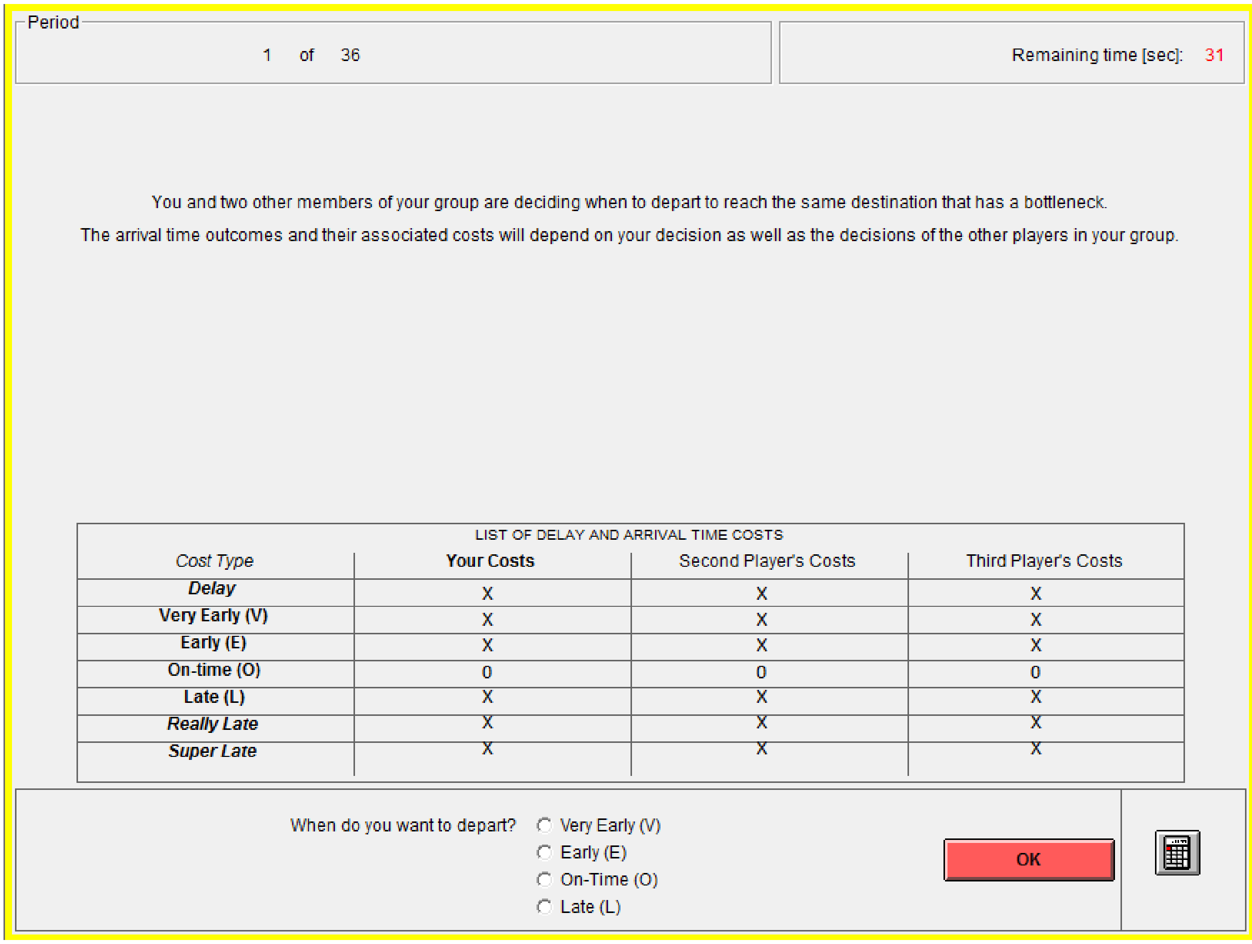
You and the other two members in your group will start with 400 tokens at the beginning of the experiment and will be assigned a set of values that represent how much costs you will receive for being Delayed and for the time you arrive: Very Early, Early, On-time, Late, Really Late, and Super Late. An On-time arrival results in no costs unless you are delayed into that time slot. Based on the arrival cost values and cost of a Delay, you will decide when to depart.



Here are some examples of what can happen (*denotes arrivals that were randomly determined and italics denote players that were delayed):

	Departure Decisions				**Arrival Outcomes**		
	Player 1	**Player 2**	**Player 3**		**Player 1**	**Player 2**	**Player 3**
Example 1:	Early	On-Time	Late	→	Early	On-Time	Late
Example 2:	Early	Early	Late	→	Early*	_On-Time*_	Late
Example 3:	Early	Early	On-time	→	_On-Time*_	Early*	_Late_
Example 4:	Early	Early	Early	→	_Late*_	Early*	_On-Time*_

You and the other members in your group will see a screen like this (Note that in the actual experiment you will see numbers instead of Xs):



Period

1 of 36

Remaining time [sec]: 31

You and two other members of your group are deciding when to depart to reach the same destination that has a bottleneck.
The arrival time outcomes and their associated costs will depend on your decision as well as the decisions of the other players in your group.

LIST OF DELAY AND ARRIVAL TIME COSTS

Cost Type	**Your Costs**	Second Player's Costs	Third Player's Costs
Delay	X	X	X
Very Early (V)	X	X	X
Early (E)	X	X	X
On-time (O)	0	0	0
Late (L)	X	X	X
Really Late	X	X	X
Super Late	X	X	X

When do you want to depart?
○ Very Early (V)
○ Early (E)
○ On-Time (O)
○ Late (L)

On this screen you have the option to select whether to depart Very Early, Early, On-time, or Late. Your payoff will be the sum of any cost of being Delayed and the cost associated to your arrival time. These costs will be subtracted from your initial endowment. Your objective is to obtain the least amount of costs. (Note: you will only be paid after you complete all market sessions for this laboratory experiment.)

Voting

After a market session of four periods, you and the other participants will face a referendum that presents a decision to implement a policy. The policy is explained below. Each person will have the option to vote either for or against the policy. The option that receives the majority of votes in your group will be applied to the next market session of four periods.

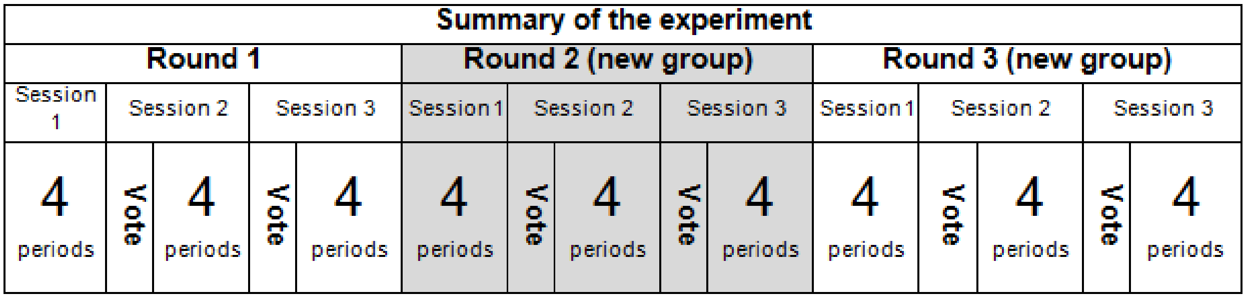
At the conclusion of that market session, you and the other members will face the same referendum. Again, people in your group will vote for either for or against the policy and the option that receives the majority of votes will be applied to the next market session. This will conclude the first of three rounds.

Second and Third Rounds

After the first round of market sessions where you are in the same group of 3, you will be randomly assigned to another group of 3 and begin a new round. You will be provided different cost values of being delayed and when you arrive. You and the other members of the group will repeat the same decision making process as the first round where you participate in 3 sessions where a referendum vote will occur after the first and second sessions.

For the third round, you are once again randomly assigned to another group of 3. And again, you are given new cost values for being delayed and when you arrive. These cost values are once again the same for all members in your group. And the process of the third round is the same as the first and second rounds.

A summary of the experiment

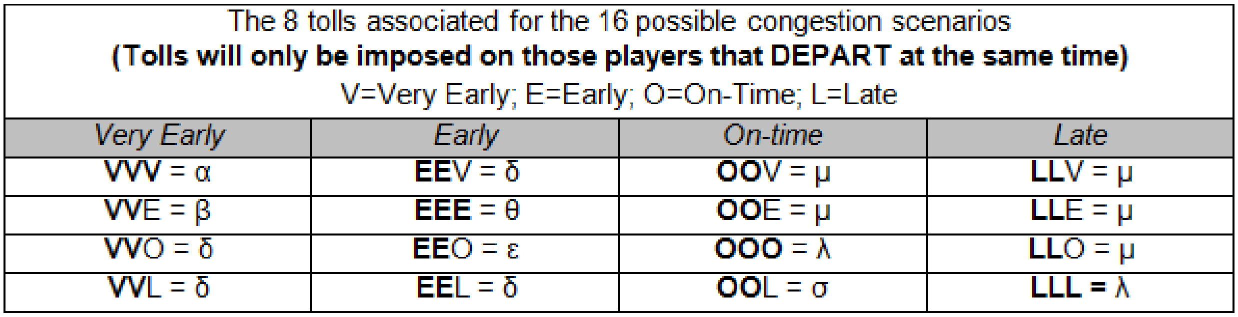


Summary of the experiment														
Round 1					Round 2 (new group)					Round 3 (new group)				
Session 1	Session 2		Session 3		Session 1	Session 2		Session 3		Session 1	Session 2		Session 3	
4 periods	Vote	4 periods	Vote	4 periods	4 periods	Vote	4 periods	Vote	4 periods	4 periods	Vote	4 periods	Vote	4 periods

The Policy

The referendum will present the option of voting for or against a policy option.

The experimenter will propose a policy for the next 4-period market session. The policy can impose up to 8 different tolls associated for the 16 possible congestion scenarios. The tolls will ONLY BE IMPOSED on those members of the group that depart at the same time. In other words, players that do not create congestion will not have to pay a toll. All toll revenue is collected by the experimenter and then redistributed equally to all members of the group at the end of the 4-period market session.



The 8 tolls associated for the 16 possible congestion scenarios
(Tolls will only be imposed on those players that DEPART at the same time)
V=Very Early; E=Early; O=On-Time; L=Late

Very Early	*Early*	*On-time*	*Late*
VVV = α	**EE**V = δ	**OO**V = μ	**LL**V = μ
VVE = β	**EEE** = θ	**OO**E = μ	**LL**E = μ
VVO = δ	**EE**O = ε	**OOO** = λ	**LL**O = μ
VVL = δ	**EE**L = δ	**OO**L = σ	**LLL =** λ

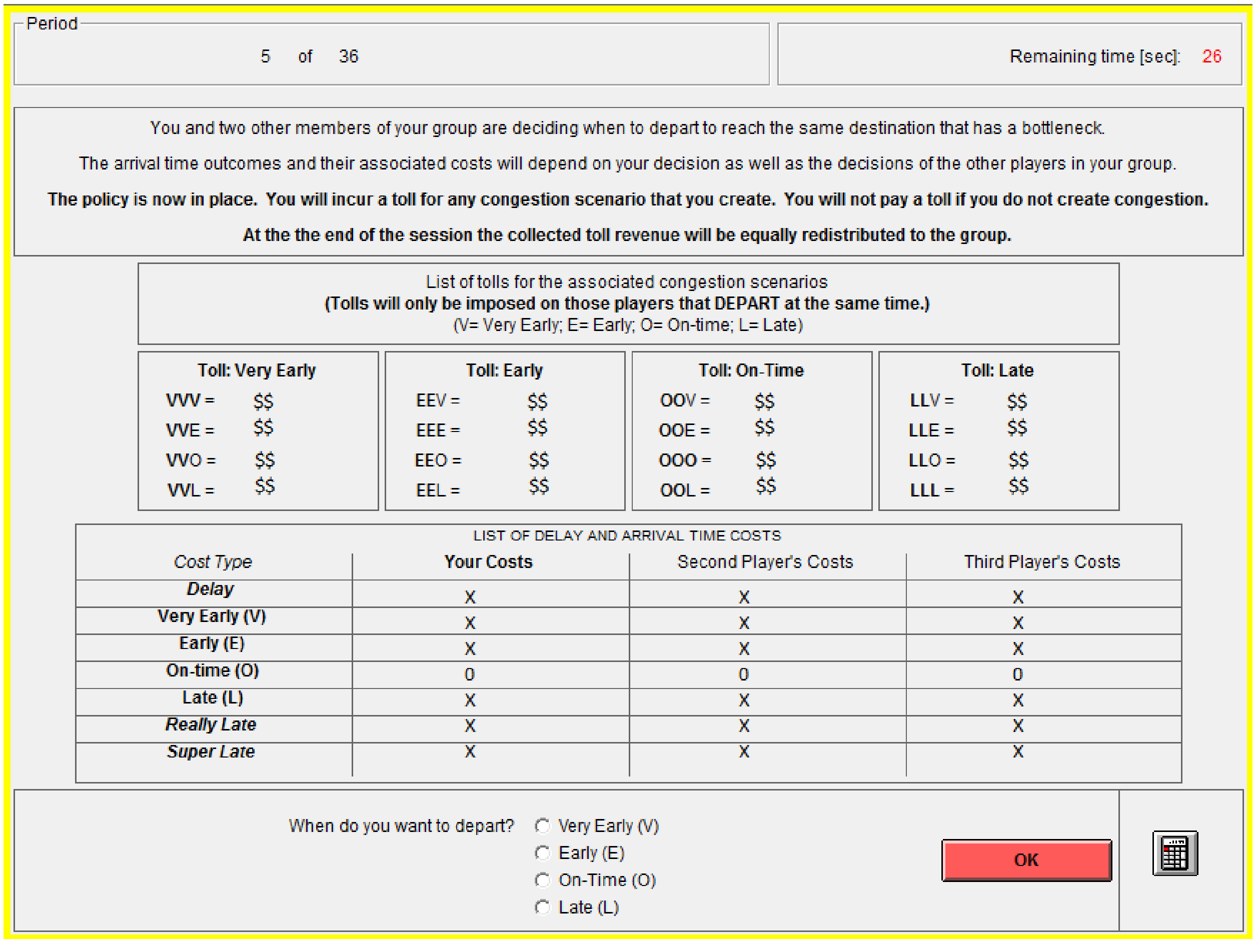
The above is a list of all possible tolls. (Note that the value of the above α, β**,** δ**,** ε**,** λ**,** σ**,** θ**, and** μ **token tolls** will be known to the group and will be shown on your screen before you make both your voting and departing decisions.) Notice that the tolls depend on your departure decision and not your arrival decision and that it is only those players that depart at the same time (**in bold**) that pay the associated toll.

Depending on your session, some tolls will be relatively higher or lower than others with some possibly equaling zero. Also notice that some tolls are the same for different congestion scenarios. Again, tolls will only be incurred to users that create a congestible scenario. For example, an α **token toll** will be imposed on all members of the group that depart Very Early (the **VVV** congestion scenario). And if two people depart Early with the other departing Very Early (the **EE**V congestion scenario) then a δ **token toll** will be imposed on only those members of the group that departed Early. All toll revenue is collected by the experimenter and then redistributed equally after a market session.

A vote of AGAINST: A vote of Against the Policy introduces no changes to the basic market, which will work as described above and as experienced in the first market session.

A vote of FOR: A vote of For the Policy adds the associated α, β, δ, ε, λ, σ, θ, **and** μ **token toll** to those members of the group that depart at the same time. If group members depart at different times, then no tolls will be paid. Tolls are collected by the experimenter and then are redistributed equally to all members of your group at the end of the 4-period market session

If the policy passes then you and the other members will see a screen like this when you are making your departure decisions (Note that in the actual experiment you will see numbers instead of **Xs** and **$$s**).



Period

5 of 36

Remaining time [sec]: 26

You and two other members of your group are deciding when to depart to reach the same destination that has a bottleneck.

The arrival time outcomes and their associated costs will depend on your decision as well as the decisions of the other players in your group.

The policy is now in place. You will incur a toll for any congestion scenario that you create. You will not pay a toll if you do not create congestion.

At the the end of the session the collected toll revenue will be equally redistributed to the group.

List of tolls for the associated congestion scenarios
(Tolls will only be imposed on those players that DEPART at the same time.)
(V= Very Early; E= Early; O= On-time; L= Late)

Toll: Very Early
VVV = $$
VVE = $$
VVO = $$
VVL = $$

Toll: Early
EEV = $$
EEE = $$
EEO = $$
EEL = $$

Toll: On-Time
OOV = $$
OOE = $$
OOO = $$
OOL = $$

Toll: Late
LLV = $$
LLE = $$
LLO = $$
LLL = $$

LIST OF DELAY AND ARRIVAL TIME COSTS

Cost Type	**Your Costs**	Second Player's Costs	Third Player's Costs
Delay	X	X	X
Very Early (V)	X	X	X
Early (E)	X	X	X
On-time (O)	0	0	0
Late (L)	X	X	X
Really Late	X	X	X
Super Late	X	X	X

When do you want to depart?
○ Very Early (V)
○ Early (E)
○ On-Time (O)
○ Late (L)

Payoff

At the conclusion of the final market session in the third round, your total costs including any adjustments from any redistribution of toll revenue from each market round are added together and are deducted from your initial endowment to obtain your total payoffs.

Are there any questions?

Practice Problems

Please use the following information to answer the following seven questions:

Departure Decisions: (Very Early, Early, On-time, Late)

Possible Arrival Outcomes: (Very Early, Early, On-time, Late, Really Late, Super Late)

<u>Costs:</u>

Very Early: **2 x $E** Early: **$E** On-time: **$0 (zero)**

Late: **$L** Really Late: **2 x $L** Super Late: **3 x $L**

Delay cost: **$D** Delay cost for being twice delayed: **2 x $D**

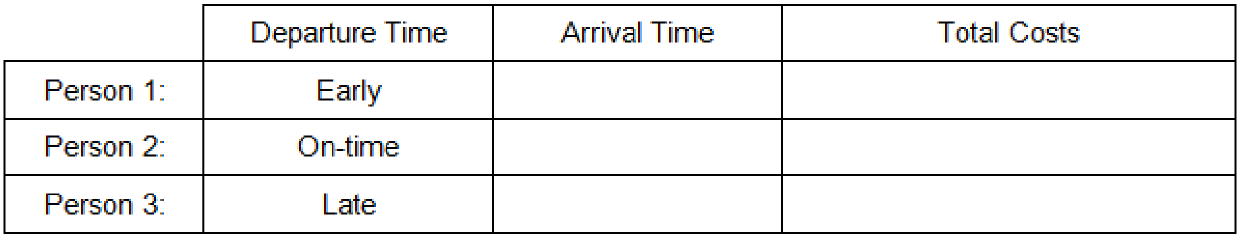
For questions 1-4 assume that there are no tolls

1) True or False If one person departs Early and you and another person both decide to depart On-time, there is a 100% chance that you will arrive On-time and not incur a Delay cost. _______

If False, what percentage chance do you have of arriving Late? _______

2) True or False If one person departs Early and you and another person both decide to depart On-time and you end up arriving On-time, you will incur a Delay cost. _______

3) If Person 1 departs Early, Person 2 departs On-time, and Person 3 departs Late, then when do they arrive and what are their total costs? Please use the information provided to fill out the table.



	Departure Time	Arrival Time	Total Costs
Person 1:	Early		
Person 2:	On-time		
Person 3:	Late		

<u>Costs:</u>

Very Early: **2 x $E** Early: **$E** On-time: **$0 (zero)**

Late: **$L**   Really Late: **2 x $L**   Super Late: **3 x $L**

Delay cost: **$D**   Delay cost for being twice delayed: **2 x $D**

4) If all three people decided to depart On-time what are their respective total costs? Please use the information provided.

	Departure Time	Arrival Time	Total Costs
Person 1:	On-time	On-time*	
Person 2:	On-time	Late*	
Person 3:	On-time	Really Late*	

**Arrival times are randomly determined when players depart at the same time*

5) Now assume that the experimenter's policy has passed and that congestion tolls are now in effect:

<table>
<tr><td colspan="4">The 8 tolls associated for the 16 possible congestion scenarios
(Tolls will only be imposed on those players that DEPART at the same time)
V=Very Early; E=Early; O=On-Time; L=Late</td></tr>
<tr><td><i>Very Early</i></td><td><i>Early</i></td><td><i>On-time</i></td><td><i>Late</i></td></tr>
<tr><td>VVV = α</td><td>EEV = δ</td><td>OOV = μ</td><td>LLV = μ</td></tr>
<tr><td>VVE = β</td><td>EEE = θ</td><td>OOE = μ</td><td>LLE = μ</td></tr>
<tr><td>VVO = δ</td><td>EEO = ε</td><td>OOO = λ</td><td>LLO = μ</td></tr>
<tr><td>VVL = δ</td><td>EEL = δ</td><td>OOL = σ</td><td>LLL = λ</td></tr>
</table>

If Person 1 departs Early, and Person 2 and Person 3 depart On-time, then when do they arrive and what are their total costs? Note that it has been randomly determined that person 2 arrives On-time. *(Note: when looking at the table of tolls, the first two of the three letters of a congestion scenario is interpreted as the individuals that are creating the congestion.)*

	Departure Time	Arrival Time	Total Costs
Person 1:	Early		
Person 2:	On-time	On-time*	
Person 3:	On-time		

**Arrival times are randomly determined when players depart at the same time*

6) True or False At least one person will pay a toll if they all depart at separate times.

____

7) If a person incurred 12 tokens in costs but the experimenter collected 15 tokens in toll revenue, how much is individually redistributed to the other people in the group? _______

What are the person's adjusted token costs? _______