Summer 8-3-2019

Essays on Competition

Susan Xu Tang

Georgia State University

ABSTRACT

ESSAYS ON COMPETITION

By

XU TANG

August 2019

Committee Chair: Dr. David L. Sjoquist

Major Department: Economics

This dissertation examines how competition shapes behaviors of governments and agents in different scenarios. Governments compete with each other to attract for mobile tax base. Agents and workers face competition to earn prizes and bonus. Competition is an effective way to incentivize proper behaviors. While in some cases, it causes inefficiency and social welfare loss. This dissertation studies environmental regulatory competition, tax competition, and tournament respectively.

The first essay explores the question of whether OECD countries engage in strategic environmental policymaking and use environmental policies to compete for the investment. I directly estimate countries' strategic interaction, which is the causal effect of other countries' changes in environmental policies on one country's environmental policy. Considering that the strategic interaction can be caused by distinct mechanisms, such as the coordination, competition for the investment, and pollution spillovers, this paper also disentangles different mechanisms. This paper employs a new index on measuring countries' environmental policy stringency and uses spatial econometrics with the Generalized Methods of Moments continuously updated Instrumental Variables estimator. The panel dataset includes 26 OECD countries for the period 1990 to 2012. I find that there is a positive and statistically significant strategic interaction on environmental policy among countries. Moreover, the strategic responses in environmental policymaking are more evident among EU countries than others, and the strategic interaction is further reinforced

after adopting the euro as a common currency. Interjurisdictional competition and transboundary pollution spillovers appear to play limited roles in causing the interaction.

Essay 2 uses laboratory experiments to explore governments' tax policies when there is tax competition. To the best of my knowledge, this is the first experiment paper on tax competition. I design a set of experiments to examine the effects of several factors on tax policies, such as the number of competing regions and the sensitivity of capital movement to the tax rate change. I find that the number of competing regions have a significant and direct impact on governments' tax choices even keeping the sensitivity of capital movement constant. This finding has not been predicted in the theoretical literature. The sensitivity of capital movement also affect the tax rate choices, but the effect is not as large as the model prediction. I also find the communication among competing regions significantly improves the tax choices and bring about higher social welfare in general. The implications of the results are two folds. The first is that when analyzing tax competition issues, both from a policy perspective and theoretical study perspective, it is important to take the effect of the number of competing regions into consideration. The second policy implication is that it is helpful to promote better and more effective communication among governments.

Essay 3 studies a multi-task tournament in which each agent undertakes two tasks. An agent's effort on one task creates externalities on the performance of the other task of the agent as well as the performances of other competing agents. We discuss the design of an optimal tournament to achieve a social optimum in the presence of such externalities. In particular, we show that the traditional single-prized tournament is unable to elicit a social optimum, while a task-specific, multi-prized tournament, which we propose in this paper, can achieve socially optimal outcomes.

ESSAYS ON COMPETITION

BY

XU TANG

**A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree
of
Doctor of Philosophy
in the Economics
Andrew Young School of Policy Studies
of
Georgia State University**

GEORGIA STATE UNIVERSITY

2019

ACCEPTANCE

This dissertation was prepared under the direction of the candidate's Dissertation Committee. It has been approved and accepted by all members of that committee, and it has been accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Economics in the Andrew Young School of Policy Studies of Georgia State University.

Dissertation Chair:	Dr. David L. Sjoquist
Committee:	Dr. H. Spencer Banzhaf
	Dr. James C. Cox
	Dr. Kelly D. Edmiston

Electronic Version Approved:

Sally Wallace, Dean
Andrew Young School of Policy Studies
Georgia State University
August, 2019

DEDICATION

I dedicate my dissertation to God Almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge, and understanding. He has been the source of my strength throughout the doctoral program and on His wings only have I soared.

I also dedicate this work to my parents, Xingguo Tang and Jane Zhang.

ACKNOWLEDGEMENT

I have been privileged to be inspired and guided by many great people in writing the dissertation. I am eternally indebted to my dissertation committee for their tireless and concerted efforts to support me throughout my graduate studies. To my advisor, Dr. David Sjoquist, thank you for being a patient, supportive, and dependable mentor. Thank you for believing in me all the time, and inspiring me to be a better researcher. To Dr. Spencer Banzhaf, thank you for always providing insightful feedback and being available to help. To Dr. James Cox, thank you for thought-provoking discussions and for deepening my interest in experimental economics. To Dr. Kelly Edmiston, thank you for your insightful and valuable advice. I am also grateful to Dr. Yongsheng Xu for your unending support and guidance starting from my undergraduate studies.

I would like to express sincere gratitude to brothers and sisters in Atlanta Chinese Christian Church and Faith Hope Love Fellowship. Thank you for all the support and help during the most challenging time. To many friends and colleagues, I appreciate you.

Contents

List of Tables

List of Figures

Essay 1

Competition or Coordination: Strategic Environmental Policymaking Across OECD Countries

1.1 Introduction

Given increasing globalization, the possibility exists that it sparks a "race to the bottom" when governments set policies. A "race to the bottom" implies that governments may choose low corporate tax rates, lax labor standards, and lax environmental standards to compete for investment. Such a possibility raises substantial concerns that public policies may not achieve social welfare maximization. Studies of public policy have found reductions in corporation tax rates and labor standards which are consistent with the "race to the bottom" hypothesis (Devereux et al., 2008; Davies and Vadlamannati, 2013; Olney, 2013). However, regarding environmental policymaking, the causal empirical evidence among countries is still lacking.

In the literature (Millmet, 2014; Carruthers and Lamoreaux, 2016; Genschel and Schwarz, 2011), a common way to study the "race to the bottom" hypothesis is to examine its one prediction, whether jurisdictions engage in strategic policymaking. To be more specific, the strategic policy interaction is the effect on one jurisdiction's environmental policy caused by other jurisdictions' changes in environmental policies. But this effect can be caused by distinct mechanisms. Besides the interjurisdictional competition that would potentially cause "race to the bottom" (Oates and Schwab, 1988; Cerny 1994; Drezner

2001; Murphy 2006)[1], other mechanisms include international coordination, pollution spillovers, and others (Kennedy, 1994; Markusen et al., 1995; Besley and Case, 1995; Brueckner, 2003). If the observed strategic interaction is not mainly caused by interjurisdictional competition, without "race", the "race to the bottom" would not become a serious issue. However, there are very few empirical papers in the environmental policy literature that disentangle the mechanism behind the effect and provide empirical evidence on the potential causes. In addition, most of papers in the literature estimate environmental interaction at the subnational level, such as across U.S. states (see Fredriksson and Millimet 2002; Fredriksson et al. 2004; Levinson 2003). The evidence on countries is limited. This paper aims to fill these gaps in the literature. This paper contributes to the literature by directly estimating the causal effect of other countries' changes in environmental policies on one country's policymaking. Considering that this effect can be caused by distinct mechanisms, this paper also unpacks different underlying mechanisms behind the interaction.

In the estimation of causal effect of other countries' policy changes, I use instrument variables to deal with the endogeneity issue due to the reverse causation. I use other countries' political characteristics as instruments for the environmental policies. Regarding the distinct mechanisms, the first mechanism this paper explores is the possible coordination and cooperation across countries in the European Union (EU). I separate observations based on whether countries have EU membership and estimate the strategic interactions among EU countries and non-EU countries respectively. I also explore the effect of adopting the euro as a common currency on the policy interdependence among EU countries. To differentiate the interactions caused by interjurisdictional competition, I separate observations based on whether countries have tight capital control (Devereux et al., 2008). Tight capital control restrains capital mobility, and thus the incentive to compete by changing policy in response to another country's policy change is greatly

[1] There are some excellent surveys on tax competition works (Wilson, 1999; Wilson and Wildasin, 2004; Keen and Konard, 2013; Boadway and Tremblay, 2012).

diminished. If interjurisdictional competition plays a major role in the strategic interaction, we would expect different interactions among countries without capital control than among countries with capital control. The third potential mechanism of strategic interaction, pollution spillovers across nations, is also explored. When pollution spillovers exist, other jurisdictions' environmental policies which have an impact on their own countries' pollution directly affect the receiving jurisdiction's environmental quality. When the receiving jurisdiction takes this spillover effect into account in the policy making (Kennedy, 1994; Markusen et al., 1995), transboundary spillovers bring about a strategic interaction. To separate the interaction caused by transboundary spillovers, I study the spillovers of oxidized sulphur and control for the pollution transported from other jurisdictions. After controlling for pollution spillovers, the coefficient on others' environmental policies does not estimate the strategic interaction through the spillovers mechanism[2].

I find that a weighted average stringency of environmental policies in other countries has a positive and statistically significant causal impact on the home country's policy stringency. The coefficient is 1.064 when GDP per capita is used as the weight. As with the analysis on EU and non-EU countries, I find that EU countries' environmental policies have a positive impact on both other EU and non-EU countries. Moreover, when the home country is in the EU, it reacts more to other EU countries than to non-EU countries. The strong policy interaction across EU countries may indicate the coordination efforts. Also, this strategic interaction becomes stronger after adopting the euro as a common currency. Regarding differentiating interjurisdictional competition, empirical results show the strategic interaction among countries without tight capital control is not statistically different from the interaction among countries with capital control. This result indicates that interjurisdictional competition plays a limited role behind the environmental policy interdependence. Regarding transboundary spillovers, the results show that pollution from

[2] One related paper is Murdoch, Sandler, and Vijverberg (2003), which explores the effect of transboundary pollution spillovers on environmental treaty participation using 25 European countries' cross-section data. My paper combines the method in Murdoch et al. (2003) and spatial econometrics to disentangle the interaction brought about by transboundary spillovers.

other countries has a positive effect on the receiving country's environmental policy stringency, indicating that cross-border spillovers play a role in the environmental policymaking process. The scale of impact of pollution spillovers on environmental policy interaction is relatively small, though.

It is important to study strategic interactions among countries besides among subnational governments, such as U.S. states. Countries play an important role in combating pollution, reducing emissions and promoting environmental protection. Moreover, the behavior of countries may show different interaction pattern for the following reasons. First, countries have more discretion in deciding environmental policies as compared with subnational governments. There is no powerful central authority for countries as there is when considering state governments. Even though there are some supranational organizations, such as the European Union, the delegation of environmental authority is mainly of member countries (Principle of Subsidiarity). Second, the movement of resources, such as capital, has more friction across countries than within a country because of different cultures, languages, legal environments, and possible trade barriers. The increase in movement resistance may affect the reaction of capital flows with respect to environmental policy, which in turn affects the interjurisdictional competition pattern. Finally, political considerations, such as national images, responsibilities, and pressures from other countries[3] could also play a role in policy decisions at the country level.

One reason for the limited national level analysis of environmental policy is the lack of measure of environmental policy which is appropriate and comparable across countries and has longitudinal data. Studies tend to use proxies to measure environmental policy stringency. For example, Kellenberg (2009) uses survey questions from the Global Competitiveness Report (GCR), which were answered by business executives. Davies and Naughton (2014) use the number of environmental treaties a country has ratified as a measure of environmental policy. Cole et al. (2006) and Cole and Fredriksson (2009) use

[3]One example is that after President Trump declared to withdraw U.S. from the Paris Climate Accord on June, 2017, global debates, criticisms even outrages are provoked.

grams of lead content per gallon of gasoline as a proxy, while Mulatu et al. (2010) employ an Environmental Sustainability Index. These indicators tend to measure policy stringency in one dimension, and also lack consistency[4]. In this paper, I use a new composite index, namely Environmental Policy Stringency (EPS) developed by the OECD (Botta and Kozluk, 2014). This index attempts to capture the multidimensionality of regulations and improve cross-country comparisons. Both market-based and non-market-based policy instruments are considered[5].

Differentiating the underlying mechanisms for the strategic interaction helps us to better understand the stringency of environmental policy that is adopted. My empirical results do not support the position that interjurisdictional competition plays a significant role in setting a country's environmental policies. If interjurisdictional competition is limited, the possibility of a "race to the bottom" would not be a serious concern. Carruthers and Lamoreaux (2016) also support this view after a detailed review of the related literature on the environmental regulation competition. The limited impact of interjurisdictional competition on environmental policy stands in contrast with corporate tax interaction; Devereux et al. (2008) find that reductions in equilibrium tax rates can be explained almost entirely by intense competition across countries. The contrasting impact of interjurisdictional competition on environmental policy or corporate taxation could partly explain the distinct trends in the two policies.

There is a possibility that the estimates in this paper are biased by the presence of unobserved shocks, and the results merely demonstrate a co-movement across countries' environmental policies. This paper utilizes several ways to address this. First, I construct instrumental variables for the main independent variable of interest, other countries' environmental policies. I use other countries' political characteristics to construct

[4]Brunel and Levinson (2013) provide a review and comparison on different measures.

[5]The OECD EPS database contains information on 15 different environmental policy instruments implemented in OECD countries, which include both Non-Market Based (NMB) and Market Based (MB) instruments. EPS has been used to in other papers, such as Albrizio et al. (2016). In addition, the credibility of EPS has been confirmed by comparisons with other measures of environmental policy stringency, such as Global Competitiveness Report (GCR) responses.

instruments, and the results of econometric tests confirm the validity and relevance of my instruments. Second, I control for time fixed effects, country fixed effects and country-specific time trend to absorb time-specific common shocks, country permanent characteristics, as well as policy trend that is specific to each country. Third, to confirm the credibility of my estimates, I present a number of specification tests and robustness checks to further probe the validity of the estimates. I utilize four different weighting schemes to construct the weighted average of other countries' environmental policies, and the results of positive strategic interaction are consistent across different weights. Moreover, to check the robustness of estimates, control variables are one-year, two-year, and three-year lagged, respectively. Considering that environmental policy usually changes progressively, I also control for the one-year lagged dependent variable in one robustness check and find that there is still positive strategic interaction across countries. In another robustness check, I recalculate the measure on the environmental policy (EPS) to exclude the potential correlation across countries in the calculation of EPS and find that the positive interaction still exists.

The rest of the paper proceeds as follows: Section 2.2 provides a theoretical framework for the empirical approach. Section 1.3 describes both the empirical specifications and data. Results and robustness checks are presented in sections 1.4 and 2.6, respectively. Section 1.6 presents discussions and conclusions.

1.2 The Model

To frame the empirical analysis, this section presents a simple model of a jurisdiction's choice of environmental policy. Governments strategically interact on environmental policymaking due to the existence of interjurisdictional competition and transboundary pollution spillovers. Besides these two mechanisms of strategic policy interaction, another possible mechanism is coordination and cooperation, which is not considered in the current model. However, the model can be easily generalized to incorporate other mechanisms. The main purposes of the model are to provide intuition on how the two mechanisms affect government's policy strategic interactions and provide theoretical foundations for the econometric models.

This model is based on the canonical model of interjurisdictional competition (Oates and Schwab, 1988) and extends Oates and Schwab by considering transboundary pollution spillovers. In this model, the government in each jurisdiction devises environmental policy to maximize local social welfare.

1.2.1 Social Welfare and Production

Assume there are n jurisdictions. For each jurisdiction, the social welfare is modeled as the utility of a single representative agent, i, who resides in the jurisdiction. This agent get utility from consuming a composite private good, denoted by c_i, and consuming a local public good g_i. This resident also suffers from local environmental damage e_i. The utility can thus be denoted as:

$$u_i(c_i, g_i, e_i; \tilde{X}_i) \tag{1.2.1}$$

where $\tilde{X}_i$ is a vector of other characteristics of jurisdiction i. The utility function is increasing and concave in c_i and g_i, and it is decreasing and convex in e_i The marginal utilities of the private good and public good are positive, respectively $u_{ic} > 0$ and $u_{ig} > 0$, while the marginal utility of environmental damage is negative, $u_{ie} < 0$. We make no assumptions about the cross-partial. The utility function may differ across jurisdictions.

The production process in jurisdiction i uses capital K_i and some immobile factor, which are assumed to be labor L_i. Assume that all residents work for simplicity. Thus L_i is also the number of residents. Local environmental policy, Q_i also affects local productive activity. Posit that the production function exhibits constant returns to scale. The production function is:

$$
\begin{aligned}
Y =& F_i(K_i, L_i, Q_i) \\
=& L_i F_i(K_i/L_i, 1, Q_i/L_i) \\
=& L_i f_i(k_i, q_i)
\end{aligned}
\tag{1.2.2}
$$

where $y = f_i(k_i, q_i)$ is the output per person. k_i denote the amount of capital per person employed in locality i. In the production function, besides capital, the environmental policy also has effect on the output. Take one type of environmental policy, "cap and trade" as example. Assume that local government uses "cap and trade" to regulate emissions. In this case, government sets a total limit on aggregate allowable emissions. The stringency of environmental policy affects the amount of allowable emissions. Larger amounts of allowable emissions means less abatement and higher optimal output for firms and thus higher output per person in local jurisdiction. To simplify the interpretation, let q_i be the total allowable emissions per person in jurisdiction i. Also, assume that the amount of allowable emissions is equal to the amount of actual emissions because environmental law is perfectly enforced and the allowable emission limit is binding.

Let's assume a well-behaved neoclassical production function exhibiting constant returns to scale in all factors, with f_i increasing and strictly concave in the amount of capital and allowable emissions. This means $f_{ik} > 0 > f_{ikk}$ and $f_{iq} > 0 > f_{iqq}$. An increase in q_i raises the marginal product of capital, $f_{ikq} > 0$. The production functions may differ across jurisdictions; the technologies are not necessarily identical.

1.2.2 Mechanism 1: Interjurisdictional Competition

The n jurisdictions interact with each other. One mechanism behind the interaction is interjurisdictional competition for mobile capital. Governments set policies to compete for capital which is freely mobile among jurisdictions and fixed at the national level. Let $\overline{k_i}$

denote the stock of capital per person with which residents of jurisdiction i are endowed. The allocation of capital satisfies the following capital market clear condition:

$$\sum_i \overline{k_i} * L_i = \sum_i k_i * L_i \tag{1.2.3}$$

Jurisdictions have an incentive to compete for capital because it contributes to social welfare in two aspects. First, capital is a production factor, and it increases output and therefore local consumption of the composite private good. We know that the total value of private good production is $f_i(k_i)$, and the gross return per unit of capital is $f_{ik}(k_i)$. Thus the total return to the immobile factor, labor, and permitted emissions of production is $f_i(k_i) - k_i f_{ik}(k_i)$, which is labor income of the representative resident. Residents also receive income from their endowment of capital $r\overline{k_i}$, where r is the net return to capital. The private good consumption of the representative resident in jurisdiction i is:

$$c_i = f_i(k_i) - k_i f_{ik}(k_i) + r\overline{k_i} \tag{1.2.4}$$

The second way through which capital promotes social welfare is that taxes on capital generate government revenue to finance public goods. Local government levies taxes on capital at tax rate t_i and spend government expenditures on the local public good:

$$g_i = t_i k_i \tag{1.2.5}$$

Since capital contributes to the private goods consumption and public goods provision, governments has an incentive to compete for the capital. And the movement of capital follows the rule that the net return to capital must be equal across jurisdictions in equilibrium:

$$f_{ik} - t_i = r \quad \forall i \tag{1.2.6}$$

Given the above capital mobility constraint, government in locality i is able to compete for a larger amount of mobile capital through adjusting two policy instruments. One is to reduce tax rate t_i and the other is to increase the allowable emissions q_i to increase f_{ik}, which means lower environmental standard. Since the net return to capital r is affected by other jurisdictions' policies, in order to attract the amount of capital that maximizes its social welfare, each government would strategically set its own policies in response to other jurisdictions' policies. See section 3.1.4 for the formal derivation.

1.2.3 Mechanism 2: Transboundary Pollution Spillovers

Another mechanism that drives the strategic interaction across jurisdictions is transboundary pollution spillovers. Environmental damage e_i in jurisdiction i is linked to the pollutant emissions not only of those from its own jurisdiction, but also those spilled over from neighboring jurisdictions. From section 3.1.1, we know that the actual pollutant emissions in jurisdiction i is equal to the permitted emissions q_i. Assume that each unit of emission orginated from jurisdiction i deposits α_i percentage in its own jurisdiction. Each unit of emission originated from jurisdiction j deposits β_{ij} percentage to jurisdiction i. Thus, the pollution depositions in jurisdiction i is the sum of those from its own emissions $\alpha_i q_i$ and those transmitted from all other jurisdictions $\sum\limits_{j \neq i} \beta_{ij} q_j$. The environmental damage can be written as a function of pollution depositions:

$$e_i = e_i(\alpha_i q_i + \sum_{j \neq i} \beta_{ij} q_j) \tag{1.2.7}$$

where $\alpha_i, \beta_{ij} \in [0, 1]$. Assume the environmental damage function e_i to be increasing and strictly convex in the amount of pollution depositions. This means $e_{iq}, e_{iqq} > 0$.

Note that this equation reflects two types of spillovers. One type is represented by $1 - \alpha_i$, which is the fraction of emissions that are not deposited on own locality, meaning the fraction of emissions that spill out to other jurisdictions or public areas (such as public sea). Let's call this type of spillovers "spill-out" for the rest of this paper. The second type is $\sum_{j \neq i} \beta_{ij} q_j$, which reflects neighbors' pollution which flowed into one's jurisdiction. We use "spill-in" to refer to this type.

When transboundary pollution spillovers exist, the environmental quality in jurisdiction i is directly influenced by other jurisdictions' environmental policies. To achieve the optimal level of environmental quality, jurisdiction i thus adjusts its environmental policy based on other jurisdictions' policies; it forms a policy strategic interdependence.

1.2.4 Strategic Interaction on Environmental Policy

The government in each jurisdiction has discretion on two policy instruments: capital taxation and environmental policy. Given government policies, other resource allocation decisions are made by private-sector agents operating in competitive markets. Governments choose capital tax rate and environmental policies to maximize the equilibrium level of social welfare, that is, the utility of a representative resident.

$$\max_{t_i, q_i} [u_i(c_i, g_i, e_i; \tilde{X}_i)] \tag{1.2.8}$$

Substituting c_i, g_i, e_i by using private goods consumption (1.2.4), public goods provision (1.2.5) and environmental damage function (1.2.7), respectively, we get

$$\max_{t_i, q_i} [u_i[f_i(k_i) - k_i f_{ik}(k_i) + r\overline{k_i}, t_i k_i, e_i(\alpha_i q_i + \sum_{j \neq i} \beta_{ij} q_j); \tilde{X}_i]] \tag{1.2.9}$$

The equilibrium allocation of capital and the equilibrium net rate of return r are determined through a system of capital mobility constraints (equation 1.2.6 for jurisdiction i and similar equations for other jurisdictions) and capital market clearing condition (1.2.3). The equilibrium capital in jurisdiction i and net rate of return r are thus functions of the vector of capital tax rates $\mathbf{t} \equiv (t_1, ..., t_n)$ and the vector of environmental policies

$\mathbf{q} \equiv (q_1, ..., q_n)$. The private goods consumption c_i and public goods consumption g_i, which are functions of capital and net rate of return, are thus also functions of $\mathbf{t}$ and $\mathbf{q}$. We can simplify the objective function as follows:

$$\max_{t_i, q_i}[u_i[V_i(\mathbf{t}, \mathbf{q}), e_i(\alpha_i q_i + \sum_{j \neq i} \beta_{ij} q_j); \tilde{X}_i]] \tag{1.2.10}$$

where $V(\mathbf{t}, \mathbf{q})$ is a vector of private goods and public goods consumption. The two first order conditions that describe the solution to this local optimization problem are:

$$\frac{\partial u_i}{\partial t_i} = u_{iV} \frac{\partial V_i}{\partial t_i} = 0 \tag{1.2.11}$$

$$\frac{\partial u_i}{\partial q_i} = u_{iV} \frac{\partial V_i}{\partial q_i} + u_{ie} e_i' \alpha_i = 0 \tag{1.2.12}$$

where u_{iV} and u_{ie} are first derivatives of utility u_i with respect to goods consumption function V_i and environmental damage e_i, respectively. e_i' is the first derivative of environmental damage over pollution depositions, $e_i' = \frac{\partial e_i}{\partial(\alpha_i q_i + \sum_{j \neq i} \beta_{ij} q_j)}$. The above first order conditions imply that government jointly sets tax rates and environmental policy to maximize local social welfare. Considering that the focus of this paper is on environmental policy, the determination of tax rates will not be discussed here. To control for the interplay of tax rate and environmental policy, in the econometric equation, the corporate tax rate is included as one of the control variables.

The first order condition (1.2.12) generates the environmental policy reaction function of jurisdiction i. Treating the environmental policies of other jurisdictions, i.e. q_j, as exogenous, the environmental policy in jurisdiction i, q_i, strategically reacts to q_j. The reaction function can be generated through differentiation of first order condition (1.2.12)[6].

$$\begin{aligned}\frac{dq_i}{dq_j} &= -\frac{u_{iV}\frac{\partial^2 V_i}{\partial q_j \partial q_i} + \frac{\partial u_{iV}}{\partial q_j}\frac{\partial V_i}{\partial q_i}) + (u_{ie}e_i^{''}\beta_{ij}\alpha_i + \frac{\partial u_{ie}}{\partial e_i}e_i^{'}\beta_{ij}e_i^{'}\alpha_i)}{\partial(u_{iV}\frac{\partial V_i}{\partial q_i} + u_{ie}e_i'\alpha_i)/\partial q_i} \\ &= (-\frac{u_{iV}\frac{\partial^2 V_i}{\partial q_j \partial q_i} + \frac{\partial u_{iV}}{\partial q_j}\frac{\partial V_i}{\partial q_i}}{\partial(u_{iV}\frac{\partial V_i}{\partial q_i} + u_{ie}e_i'\alpha_i)/\partial q_i}) + (-\frac{u_{ie}e_i^{''}\beta_{ij}\alpha_i + \frac{\partial u_{ie}}{\partial e_i}e_i^{'}\beta_{ij}e_i^{'}\alpha_i}{\partial(u_{iV}\frac{\partial V_i}{\partial q_i} + u_{ie}e_i'\alpha_i)/\partial q_i}) \\ &= A + B\end{aligned} \quad (1.2.13)$$

where e_i'' is the second derivative of environmental damage e_i over pollution depositions $(\alpha_i q_i + \sum_{j \neq i} \beta_{ij} q_j)$.

As we can see from equation (1.2.13), there are two parts in the strategic reaction, denoted as A and B. A and B reflect the two reasons why q_i responds to q_j[7]:

- In A, the response is due to q_j having an effect on the private and public goods consumption in jurisdiction i, $V_i(\cdot)$. q_j's impact on $V_i(\cdot)$ is caused through q_j's impact on the amount of capital in jurisdiction i. So the mechanism behind the strategic reaction, part A, is the effect of others' environmental policies on capital, which is Mechanism 1: interjurisdictional competition. The sign of part A is ambiguous since the sign of $\frac{\partial u_{iV}}{\partial q_j}$ is ambiguous.

- Part B indicates the policy reaction that is caused by q_j's impact on environmental damage in locality i, e_i. Due to transboundary pollution spillovers, other jurisdictions' emissions can spill into locality i and affect local environmental damage. The degree of pollution spillovers is parameter β_{ij}. If there is no transboundary spillovers, which means $\beta_{ij} = 0$, then the strategic interaction of part B is also zero. Thus the mechanism behind part B is transboundary pollution spillovers, denoted as

[6] Assume implicit function $G(\mathbf{q}) = G(q_i, ..., q_j, ..., q_n) = u_{iV}\frac{\partial V_i}{\partial q_i} + u_{ie}e_i'\alpha_i = 0$, the implicit partial differentiation describes that $\frac{dq_i}{dq_j} = -\frac{\partial G(q_i,q_j)/\partial q_j}{\partial G(q_i,q_j)/\partial q_i}$. Calculation on $\partial G(q_i, q_j)/\partial q_j$ and $\partial G(q_i, q_j)/\partial q_i$ achieves equation (1.2.13).

[7] Note that the yardstick competition is not considered in this model. However this model can be easily generalized to incorporate the yardstick competition by generalize the utility function as: $u_i(c_i, g_i, e_i; q_{-i}; \tilde{X}_i)$, where q_{-i} is a vector of other jurisdictions' environmental policies. In this case, others' policies have direct impact on i's utility, and the strategic interaction have an additional component to reflect this impact.

Mechanism 2. The sign of part B is also ambiguous. $u_{ie}e_i^{''}\beta_{ij}\alpha_i$ is negative since $u_{ie} < 0$, $e_i^{''}, \beta_{ij}, \alpha_i > 0$. While $\frac{\partial u_{ie}}{\partial e_i} e_i^{'}\beta_{ij}e_i^{'}\alpha_i$ is positive.

Thus, the slope of the reaction function may take either sign and needs to be estimated in the empirical part. There are various factors that have an impact on the magnitude of the reaction function (1.2.13). For example, in part A, $\frac{\partial V_i}{\partial q_j}$ indicates the effect of jurisdiction j's environmental policy on jurisdiction i's goods consumption. The larger this effect is, the larger the magnitude of the strategic reaction will be. In part B, β_{ij} is the fraction of pollution emissions that originated from jurisdiction j and transported to jurisdiction i. The higher the degree of the spillovers, the larger policy response will be.

Equation (1.2.13) shows the environmental policy strategic response of jurisdiction i to jurisdiction j's policy. Similar equations can be applied to the response functions of jurisdiction i to other jurisdictions, such as k. Estimating the reaction function (1.2.13) is currently impossible due to the lack of data. The empirical work in the literature usually estimates the reaction function $\frac{dq_i}{d\sum\limits_{j\neq i} w_{ij}q_j}$, which is the reaction of jurisdiction i's environmental policy to the weighted average of many other jurisdictions' policies; w_{ij} denotes the weight assigned to locality j by i. $\frac{dq_i}{d\sum\limits_{j\neq i} w_{ij}q_j}$ is a function of equation (1.2.13) and a vector of weights, $\mathbf{w}$, illustrated as follows:

$$\frac{dq_i}{d\sum\limits_{j\neq i} w_{ij}q_j} = R(\frac{dq_i}{dq_1}, ..., \frac{dq_i}{dq_{i-1}}, \frac{dq_i}{dq_{i+1}}, ..., \frac{dq_i}{dq_n}, \mathbf{w}) \tag{1.2.14}$$

1.3 Empirical Strategy and Data

This section describes the estimation specifications and data used for estimating government environmental policy strategic interaction. The econometric equations are based on the discussion in Section 2.2, which includes estimation on strategic interaction and ways to differentiate different mechanisms behind strategic interaction.

1.3.1 Estimating Strategic Interaction

To examine the effect of other countries' environmental policies on one country's environmental policy, I use the following econometric equation which is based on the equation (1.2.14) in Section 2.2:

$$q_{it} = \delta_1 \sum_{j \neq i} w_{ijt} q_{jt} + \theta X_{it-2} + \alpha_i + \eta_t + Trend_i + \varepsilon_{it} \tag{1.3.1}$$

The dependent variable, q_{it}, is a measure of environmental policy in country i at time t. $\sum_{j \neq i} w_{ijt} q_{jt}$ represents other countries' environmental policies at time t, known as the "spatial lag" in the literature. It is the weighted average of other countries' environmental policies, within which w_{ijt} is a non-negative weight used to average other countries' policies and is assigned to country j by country i at time t. To easily make a distinction between dependent variable and the spatial lag in the following discussion, I use "home country's environmental policy" to refer to the dependent variable and use "other countries' environmental policies" to represent the spatial lag. X_{it-2} is a vector of time lagged control variables including statutory corporate tax rate. ε_{it} represents idiosyncratic shocks that are uncorrelated across states and over time. Country fixed effects, α_i, time fixed effects, η_t, and country-specific trend, $Trend_i$, are also included to absorb country permanent characteristics, time-specific common shocks, and linear trends specific to each country. The above econometric equation is also known as the "spatial autoregressive model".

Control variables (X_{it-2}) are lagged considering that it takes time for environmental policy to react to changes in one country's social and economic conditions[8]. The lagged control variables could also mitigate potential endogeneity problem that is caused by the impact of environmental policy on social and economic conditions. In the main estimation, control variables are lagged by two years. In the robustness checks, one-year and three-year lagged control variables are used. In choosing the vector of control variables, I control for

[8] Other studies which use lagged control variables include Davies and Vadlamannati (2013), Olney (2013).

socioeconomic conditions in a country which has potential to impact residents' policy preferences and policy choice. I thus include the log of per capita GDP (expenditure-side real GDP at chained PPPs in constant 2011 US dollars). A country's exposure to world markets could also affect the environmental policy especially when there is international competition on investment. I include a measure of the economy openness, the sum of exports plus imports relative to GDP, to control for it. The statutory corporate tax rate is included to control for government's interplay of setting tax rate and environmental policy discussed in Section 3. I also control for some demographic variables, including the degree of urbanization, population (in log form), the percent of population that is older than 65, the percent of population that is younger than 14. Considering that young and elderly people may be more vulnerable to pollution, the populations structure could also be a factor that affects one country's environmental policy. Following Boockmann and Dreher (2003) and others, I also control for political conditions which have directly impact on the policymaking. Four political variables are included. The first is democracy, which is the average score of Freedom House's indexes on civil right and political liberty and ranges from 1 (severely limited liberties) to 7 (full liberties)[9]. The second and third variables are government fractionalization, and checks and balances, which are variables from Database of Political Institutions (Beck et al., 2001). Government fractionalization is the probability that two deputies picked at random from among the government parties will belong to different parties. The more parties in the government there are, the more fractionalized the government is, thus the larger this index is. Checks and balances measures the number of decision-makers whose agreement is necessary before policies can be changed. This variable counts the number of veto players, which is an individual or collective actor who has to agree in order for the legislative status quo to change, adjusting for whether these veto players are independent of each other. The last one is the Political Constraint Index from Henisz (2000), which estimates the extent to which a change in the preferences of any one

[9] https://freedomhouse.org/

actor may lead to a change in government policy. Table 1.9 in Appendix summarizes variables and data sources.

I employ the Generalized Methods of Moments (GMM) continuously updated (CUE) Instrumental Variables (IV) estimator (Hansen, Heaton, and Yaron, 1996). The estimator includes fixed effects and calculates errors that are robust to arbitrary heteroscedasticity and arbitrary autocorrelation. Besides, research suggests that the finite sample performance of CUE may be superior than two-step GMM. In particular, there is evidence suggesting that CUE perform better than IV/GMM in the presence of weak instrument (Hahn, Hausman, and Kuersteiner, 2004). There are several other issues in the estimation need to be properly addressed, including endogeneity problem, choosing proper weights, and the issue of time fixed effects. The discussion on these issues is as follows.

This paper uses Environmental Policy Stringency Index (EPS) as the measure of environmental policy (Botta and Kozluk, 2014). The EPS index contains information on fifteen different environmental policy instruments implemented in OECD countries, which include both non-market-based and market-based instruments. non-market-based policies include limits to pollutants (SO_x, NO_x, particulate matters and Sulfur Content of Diesel) and government energy-related R&D expenditures as a percentage of GDP. Market-based policies contain feed-in-tariffs (solar and wind)[10], taxes (on CO_2, SO_x, NO_x, and diesel), price on CO_2 trading schemes, renewable energy certificates trading scheme, energy certificate emission trading scheme and the presence of deposit and refund schemes.

Endogeneity Problem

There are several issues regarding the estimation. The first issue is the endogeneity problem associated with the "spatial lag" (other countries' environmental policies). Countries choose their environmental policies simultaneously and take the expectations on

[10]Feed-in tariffs (FITs) are a policy mechanism used to encourage deployment of renewable electricity technologies. A FIT program typically guarantees that customers who own a FIT-eligible renewable electricity generation facility, such as a roof-top solar photovoltaic system, will receive a set price from their utility for all of the electricity they generate and provide to the grid.

other countries' policies into their own policy-making consideration. This implies that the environmental policy of jurisdiction i (dependent variable q_{it}) also has an impact on other jurisdictions' environmental policies (the spatial lag $\sum_{j \neq i} w_{ijt} q_{jt}$). Due to this reverse causation issue, the spatial lag is endogenous. I use instrumental variables (IV) for the spatial lag to address it. The instruments are the weighted average of other countries' political characteristics, $\sum_{j \neq i} w_{ijt} Z_{jt}$. The weighting scheme used to construct instruments, w_{ijt}, is the same as for devising the spatial lag. The political variables that are used to construct instruments include: democracy, checks and balances, and governmental fractionalization.

Two conditions are needed to be satisfied for the instruments to be valid. First, the instruments are exogenous, which means they are not correlated with disturbance ε_{it}. Specifically, the home country's environmental policy (dependent variable q_{it}) is not directly affected by other countries' political environments (the instruments). After controlling for country fixed effects, time fixed effects and various covariates of the home country in the econometric equation, I consider our instruments more likely to be exogenous as other countries' political environments have limited direct impact on the home country's environmental policy. In practice, I conduct overidentification tests, and the Hansen's J statistics can not reject the exogeneity of instrument sets in most specifications. One possible concern is the selection issue, namely, firms and individuals may sort themselves based on other jurisdictions' environmental policies. This concern is also the reason why I do not use socioeconomic and demographic variables as instruments. Due to the selection issue, these socioeconomic variables, also instruments, become functions of the dependent variable, i.e., environmental policies, which makes the instruments endogenous. The sorting issue is of less concern regarding political variables as the cross-country mobility of officials is much more constrained than firms and individuals.

The second condition is that the instruments are correlated with the spatial lag. This means that one country's political characteristics are correlated with its environmental policies. This correlation is relatively intuitive. For example, the degree of democracy in one country has an impact on its policies. Leaders in a democratic country are more dependent on election results for their careers and thus are more likely to deliver popular policies to cater for voters. However, this phenomenon is less likely to happen in a more centralized country. This impact of democracy on policies is also found by Davis and Vadlamannati (2013), who discover that more democratic countries have significantly better labor rights. Other political variables, government fractionalization and checks and balances have a direct impact on a country's policymaking process, which are thus correlated with environmental policies. Empirically, I present the results of weak instrument tests that reject the hypothesis that the instruments are weak.

In the literature, instrumental variables (IV) method is commonly used to address this endogeneity issue as in this paper[11]. Fredriksson and Millimet (2002), Davies and Naughton (2014), and others use this method. Fredriksson and Millimet (2002) choose Z_{jt} to be neighboring states' socioeconomic and demographic characteristics including population, population density, and the degree of urbanization. One concern in using socioeconomic and demographic variables is that these variables may not be exogenous and random over subnational governments. This issue can be partly solved by using political variables to construct instruments since government officials can hardly sort themselves across countries[12]. Olney (2013) uses the strength and political ideology of the ruling party and unionization density as instruments to examine strategic interaction of employment protection policies. Like Olney (2013), I use political variables to construct instruments.

[11] Another method is the maximum likelihood methods (Anselin, 1988). Case, Rosen, and Hines (1993), Murdoch, Rahmatian, and Thayer (1993), Besley and Case (1995), Murdoch, Sandler, and Sargent (1997) and others use this method. Anselin (1988) provides detailed discussion on this method.

[12] Dahlberg and Edmark (2008) solve this issue by employing a policy intervention in Sweden as IV to estimate the strategic interaction on the welfare benefit levels.

Weighting Schemes

Choosing the proper weighting schemes for the spatial lag is another important issue. To estimate the system, we need to specify the weighting matrix as a priori. The weights assigned to country j by the home country should reflect country j's degree of importance when the home country makes policy decisions. The degree of importance varies with the reasons why the home country reacts to country j's policy change. As discussed above, the potential underlying mechanisms of government policy interaction include interjurisdictional competition, transboundary spillovers, yardstick competition and international coordination.

In this paper, I use four different weighting schemes to reflect different mechanisms. In the first weight, I use GDP per capita (GDPPC) to construct it. The weight country i assigned to country j is $w_{ijt} = \frac{GDPPC_{jt}}{\sum\limits_{k \neq i} GDPPC_{kt}}$. When the home country uses environmental policy to compete for mobile resources, the more competitive the two countries are in attracting capital, the more weight that should be assigned. Countries with higher GDP per capita may have a larger influence on the capital movement considering that Foreign Direct Investment (FDI) may be attracted to higher-skilled and/or wealthier markets.

The second weighting scheme is constructed by using the variable, openness. $w_{ijt} = \frac{Openness_{jt}}{\sum\limits_{k \neq i} Openness_{kt}}$. Openness is the sum of exports plus imports relative to GDP, which is a common proxy for the inverse of trade costs in the empirical FDI literature. Openness has an impact on the movement of capital. As discussed by Blonigen (2005), horizontal FDI takes place to avoid trade costs.

I also use similarity of income per capita to capture the similarity among countries and construct weights (following Case, Rosen and Hines, 1993). Similarity of income per capita is measured as the inverse of income per capita difference $1/(|inc_{jt} - inc_{it}|)$, where inc_{jt} is the income per capita of country j. The weights are constructed as $w_{ijt} = \frac{1/(|inc_{jt} - inc_{it}|)}{\sum\limits_{k \neq i} 1/(|inc_{kt} - inc_{it}|)}$. This weights take the mechanism of yardstick competition into consideration. When the home country makes environmental policy mainly due to voters' pressure caused by yardstick competition, countries that have more similar conditions would have larger impact on voter's preferences, and thus should be assigned with higher weights.

Besides the above weighting schemes, I also use the simple average weighting scheme $w_{ijt} = \frac{1}{n-1}$, where $n-1$ is the number of countries besides the home country. In sum, this paper uses four alternative weighting schemes to construct the spatial lag, which are GDP per capita, openness, similarity of income per capita, and simple average. These weighting schemes intend to capture other countries' degree of importance when the home country makes environmental policies in terms of different aspects. While since we are unable to measure the degree of importance precisely and comprehensively, I construct different weighting schemes. And the results of using different weighting schemes can serve as a comparison and robustness checks to each other.

Time Fixed Effects

Another issue is the time fixed effects. It is not feasible to include every year dummies to absorb the year-specific shocks that are common to all countries. This is because of the construction of spatial lag. Take the uniform weights case as an example; the spatial lag is other countries' simple average of environmental policies $\sum_{j \neq i} w_{ijt} E_{jt} = \frac{\sum_{j \neq i} E_{jt}}{n-1}$, which can be rewritten as $\frac{\sum_{j \neq i} E_{jt}}{n-1} = \frac{\sum_{j} E_{jt} - E_{it}}{n-1} = \frac{\sum_{j} E_{jt}}{n-1} - \frac{E_{it}}{n-1}$. In a certain year, $\frac{\sum_{j} E_{jt}}{n-1}$ is fixed across countries; if we include every year dummies in the regression to average out the common part across countries, $\frac{\sum_{j} E_{jt}}{n-1}$ would be averaged out, and only $-\frac{E_{it}}{n-1}$ is used for estimating the coefficient of spatial lag. And the coefficient of spatial lag on the home country's environmental policy E_{it} is thus $-\frac{1}{(n-1)}$ by construction. It is not a proper estimate of the strategic interaction. This issue has also been recognized by Devereux et al. (2008), Davies and Vadlamannatid (2013) and others. To control for the time fixed effects without bringing about the above issue, this paper includes both a country-specific time trend and a set of three-year period dummies in the regression.

1.3.2 Disentangling Different Mechanisms

Besides estimating an overall degree of strategic interaction across countries, I also differentiate the distinct underlying reasons of strategic interaction. The specifications that differentiate the coordination among EU countries, interjurisdictional competition, and transboundary pollution spillovers are presented.

To Differentiate the Coordination

To disentangle the strategic interaction that is brought about by the coordination among countries, particularly among EU countries, I explore the different interaction patterns between EU and non-EU countries. There are noticeable differences between countries holding EU membership and countries that do not. Countries in the EU enjoy a single market with almost free movement of capital, goods, services, and people. This mobility is further enhanced with the establishment of the Euro area (Eurozone) in 1999. Moreover, there have been substantial efforts on environmental policy coordination across countries in EU, especially since the adoption of the First Environmental Action Programme in 1973.

I use the following econometric equation to estimate the different strategic interaction patterns:

$$\begin{aligned} q_{it} = \delta_1^1(EU_{it})q_{-it}^{EU} + \delta_1^2(EU_{it})q_{-it}^{NEU} + \delta_1^3(1-EU_{it})q_{-it}^{EU} + \delta_1^4(1-EU_{it})q_{-it}^{NEU} \\ + \theta X_{it-2} + \alpha_i + \eta_t + Trend_i + \varepsilon_{it} \end{aligned} \tag{1.3.2}$$

This specification is similar to the specification (1.3.1) which estimates the strategic interaction. The covariates included in X_{it-2}, the country fixed effects, time fixed effects and country-specific trend are the same with specification (1.3.1). The difference between these two specifications lies in the spatial lags.

I separate the countries other than the home country i by EU membership and calculate two spatial lags within each group, one for EU countries and one for non-EU countries. The variable EU_{it} is a dummy variable and equals to 1 if country i holds the EU membership at year t. q_{-it}^{EU} is a spatial lag that is constructed within countries holding EU membership. q_{-it}^{NEU} is the spatial lag for countries without EU membership. Then the two spatial lags are interacted with whether the home country is an EU member state, which gives us four variables. The instruments are also recalculated this way. Table 1.10 in the Appendix lists the names of EU countries and non-EU countries.

This specification allows home country to respond differently to other countries depending on whether other countries hold EU membership. The coefficient δ_1^1 is the effect of policies of other EU countries on the policy of a EU country. The coefficient δ_1^4 reflects the effect of policies of other non-EU countries on the policy of a non-EU country. We expect to see larger effect among EU countries.

To Differentiate Interjurisdictional Competition

To differentiate the strategic interaction brought by interjurisdictional competition, the strength of capital control is used. Theoretically speaking, interjurisdictional competition requires free mobility of capital among jurisdictions, which leads to equal net return to capital across jurisdictions. It means that if there is no control on capital movement, then the equation (1.2.6) $f_{ik} - t_i = r \quad \forall i$ is satisfied for all jurisdictions. While if some jurisdictions have tight capital control that restrains capital mobility, say jurisdiction j^c, equation (1.2.6) does not have to hold. And the net return to capital does not necessarily equal the net return to capital in other jurisdictions, $f_{j^c k} - t_{j^c} \gtreqless r$. In the case of an extreme capital control, the amount of capital in jurisdiction j_c is fixed given its own tax rate t_{j^c} and environmental policy q_{j^c}. A fixed amount of capital implies that the private and public goods consumptions V_{j^c} are also fixed. Thus, part A in equation (1.2.13) is zero and the strategic interaction is not caused by interjurisdictional competition.

I use the following econometric equation to differentiate the strategic interaction that is brought about by interjurisdictional competition.

$$q_{it} = \delta_1^1(cc_{it})q_{-it}^C + \delta_1^2(cc_{it})q_{-it}^N + \delta_1^3(1-cc_{it})q_{-it}^C + \delta_1^4(1-cc_{it})q_{-it}^N + \theta X_{it-2} + \alpha_i + \eta_t + Trend_i + \varepsilon_{it} \tag{1.3.3}$$

Following Devereux et al. (2008), and similar to the specification (1.3.2), four spatial lags are constructed based on whether other countries and the home country have tight capital control in this equation . cc_{it} indicates whether country i has tight capital control in year t; it is equal to 1 if there is tight capital control and equal to 0 otherwise. Based on whether one country has tight capital control, I separate countries besides the home country into two groups and construct spatial lags within each group, respectively. Within countries that have tight capital control, $q_{-it}^C = \sum_{j \neq i} w_{ijt} cc_j q_{jt}$ is constructed; within countries that do not have tight capital control, $q_{-it}^N = \sum_{j \neq i} w_{ijt}(1-cc_j)q_{jt}$ is constructed. The two spatial lags are then interacted with cc_{it}, whether home country has tight capital control, which generates four variables in the econometric equation. The coefficient δ_1^4 is the effect of policies of other countries where capital is freely mobile on the policy of a home country which also does not have capital controls. Other coefficients can be interpreted similarly.

The difference in the four coefficients, δ_1^1, δ_1^2, δ_1^3, δ_1^4, manifest the strategic interaction caused by interjurisdictional competition and other mechanisms. The reason is that when a country has tight capital control, the capital mobility in this country is restrained; so, its incentive to compete for capital through strategically adjusting environmental policy is relatively weakened. The weaker incentive on interjurisdictional competition would be reflected in the difference in the values of the coefficients, especially between δ_1^1 and δ_1^4. δ_1^4 reflects the strategic interaction between the home country and other countries when neither has capital control, in which the interjurisdictional competition is relatively stronger. While δ_1^1 reflects the strategic interaction between the home country and other countries that both sides have capital control, and the interjurisdictional competition plays a limited role in policymaking. It thus reflects the interaction mainly caused by other mechanisms. The difference between the two coefficients reflect the strategic interaction that is brought about by interjurisdictional competition. If we do not find significant difference between them, we could claim that the interaction is not mainly due to interjurisdictional competition.

This paper uses the Chinn-Ito index, 2014 version, (Chinn and Ito, 2006) to measure capital control. The Chinn-Ito index is an index measuring a country's degree of capital account openness and is based on the binary dummy variables that codify the tabulation of restrictions on cross-border financial transactions reported in the IMF's *Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER)*. The indexes on the "most financially open" countries and "least financially open" countries are 2.39 and -1.89 respectively. To distinguish between countries which are principally open to capital flows and which are not, I divided the observations based on the value of the index. For countries in time t that has a value of the index above 1, they are regarded as "has no tight capital control" and $cc_{it} = 0$. Otherwise, the country is regarded as "has tight capital control" and $cc_{it} = 1$. Besides using 1 as the number to divide whether there is tight capital control, I also use alternative number, 0, to check the robustness.

To Differentiate Transboundary Pollution Spillovers

The strategic interaction can also be caused by transboundary pollution spillovers; other jurisdictions environmental policies determine the amount of local pollution emissions which can transport to the home country and affect its environmental quality. To differentiate the strategic interaction brought by transboundary spillovers, I control for the pollution depositions from other countries. I use the following specification to estimate.

$$q_{it}^{OSP} = \delta_1^{OSP} \sum_{j \neq i} w_{ijt} q_{jt}^{OSP} + \delta_2 D_{-it} + \delta_3 (1 - \alpha_{it}) + \theta X_{it-2} + \alpha_i + \eta_t + Trend_i + \varepsilon_{it} \quad (1.3.4)$$

Similarly, the covariates in the X_{it-2}, the country fixed effect, time fixed effect and country-specific trend in the above specification are the same as for specification (1.3.1). Besides the similarities, there are two differences. The first is this equation explores the strategic interaction specifically on countries' oxidized sulphur policies instead of general environmental policies as in specification (1.3.1). Considering that the degree of transboundary spillovers varies greatly across different types of pollutants, I choose one type of pollutant, oxidized sulphur, as the example to study the transboundary pollution spillovers. Thus, the environmental policies used in the equation are chosen to be most related to oxidized sulphur. I employ an Oxidized Sulphur Policy index (OSP) instead of EPS to construct the dependent variable and the spatial lag. OSP is an index that is created by the author by employing the same information on SO_x taxes and SO_x emission limit when constructing EPS. The second distinction from specification (1.3.1) is that this specification adds two transboundary spillover variables, which are called "spill-in" and "spill-out". Spill-in, denoted as D_{-it} in the equation, reflects that neighbors' pollution flowed into the home country, and this paper uses oxidized sulphur pollution depositions which are from all other countries to measure it. Spill-out reflects that one own jurisdiction's pollution spills out to neighboring jurisdictions, which is quantified as the fraction of total sulfur emissions that are deposited on other countries $(1 - \alpha_{it})$. The level of emissions is not used due to its high correlation with the dependent variable, environmental policies.

Regarding strategic interaction, when we control for the spill-ins, D_{-it}, in the regression, δ_1^{OSP} does not reflect the impact caused by transboundary pollution spillovers. This is because that when the pollution depositions from other countries, D_{-it}, are controlled for, the environmental quality in the home country is not influenced by other countries' environmental policies through transboundary pollution spillovers. Thus, under this specification, the home country would not strategically react to other countries' environmental policies due to the transboundary spillovers. The strategic interaction that is caused by the transboundary spillovers can be reflected by the difference between coefficients of the spatial lag in the case of controlling or not controlling for the spill-ins.

Regarding the coefficients on the two spillover variables, δ_2 directly measures the impact of spill-ins on environmental policy stringency. A positive coefficient indicates that when there are more pollution spilled over from other countries, government may increase standard to mitigate the damage of more pollution. δ_3 reflects how government responds to the spill-outs, and a negative coefficient shows that governments relax environmental standard when they can spill a higher fraction of pollution to other countries. In this case, a negative δ_3 reveals free-riding behavior.

The spillover variables are constructed using transport matrix from European Monitoring and Evaluation Programme (EMEP) (Eliassen and Saltbones, 1983; EMEP/MSC-W calculated SR country tables and data[13]). This matrix measures the amount of sulfur emitted by country j (column entries) that falls on country i (row entry). The sulfur depositions imported from other countries and the fraction of one country's emission deposited on its own are constructed, respectively. I use only European countries in this estimation since other countries are sparsely located on different continents, and the cross-continent spillovers are quite limited. Some countries, like Australia, barely have spillovers with other countries.

1.3.3 Summary Statistics

The data used in the estimation covers 26 OECD countries from 1990 to 2012. In the specification (1.3.1) and (1.3.3), OECD Environmental Policy Stringency Index (EPS) is used to measure each country's environmental policy stringency. In the specification (1.3.4), Oxidized Sulphur Policy (OSP) index is used to measure environmental policy on oxidized sulphur. OSP is created by the author by employing the same data on the SO_x

[13]See http://emep.int/mscw/ for details

taxes and SO_x emission limit when constructing EPS. Table 1.9 in Appendix shows variables and data sources.

Figure 2.1 shows the trend of Environmental Policy Stringency (EPS) over time. Overall, from 1990 to 2012, the average environmental policy became more and more stringent. On average, EU countries have higher policy stringency than non-EU countries. For EU countries, there are two times that EPS falls, 2007 and 2012. These are mainly due to the swings in the carbon price of EU Emissions Trading System (ETS). The trend of increasingly stringent environmental policies across OECD countries is not consistent with the prediction of the "race to the bottom."

Figure 2.2 and Figure 2.4 plot the OECD countries' EPS for 1995 and 2010 on a world map, respectively. The categories are the same across maps. We can see that every country has increased the environmental policy stringency since 1995. The country with strictest environmental policy in 2010 is Netherland. Table 2.1 shows the evolution of different categories EPS. And the Oxidized Sulphur Policy which is used in the specification (1.3.4) is calculated as the average of index of SO_x taxes and SO_x emission limit. We can see a tightening of EPS in almost all categories over time. Table 2.2 reports the summary statistics for variables used in the estimation.

1.4 Empirical Results

This section presents the empirical results from the main specifications. The results from estimating strategic interaction are presented first. Then results of differentiating underlying reasons follow.

Figure 2.6 shows a series of bin scatter-plots of the home country's environmental policy against the spatial lag across continents. The spatial lag is other countries' environmental policies, which is constructed using similarity of income per capita as the weighting scheme. We observe a positive relationship between the home country's environmental policy and the spatial lag in all the continents studied in this paper.

1.4.1 Results on Estimating the Strategic Interaction

The regression results of estimating strategic interaction across countries, specification (1.3.1), are shown in Table 2.3 and Table 2.7. One country's environmental policy stringency (EPS) is the dependent variable. Spatial lag, other countries' environmental stringency, is the key explanatory variable of interest. Control variables are two-year lagged.

Table 2.3 shows the results of using similarity of income per capital as the weighting matrix. All regressions contain spatial lag and country fixed effects. From column (1) to (4), control variables, country-specific trend and time fixed effects are added correspondingly. In all the columns, we can see that there is a positive and statistically significant effect of other countries' environmental policy stringency on one country's environmental policy. And the coefficients are larger than one. Our preferred specification is that of column (4), which controls for covariates and absorbs country permanent characteristics, time-varying year-specific common shocks as well as a linear trend that are specific to each country. The coefficient of the spatial lag is 1.25, which is significant at the 1 percent level. A rough interpretation of it is that if the average of other countries' environmental policy stringency increase by 1 point, the home country would increase its environmental policy stringency by 1.25 point. Other variables also have an impact on the stringency of environmental policy. Countries that hold membership of European Union have higher GDP per capita, are more democratic and have higher corporate tax rate tend to have more stringent environmental policies. The degree of urbanization tends to lower the policy stringency. With respect to the instruments, results of the various test are also reported. I test for underidentification using Kleibergen-Paap rk LM statistic (Kleibergen and Paap, 2006). The probability value indicates that we can reject the null-hypothesis of underidentification at the 1% level. I also test for the validity of instruments (overidentification test) using Hansen's J-test (Hansen, 1982), and we are unable to reject the null-hypothesis of exogeneity at the conventional level of significance indicating the validity of instruments. Weak instrument issue is tested using Kleibergen-Paap rk Wald F statistic, which shows that we can reject that the instruments are weak.

Table 2.7 shows the results of repeating the specification in column (4) of Table 2.3 using other three weights, including simple average, GDP per capita and openness. Control variables, country-specific trend and time fixed effects are all included. Compared with Table 2.3, we still find positive strategic interaction on setting environmental policies. The scales of the coefficients are smaller, and the statistical significance of the coefficients are lower compared with the results of using similarity of income per capita as the weighting scheme. The test statistics also show that the estimation models are not underidentified and instruments are exogenous and not weak.

Although the positive strategic interaction across countries is consistent with the prediction of interjurisdictional competition on capital, it's possible that other underlying reasons drive the policy interdependence. The positive coefficient could reflect the policy imitation across countries due to yardstick competition, in which case voters use other countries' environmental policies as yardstick to evaluate the home country officials' performances. It could also be possible that countries increase the stringency to positively reciprocate the lower transboundary pollution spillovers due to other countries' more stringent policies. The positive coefficient could also be capturing the international coordination of combating environmental issues. The various international treaties and agreements reflect the coordination efforts. Further analysis is needed to differentiate the underlying mechanism of the strategic interaction, to which we turn.

1.4.2 Results of Differentiating the Coordination

From 2.3 and Table 2.7, we find positive strategic interaction across countries. We do not know what mechanism and reasons that this relationship can be attributed to. I estimate the specification (1.3.2) to disentangle the international coordination efforts. Results are shown in table 1.7. Note that in column (4), there is potential weak identification (low Kleibergen-Paap rk Wald F statistic) and underidentification issue (high underidentification test p Value) when using similarity of income per capita as weighting schemes. Thus the results from the column (1) to (3) are preferred. The coefficients on the first variable, which indicate the reaction of an EU country to other EU countries' policy changes, are positive and statistically significant at 1% level in most specifications. This results indicate that there are strong strategic interactions across EU countries. The coefficients on the third variable, which indicate the response of a non-EU country to other EU countries' policy changes, are also positive and statistically significant at the conventional level. It means that when EU countries increase the environmental standard, other countries also increase their environmental standards. While this positive reaction is not found when the spatial lag is non-EU countries, as shown in the coefficients of the second and fourth variable in the column (1) to (3). I also check the difference across coefficients and find that there is statistically significant difference between the coefficients of the first variable and second variable in most specifications. This means that when the home country is an EU member, it reacts significantly more to other EU countries than to other non-EU countries. Differences across other variables are not found.

I also consider the effect of euro area on the strategic interaction. Results are presented in Table 1.8. The variable "Eurozone" is a dummy and equals to one if this country is in euro area that year. In our dataset, most EU countries, twelve out of eighteen, adopt the euro as their common currency, mostly in 1999. The coefficients of the first variable, Eurozone * Home country in EU * Spatial lag of EU, are positive and statistically significant in most specifications. This results indicates that the strategic interaction on environmental policymaking is stronger after adopting the euro as their common currency.

In summary, there is a positive impact of environmental policies in EU countries on other countries. The strategic interaction across EU countries is positive and statistically stronger than the interaction across other countries. This interaction is enhanced with the adoption of the euro as a common currency among EU countries.

1.4.3 Results of Differentiating the Interjurisdictional Competition

I estimate the specification (1.3.3) to differentiate interjurisdictional competition, results are reported in Table 2.8. As in Table 2.7, control variables, country-specific trend and time fixed effects are all included in this set of estimates. The four variables displayed in the table are the interaction of two set of variables; one is whether the home country has tight capital control; the other is whether other countries have tight capital control. For example, the coefficient of the first variable, Home country with capital control * Spatial lag with capital control, captures whether the environmental policy in the home country that have capital control strategically react to policies in other countries that also have capital control. The coefficient of the fourth variable, Home country without capital control * Spatial lag without capital control, captures the effect of policies in other countries where capital is freely mobile on policies in the home country where capital is freely mobile too. The coefficient of the fourth variable is expected to be larger if interjurisdictional competition mainly drives the interaction.

From the results, we can see that the coefficients of the first variable, Home country with capital control * Spatial lag with capital control, are statistically significant at conventional level in all the specifications, which indicates that the other reasons besides interjurisdictional competition contribute to the strategic interaction. When both countries in spatial lag and the home country have no tight capital control (the fourth variable), we expect that the interjurisdictional competition has a larger effect on the strategic interaction. If interjurisdictional competition plays an important role in the strategic interaction, we expect that this impact would be reflected in the difference between the coefficient of the fourth variable and other variables. I test the difference between the coefficient of the first variable and the coefficient of the fourth variable and find that we are unable to reject that these two coefficients are the same for column (1) to (3). The p values are 0.683, 0.202 and 0.843 respectively for the similarity tests of column (1) to (3). In column (4), the coefficient of the fourth variable is negative and statistically insignificant, and the strategic interaction across countries with capital control is stronger than that of countries without capital control.

In sum, I find a lack of difference between the coefficient of the first and fourth variable, which shows that the strategic interactions on environmental policy are similar across countries with or without capital control. This finding indicates that the interaction on environmental policies are not mainly driven by capital movement across countries. The implication is that interjurisdictional competition plays a quite limited role in the strategic interaction on environmental policies.

1.4.4 Results of Differentiating the Transboundary Spillovers

The regression results of differentiating the transboundary spillovers is shown in table 2.9, which is estimated based on specification (1.3.4). Considering the degree of transboundary spillovers varies greatly across pollutants, I use oxidized sulphur as an example to explore the effect of transboundary spillovers on policy stringency. The dependent variable is Oxidized Sulphur Policy (OSP) in one country, which mainly includes taxes and emission limit on SO_x. The spatial lag is other countries' Oxidized Sulphur Policies. Two types of transboundary spillovers are included, "spill-out" which is the fraction of emissions deposited on other countries, and "spill-ins" which is the pollution depositions transported from other countries[14].

Regarding two spillover variables, spill-ins have statistically significant and positive impact on OSP. The results mean that when pollution depositions from other countries increase, the home country tends to increase its environmental policy, presumably to mitigate the harmful effect of pollution. On the other hand, when pollution depositions decrease, the home country tend to relax environmental policy stringency. The coefficient is 0.429 when using similarity of income per capita for the weighting matrix. A rough interpretation is that if oxidized sulphur pollution transported from other countries increases by 10%, the home country will increase the stringency of OSP by 0.0429 point. Considering that the mean of the stringency of OSP is 1.69, the scale of the impact is relatively small. When controlling for the spill-ins, the coefficients on the spatial lag of OSP are still positive and statistically significant in most specifications, which means the strategic interaction still exists. These results indicate that other mechanisms besides transboundary spillovers also play a role in generating countries' interaction. I repeat this regression but without controlling for the spill-ins; results are shown in Appendix Table 1.17. The coefficients of spatial lag are quite similar with or without controlling for spill-ins. Considering that the strategic interaction of controlling for spill-ins does not include the interaction caused by transboundary spillovers, similar coefficients mean that the transboundary spillovers play a limited role in the strategic interaction.

Spill-outs, fraction of emissions deposited on other countries, have a positive effect on environmental stringency; none of the coefficients of spill-outs are negative. The results show that when the home country exports a larger fraction of emissions on other countries, it tends to increase policy stringency rather than loosening policy in order to free ride. These results indicate limited free-riding behaviors on setting oxidized sulphur policies

[14] The sample used for the specifications includes only 21 European countries. Other countries that are sparsely located in different continents have very limited pollution spillovers between them, which are thus not considered in the estimation. The results of using the same sample but without controlling the spill-ins, depositions from other countries, are reported in Appendix Table 1.17

among European countries. To the opposite, there is even a certain degree of cooperation. This finding is consistent with results of Sigman (2002) who finds cooperative behaviors, not free-riding, on water pollution among European countries.

To summarize, transboundary pollution spillovers have impact on countries' environmental policies. Countries increase policy stringency to mitigate larger pollution spill-ins, but the scale of impact is relatively small. The strategic interaction that is caused by spillovers is also limited. Also, I find certain degree of cooperation instead of free-riding behavior on setting environmental policy among European countries.

1.5 Robustness Checks

A battery of additional robustness checks is also carried out. The first set of estimates replaces the two-year lagged control variables with one-year lagged and three-year lagged control variables. Results are shown in Table 1.11 and Table 1.12, respectively. Using one-year and three-year lagged control variables, there is still a statistically significant and positive effect of other countries' environmental policy stringency on the home country policy, but only under the weighting scheme of similarity of income per capita. Under other weighting schemes, the coefficients on spatial lag are also positive but not statistically significant at the conventional level. Comparing with the results of using two-year lagged control variables, the magnitude of coefficients is relatively smaller in the specifications using one-year and three-year lagged control variables.

In the second set of estimates, I include a one-year lag of the dependent variable to control for potential dynamic effects. As shown in Table 1.13, the lagged dependent variable is positive and statistically significant. After controlling for the lag of the dependent variable, the spatial lag, other countries' environmental policies, still shows a positive and statistically significant effect, although the coefficients are smaller.

Third, I recalculate the measure on the environmental policy (EPS) to exclude the potential correlation across countries in the calculation of EPS. In calculating one country's environmental policy stringency, one piece of information that is used is the carbon price in the "cap and trade" carbon market. To be more specific, in 2005, EU countries introduce emissions trading system (ETS) which links the greenhouse gas emissions in 31 European countries into one market. Since the carbon price in ETS is the same across participating countries, if we use the carbon price to calculate environmental policy stringency, the calculated policy stringency is correlated across countries by construction. This correlation may overestimate the strategic interaction on environmental policy that we intend to measure. Besides, the carbon price may be correlated with economic outcomes and brings a certain degree of endogeneity. So I recalculate the environmental policy stringency (EPS) by excluding the price in carbon market and rerun the regressions using new EPS. The results are shown in Table 1.14. There is still positive and statistically significant effect of other countries' environmental policy when using similarity of income per capita as the weighting matrix. The coefficients of using other weighting schemes are not statistically significant, but have a positive sign in first two columns, simple average and GDP per capita as weights, and negative sign of using openness as weights.

Fourth, I use the spatial lag variable that is two years in the future to run the regression. A county should not react to a policy change that has not been made yet, and thus we expect the coefficient should be statistically insignificant. The results are shown in Table 1.15. The spatial lag is not statistically significant in all specifications as expected. Also, we can not reject that the coefficients are equal to zero in all specifications.

Fifth, I also check how sensitive the results of differentiating interjurisdictional competition to the way of specifying countries with tight capital control. Instead of using one as the number to divide countries with or without tight capital control, I use zero as the number. Under this setting, when the capital control index of one country, Chinn-Ito index, is larger than zero, then this country is specified as "has no tight capital control".

Otherwise, it is specified as "has tight capital control". The results of estimating specification (1.3.3) are presented in Table 1.16. Under this group scheme, there is no country that is classified as "has tight capital control" since 2008. Thus, the sample size is smaller than before. But we still can not find statistically significant difference between the coefficients of the four variables.

1.6 Discussion and Conclusion

This paper explores the question of whether OECD countries engage in strategic environmental policymaking and disentangles distinct mechanisms behind the policy interaction. My analysis suggests that there is a positive interaction between countries' environmental policies. Through differentiating the potential mechanisms behind the interaction, I find that the interaction mainly manifests the international coordination on environmental policies, especially among EU countries. Also, EU countries' policies are increasingly coordinated with each others' since the adoption of the euro as a common currency. The interjurisdictional competition and pollution spillovers play limited roles behind the interaction.

My finding can partly explain the trend of increasingly stringent environmental policy since if there is limited race across countries, we do not expect to see the "race to the bottom" on environmental policy. The reasons of limited regulatory races on environmental policy are multilayered. On the one hand, environmental regulations are seldom definitive for firms' locational decisions at the international level. Studies on this topic include Kirkpatrick and Shimamoto (2008), Mulatu et al. (2010) and a review paper, Carruthers and Lamoreaux (2016). Given the limited impact of environmental regulation on capital, countries may not choose environmental policy to compete for capital, but use other policy instruments that have a larger influence on capital movement, such as the corporate tax rate. On the other hand, there has been considerable international cooperation on combating environmental issues. The participation on international environmental treaties is one example. Note that the lack of interjurisdictional competition in setting environmental policies does not imply that there is no competition regarding other government policies. Governments may use other instruments, such as corporate and personal tax rates, to compete for the capital.

It is also important to further explore the incentives and reasons behind the international coordination on environmental policies. Here I discuss some potential reasons. First, some environmental problems and pollution produce externalities across countries. The spillover effects provide an incentive on international coordination. In the empirical results, I also find limited free-riding behaviors on setting oxidized sulphur policies among European countries, which is consistent with the coordination behavior. Second, the environmental standard coordination could reflect the harmonization of product standards among trade partners. To avoid market segmentation, industries in both low-regulating and high-regulating countries have a common interest in harmonizing product standards (Holzinger and Sommerer, 2011). The third potential mechanism is reciprocity. Countries may increase the environmental standards to reciprocate other countries' efforts on combating environmental issues.

The results in this paper have policy implications. The first implication is that decentralized environmental policymaking does not necessarily bring about a "race to the bottom." And the responsibility for providing environmental quality need not rest entirely on a central authority. Second, when a country adopts a more stringent environmental policy, it has a positive external effect on other countries' environmental policymaking. This externality needs to be noticed both from the academic and the public policy perspective. I also recommend to devise certain mechanisms to reward and compensate the positive externality so that our environmental policies achieve more desired outcomes. Third, further coordination and cooperation to reinforce the policymaking interaction are suggested.

These conclusions should be interpreted cautiously because they are based on the analysis of developed OECD countries. In the future, expanding the dataset to include developing countries and embedding different mechanisms in a more complete model are logic next steps for research. Another research direction is to examine what motivates countries' policy coordination and cooperation.

Figure 1.1: Environmental Policy Stringency (EPS) Over Time

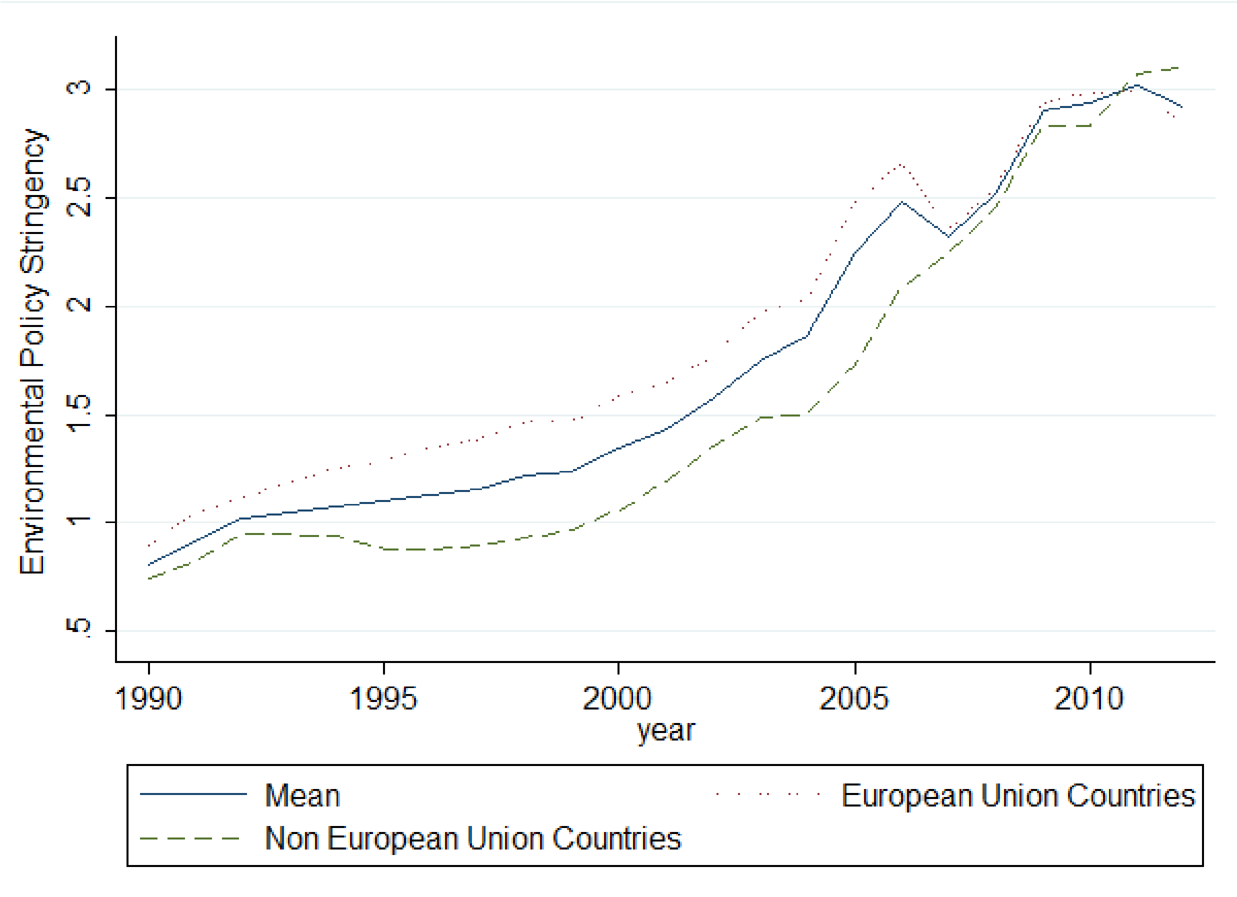


Figure 1.2: OECD countries' EPS Plotted on a World Map, 1995

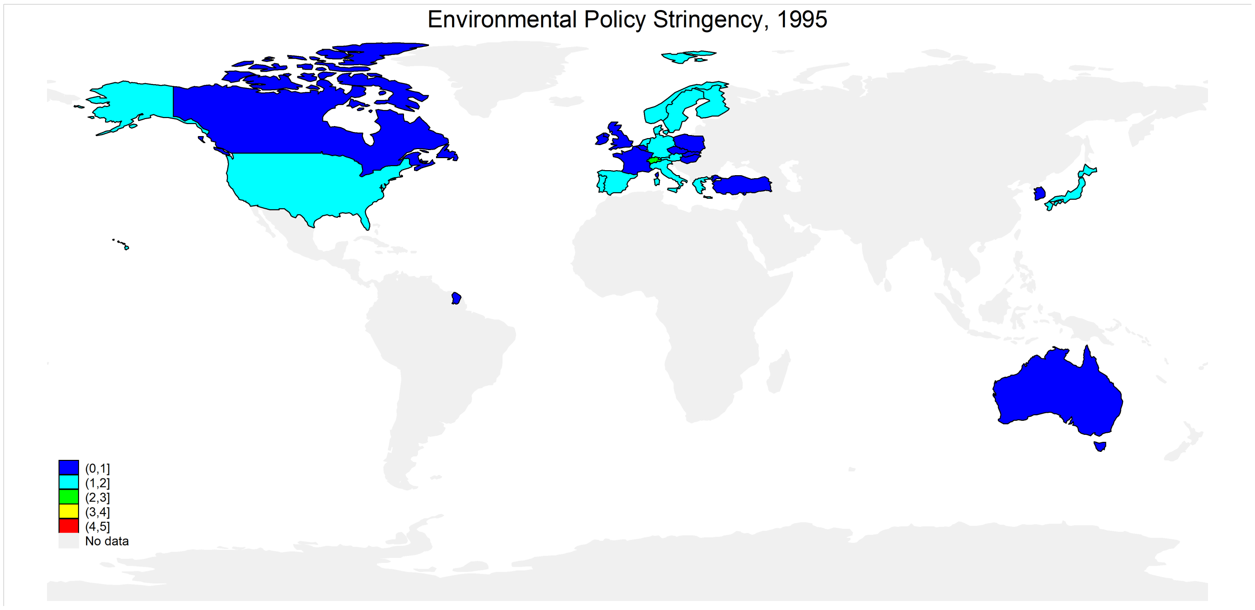


Figure 1.3: OECD countries' EPS Plotted on a World Map, 2010

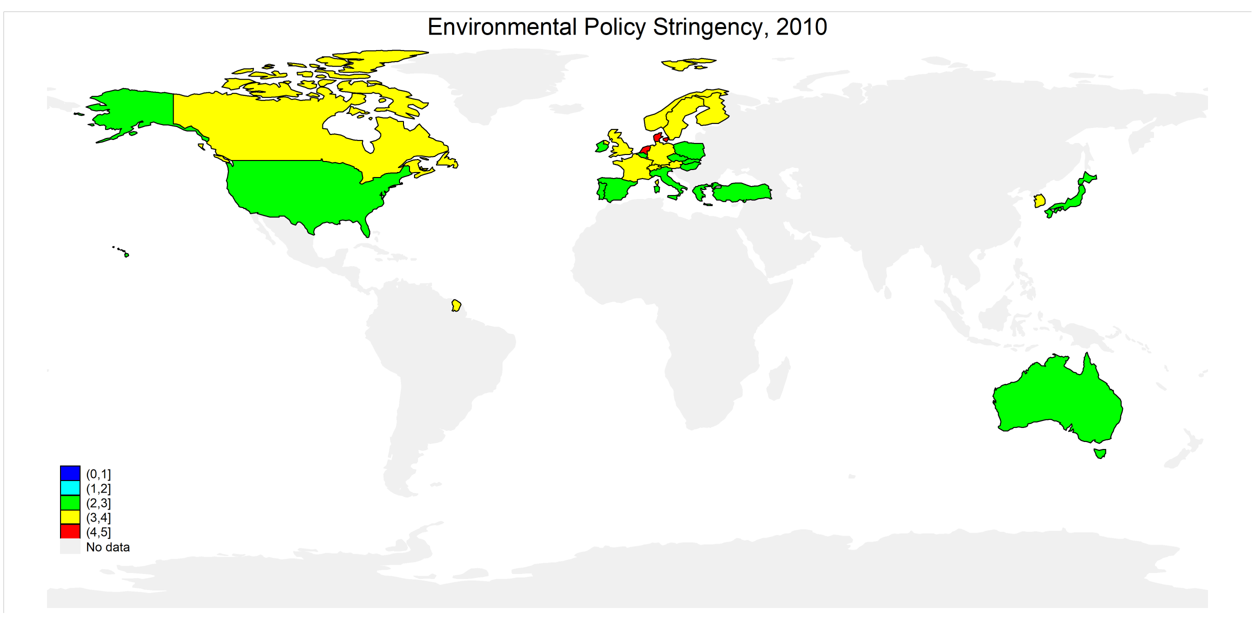
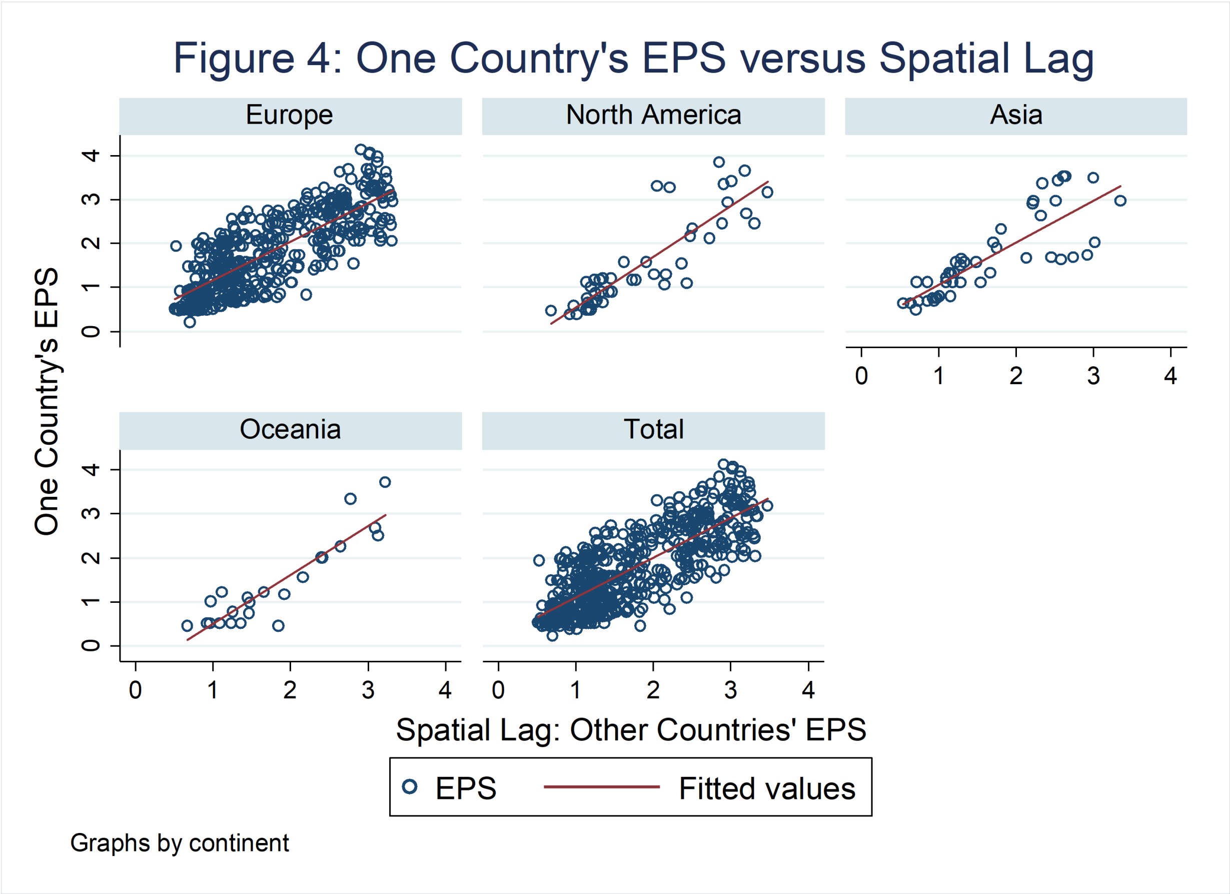


Figure 1.4: One Country's EPS versus Spatial Lag



Notes: The weighting matrix for constructing the spatial lag is similarity of income per capita.

Table 1.1: Evolution of EPS, Different Categories

year period	1990-1995	1996-2000	2001-2005	2006-2010	2011-2012	Total
EPS	0.994	1.218	1.775	2.634	2.968	1.74
EPS, Market Based Policy	0.565	0.834	1.221	1.918	2.008	1.186
EPS, Non Market Based Policy	1.423	1.605	2.332	3.352	3.929	2.297
EPS, Oxidized Sulphur Policy	0.583	0.846	2.035	2.985	3.038	1.691
EPS, SOx tax	0.385	0.715	1.4	1.485	1.404	1.005
EPS, SOx limit	0.782	0.977	2.669	4.485	4.673	2.378

Table 1.2: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
EPS	598	1.74	0.9	0.21	4.13
OSP	598	1.69	1.44	0	5.5
Democracy	598	1.32	0.62	1	5
Gov Fractionalization	598	0.3	0.27	0	0.83
Checks and Balances	598	4.22	1.26	1	11
Spill-ins: Depositions from Others	483	911.54	844.34	59.74	7067
Spill-outs: Fraction of Emissions on Others (%)	483	76.86	8.41	56.12	92
EU Membership	598	0.57	0.49	0	1
GDP Per Capita (Log)	598	10.26	0.39	8.96	11.06
Openness (%)	598	79.31	46.93	12.05	286.3
Corporate Tax Rate (%)	598	32.8	8.53	12.5	58.15
Urbanization	598	74.4	10.14	47.92	97.73
Population (Log)	598	16.8	1.15	15.07	19.57
Population $>$ 65 (%)	598	14.47	3.24	4.54	24.29
Population $<$ 14 (%)	598	18.38	3.58	13.13	36.25
Political Constraint Index	598	0.78	0.09	0.34	0.89

Table 1.3: Results of Estimating Overall Effect of Strategic Interaction, Similarity of Income per Capita as Weights

	(1)	(2)	(3)	(4)
	Environmental Policy Stringency (EPS)			
Weighing Matrix	Similarity of income per capital			
Spatial Lag	1.042***	1.436***	1.201***	1.250***
	(0.0345)	(0.357)	(0.219)	(0.283)
EU membership		-0.0111	0.272**	0.254**
		(0.111)	(0.107)	(0.111)
GDP per capita (log)		-0.146	0.476	0.617*
		(0.38)	(0.347)	(0.35)
Openness		-0.00251	-0.00303	-0.00178
		(0.00413)	(0.0028)	(0.00242)
Corporate tax rate		0.0284***	0.00907**	0.00989***
		(0.00588)	(0.00366)	(0.00373)
Urbanization		0.0117	-0.137***	-0.147***
		(0.0149)	(0.043)	(0.0393)
Population		-3.534	1.333	0.682
		(2.517)	(1.88)	(1.772)
Age structure (> 65 %)		-0.164***	-0.00599	-0.0187
		(0.0631)	(0.0701)	(0.0703)
Age structure (< 14 %)		-0.106***	-0.0850**	-0.0758
		(0.0318)	(0.043)	(0.0546)
Democracy		0.152*	0.194**	0.186***
		(0.0878)	(0.083)	(0.0719)
Political constraint		0.469	0.234	0.244
		(0.339)	(0.261)	(0.257)
Government fractionalization		0.061	-0.0172	0.00668
		(0.155)	(0.12)	(0.119)
Government checks and balance		-0.033	-0.015	-0.0196
		(0.0288)	(0.0179)	(0.0176)
Observations	543	543	543	543
R-squared	0.746	0.713	0.845	0.841
Country-specific Trend	NO	NO	YES	YES
Year FE	NO	NO	NO	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0	0.00402	0.00137	0.000316
Hansen's J p Value	0.206	0.521	0.253	0.211
Kleibergen-Paap rk Wald F statistic	27.23	6.179	13.1	14.14

Notes: Each column is from a separate regression. Coefficients are estimates from equation (4.1). All specifications are estimated by GMM CUE IV estimation. Instrument sets for the spatial lag include democracy, government fractionalization, checks and balances from other countries, using the same weighting scheme as the spatial lag. Except for spatial lag, other control variables are two-year lagged. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Table 1.4: Results of Estimating Overall Effect of Strategic Interaction, Other Weights

	(1)	(2)	(3)
	Environmental Policy Stringency (EPS)		
Weighing Matrix	Simple Average	GDP per capita	Openness
Spatial Lag	0.79	1.064*	0.351
	(0.542)	(0.639)	(0.375)
Observations	546	546	546
R-squared	0.895	0.893	0.895
Country-specific Trend	YES	YES	YES
Year FE	YES	YES	YES
Country FE	YES	YES	YES
Underidentification Test p Value	0	0	0
Hansen's J p Value	0.768	0.732	0.43
Kleibergen-Paap rk Wald F statistic	17.22	15	17.05

Notes: All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. Coefficients are estimates of δ_1 from equation (4.1).

All specifications are estimated by GMM CUE IV estimation. Instrument sets for the spatial lag include democracy, government fractionalization, checks and balances from other countries, using the same weighting scheme as the spatial lag. Except for spatial lag, other control variables are two-year lagged. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Table 1.5: Results of Differentiating Interjurisdictional Competition, All Weights

	(1)	(2)	(3)	(4)
	Environmental Policy Stringency (EPS)			
Weighting Matrix	Simple Average	GDP per capita	Openness	Similarity of income per capita
Home country with capital control * Spatial lag with capital control	0.485**	0.300*	0.402**	2.875***
	(0.211)	(0.163)	(0.200)	(0.501)
Home country with capital control * Spatial lag without capital control	0.373	0.532	0.193	-1.619***
	(0.423)	(0.377)	(0.519)	(0.421)
Home country without capital control * Spatial lag with capital control	0.0651	0.0184	0.0166	0.599***
	(0.187)	(0.144)	(0.161)	(0.173)
Home country without capital control * Spatial lag without capital control	0.712*	0.896**	0.526	-0.115
	(0.414)	(0.366)	(0.476)	(0.326)
Observations	546	546	546	543
R-squared	0.893	0.888	0.894	0.832
Country-specific Trend	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0	0	0	0
Hansen's J p Value	0.803	0.782	0.473	0.568
Kleibergen-Paap rk Wald F statistic	8.820	10.94	6.697	2.944

Notes: All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. There are four spatial lags in each specification. Coefficients of the four spatial lags are estimates of $\delta_1^1, \delta_1^2, \delta_1^3, \delta_1^4$ from equation (4.2). The coefficient on variable "Home country with capital control * Spatial lag with capital control" captures whether environmental policy in home country that have capital control strategically react to policies in other countries that also have capital control. The coefficients on other spatial lags can be interpreted similarly.

All specifications are estimated by GMM CUE IV estimation. Except for spatial lags, other control variables are two-year lagged. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Table 1.6: Results of Differentiating Transboundary Spillovers, All Weights

	(1)	(2)	(3)	(4)
	Oxidized Sulphur Policy			
Weighting Matrix	Simple Average	GDP per capita	Openness	Similarity of income per capita
Spatial Lag of Oxidized Sulphur Policy	1.029**	0.613	0.804*	0.612***
	(0.438)	(0.392)	(0.487)	(0.194)
Spill-outs: fraction of emissions deposited on other countries	0.0116	0.0154*	0.0103	0.0192**
	(0.00881)	(0.00918)	(0.0101)	(0.00907)
Spill-ins: pollution depositions transported from other countries (log)	0.504***	0.498***	0.510***	0.429**
	(0.183)	(0.176)	(0.183)	(0.211)
Observations	441	441	441	438
R-squared	0.886	0.889	0.887	0.857
Country-specific Trend	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0	0	0	0
Hansen's J p Value	0.857	0.665	0.299	0.327
Kleibergen-Paap rk Wald F statistic	23.24	25.37	10.03	12.59

Notes: All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. The dependent variable is Oxidized Sulphur Policy which is an index on environmental policies of oxidized sulphur. Coefficients of the three variables are estimates of $\delta_1^{'}, \delta_2, \delta_3$ from equation (4.3). Two variables on the oxidized sulphur spillovers are included in the specifications. Spill-outs captures the oxidized sulphur pollution depositions emitted from home country and transported to other countries, which are measured by the fraction of total emissions that are deposited on other countries. Spill-ins captures the oxidized sulphur pollution depositions that are originated from other countries and spilled inside home country. The sample used for the specifications includes only 21 European countries. Other countries that are sparsely located in different continents have very limited pollution spillovers between them, which are thus not considered in the estimation.

All specifications are estimated by GMM CUE IV estimation. Except for spatial lag, other control variables are two-year lagged. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Table 1.7: Results of EU and non-EU Countries, All Weights

	(1)	(2)	(3)	(4)
	Environmental Policy Stringency (EPS)			
Weighting Matrix	Simple Average	GDP per capita	Openness	Similarity of income per capita
Home country in EU * Spatial lag of EU	0.899***	0.858***	0.736***	0.363
	(0.261)	(0.232)	(0.217)	(0.425)
Home country in EU * Spatial lag of non-EU	0.048	-0.136	0.109	1.216***
	(0.256)	(0.243)	(0.251)	(0.33)
Home country not in EU * Spatial lag of EU	0.669**	0.473*	0.561**	0.49
	(0.294)	(0.266)	(0.245)	(0.478)
Home country not in EU * Spatial lag of non-EU	0.224	0.227	0.178	0.648*
	(0.299)	(0.301)	(0.248)	(0.335)
Observations	546	546	546	543
R-squared	0.887	0.891	0.876	0.821
Country-specific Trend	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0	0	0	0.126
Hansen's J p Value	0.369	0.229	0.185	0.114
Kleibergen-Paap rk Wald F statistic	11.06	11.76	14.71	1.43

Notes: All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. There are four spatial lags in each specification which are constructed based on whether other countries or home country are in EU. The coefficient on variable "Spatial lag of EU * home country in EU" captures whether environmental policy in home country that is in EU strategically react to policy changes in other EU countries. The coefficients on other spatial lags can be interpreted similarly.
All specifications are estimated by GMM CUE IV estimation. Except for spatial lags, other control variables are two-year lagged. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Table 1.8: Results of the Effect of Eurozone on EU Countries, All Weights

	(1)	(2)	(3)	(4)
	Environmental Policy Stringency (EPS)			
Weighting Matrix	Simple Average	GDP per capita	Openness	Similarity of income per capita
Eurozone * Home country in EU * Spatial lag of EU	0.683***	0.600***	0.570***	3.749
	(0.155)	(0.142)	(0.152)	(3.992)
Home country in EU * Spatial lag of EU	0.442*	0.529**	0.553***	-27.39***
	(0.240)	(0.216)	(0.206)	(7.829)
Home country in EU * Spatial lag of non-EU	-0.285	-0.252	-0.220	4.745
	(0.251)	(0.235)	(0.241)	(3.921)
Home country not in EU * Spatial lag of EU	-0.242	-0.209	-0.0336	-34.20***
	(0.328)	(0.286)	(0.267)	(9.844)
Home country not in EU * Spatial lag of non-EU	0.475	0.534*	0.325	14.42***
	(0.294)	(0.283)	(0.230)	(5.104)
Observations	546	546	546	543
R-squared	0.896	0.897	0.890	-36.705
Country-specific Trend	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0	0	0	0.0844
Hansen's J p Value	0.608	0.564	0.334	0.197
Kleibergen-Paap rk Wald F statistic	10.97	10.44	12.21	1.514

Notes: All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. There are five spatial lags in each specification which are constructed based on whether other countries or home country are in EU. The variable "Eurozone" is a dummy and equals to 1 if this country is in euro area that year.

All specifications are estimated by GMM CUE IV estimation. Except for spatial lags, other control variables are two-year lagged. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

1.7 Appendices

Table 1.9: Variables and Data Source

Variables	Source
Stringency of environmental policy	OECD Environmental Policy Stringency Index (EPS)
Democracy (simple average of Political Right and Civil Liberty)	Freedom House
Government fractionalization, Checks and balances	Database of Political Institutions (DPI)
Sulphur transport matrix	European Monitoring and Evaluation Programme (EMEP)
GDP per capita (log), Openness	Penn World Table 9.0 (Feenstra, et al. 2015)
Corporate income tax rate	OECD
Urbanization, Population related variables	World Bank's World Development Indicators database
Political Constraint Index	Political Constraint Index (POLCON) Dataset (Henisz, 2000)

Table 1.10: List of Countries and EU Membership

EU Countries	non-EU Countries
Austria (1995), Belgium	Australia, Canada
Czech Republic (2004), Denmark, Finland (1995)	Japan, Republic of Korea
France, Germany, Greece, Hungary (2004)	Norway, Switzerland
Ireland, Italy, Netherlands	Turkey, United States
Poland (2004), Portugal, Slovakia (2004)	
Spain, Sweden (1995), United Kingdom	

Notes: For countries with brackets, the regarding number inside the brackets is the year of becoming a European Union member. For countries without brackets in the column of EU Countries, they are EU members for the whole period of our dataset.

Table 1.11: Robustness, Control Variables are One-Year Lagged

	(1)	(2)	(3)	(4)
	Environmental Policy Stringency (EPS)			
Weighting Matrix	Simple Average	GDP per capita	Openness	Similarity of income per capita
Spatial Lag	0.284	0.28	0.26	1.221***
	(0.553)	(0.74)	(0.444)	(0.283)
Observations	572	572	572	568
R-squared	0.895	0.895	0.896	0.845
Country-specific Trend	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0	0	0	0
Hansen's J p Value	0.283	0.365	0.55	0.44
Kleibergen-Paap rk Wald F statistic	16.77	10.4	16.22	14.62

Notes: All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. Coefficients are estimates of δ_1 from equation (4.1) except that control variables are one-year lagged instead of two-year lagged.

All specifications are estimated by GMM CUE IV estimation. Instrument sets for the spatial lag include democracy, government fractionalization, checks and balances from other countries, using the same weighting scheme as the spatial lag. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Table 1.12: Robustness, Control Variables are Three-Year Lagged

	(1)	(2)	(3)	(4)
	Environmental Policy Stringency (EPS)			
Weighting Matrix	Simple Average	GDP per capita	Openness	Similarity of income per capita
Spatial Lag	0.547	0.399	0.533	1.475***
	(0.53)	(0.568)	(0.359)	(0.34)
Observations	520	520	520	518
R-squared	0.895	0.894	0.895	0.82
Country-specific Trend	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0	0	0	0
Hansen's J p Value	0.541	0.307	0.682	0.24
Kleibergen-Paap rk Wald F statistic	15.17	14.7	18.11	11.74

Notes: All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. Coefficients are estimates of δ_1 from equation (4.1) except that control variables are three-year lagged instead of two-year lagged.

All specifications are estimated by GMM CUE IV estimation. Instrument sets for the spatial lag include democracy, government fractionalization, checks and balances from other countries, using the same weighting scheme as the spatial lag. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Table 1.13: Robustness, Include Lagged Dependent Variable

	(1)	(2)	(3)	(4)
	Environmental Policy Stringency (EPS)			
Weighting Matrix	Simple Average	GDP per capita	Openness	Similarity of Income per capita
Spatial Lag	0.851*	0.953*	0.45	0.827***
	(0.469)	(0.559)	(0.325)	(0.208)
Lagged EPS	0.515***	0.507***	0.539***	0.536***
	(0.0557)	(0.0597)	(0.0521)	(0.055)
Observations	546	546	546	543
R-squared	0.921	0.92	0.924	0.901
Country-specific Trend	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0	0	0	0
Hansen's J p Value	0.683	0.231	0.186	0.186
Kleibergen-Paap rk Wald F statistic	17.64	14.38	17.56	17.56

Notes: All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. Coefficients are estimates of δ_1 from equation (4.1) except that one-year lagged dependent variable is also included.

All specifications are estimated by GMM CUE IV estimation. Instrument sets for the spatial lag include democracy, government fractionalization, checks and balances from other countries, using the same weighting scheme as the spatial lag. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Table 1.14: Robustness, Recalculated EPS, not Consider CO_2 Trading Scheme

	(1)	(2)	(3)	(4)
	Recalculated Environmental Policy Stringency (EPS)			
Weighting Matrix	Simple Average	GDP per capita	Openness	Similarity of income per capita
Spatial Lag	1.368	0.353	-0.767	1.372***
	(1.573)	(1.521)	(0.976)	(0.353)
Observations	546	546	546	543
R-squared	0.874	0.879	0.863	0.802
Country-specific Trend	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0.0978	0.0387	0.0012	0.00123
Hansen's J p Value	0.807	0.811	0.532	0.737
Kleibergen-Paap rk Wald F statistic	2.154	2.556	4.701	11.55

Notes: The dependent variable and spatial lag are constructed using recalculated EPS. In the constructed of index on environmental policy, recalculated EPS doesn't consider the carbon price in CO_2 trading system to avoid the correlation across countries in the calculation. All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. Coefficients are estimates of δ_1 from equation (4.1).

All specifications are estimated by GMM CUE IV estimation. Instrument sets for the spatial lag include democracy, government fractionalization, checks and balances from other countries, using the same weighting scheme as the spatial lag. Except for spatial lag, other control variables are two-year lagged. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Table 1.15: Robustness, Use Spatial Lag that are Two Years in the Future

	(1)	(2)	(3)	(4)
	Recalculated Environmental Policy Stringency (EPS)			
Weighting Matrix	Simple Average	GDP per capita	Openness	Similarity of income per capita
Spatial Lag	0.218	0.450	0.207	0.376
	(0.240)	(0.290)	(0.199)	(0.257)
Observations	494	494	494	493
R-squared	0.895	0.890	0.893	0.893
Country-specific Trend	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0	0	0	0.0291
Hansen's J p Value	0.00138	0.000441	0.000349	0.210
Kleibergen-Paap rk Wald F statistic	45.81	31.96	48.39	5.454

Notes: All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. The spatial lag is two years in the future.

All specifications are estimated by GMM CUE IV estimation. Instrument sets for the spatial lag include democracy, government fractionalization, checks and balances from other countries, using the same weighting scheme as the spatial lag. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Table 1.16: Robustness: Use Alternative Way to Specify Whether a Country Has Capital Control

	(1)	(2)	(3)	(4)
	Environmental Policy Stringency (EPS)			
Weighting Matrix	Simple Average	GDP per capita	Openness	Similarity of income per capita
Home country with capital control * Spatial lag with capital control	0.0274	0.954***	0.0870	0.852**
	(0.446)	(0.350)	(0.304)	(0.418)
Home country with capital control * Spatial lag without capital control	0.456	-0.495	0.894	-0.114
	(1.388)	(0.723)	(0.756)	(0.234)
Home country without capital control * Spatial lag with capital control	0.388	0.329*	-0.0718	0.381**
	(0.524)	(0.171)	(0.283)	(0.162)
Home country without capital control * Spatial lag without capital control	0.470	-0.0549	1.137	0.306
	(1.432)	(0.687)	(0.782)	(0.194)
Observations	416	416	416	413
R-squared	-0.238	0.799	0.895	0.824
Country-specific Trend	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0	0	0	0.00178
Hansen's J p Value	0.416	0.304	0.0298	0.237
Kleibergen-Paap rk Wald F statistic	8.170	9.682	4.727	3.126

Notes: All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. There are four spatial lags in each specification. Coefficients of the four spatial lags are estimates of $\delta_1^1, \delta_1^2, \delta_1^3, \delta_1^4$ from equation (4.2). Countries are divided into two groups based on whether the capital control index is larger than zero.

All specifications are estimated by GMM CUE IV estimation. Instrument sets for the spatial lags include democracy, government fractionalization, checks and balances from other countries, using the same weighting scheme as the spatial lags. Except for spatial lags, other control variables are two-year lagged. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Table 1.17: Results of Using Same Sample with Table 2.9 without Controlling for Spill-ins

	(1)	(2)	(3)	(4)
	Oxidized Sulphur Policy			
Weighting Matrix	Simple Average	GDP per capita	Openness	Similarity of income per capita
Spatial Lag of Oxidized Sulphur Policy	1.079**	0.757*	0.836*	0.652***
	(0.449)	(0.401)	(0.498)	(0.196)
Spill-outs: fraction of emissions deposited on other countries	0.0059	0.00866	0.0053	0.0145
	(0.00896)	(0.00928)	(0.0103)	(0.00924)
Observations	441	441	441	438
R-squared	0.886	0.889	0.887	0.857
Country-specific Trend	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Underidentification Test p Value	0	0	0	0
Hansen's J p Value	0.857	0.665	0.299	0.327
Kleibergen-Paap rk Wald F statistic	23.24	25.37	10.03	12.59

Notes: This set of specifications use the same sample and similar econometric equation with table 6. The difference is that the spill-ins are not controlled for in this set of specifications. Without controlling for the spill-ins, the coefficient of the spatial lag reflects the strategic interaction brought by transboundary spillovers.

The dependent variable is Oxidized Sulphur Policy which is an index on environmental policies of oxidized sulphur. Coefficients of the two variables are estimates of δ_1^{OSP}, δ_3 from equation (4.3). All specifications include a full set of control variables, country-specific trend, year fixed effect and country fixed effect. Each column is from a separate regression. All specifications are estimated by GMM CUE IV estimation. Instrument sets for the spatial lag include democracy, government fractionalization, checks and balances from other countries, using the same weighting scheme as the spatial lag. Except for spatial lag, other control variables are two-year lagged. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Underidentification test uses Kleibergen-Paap rk LM statistic. Hansen's J statistic is used to determine the validity of the overidentifying restrictions in a GMM model, and high p value indicates valid instruments. Kleibergen-Paap rk Wald F statistic is used for weak instruments test.

Essay 2

Tax Competition and Social Dilemma: A Laboratory Experiment

2.1 Introduction

Tax competition exists when governments use low tax rates, tax subsidies, and other tools to attract an inflow of productive taxable resources. One example of such competition from 2017 is that to entice Amazon's second headquarter to its locality, more than 200 cities in Canada, Mexico, and the United States offered tax breaks and other incentives. One of the winners in this race, New York City, planned to give Amazon tax breaks of at least $1.525 billion and cash grants of $325 million.

Tax competition has been extensively studied in economics and political science, both theoretically and empirically. One challenge is that it is difficult to empirically test some predictions from theoretical works due to lack of data. Moreover, the identification in empirical works tend to be plagued by endogeneity problems. In this paper, I adopt a theory-based experimental approach to explore how regions choose tax policies when facing tax competition. From the best of my knowledge, there is no previous paper using experimental methods to test tax competition predictions; this paper serves as a first attempt.

In a standard tax competition model (see, for example, Zodrow and Mieszkowki, 1986; Wilson, 1986; Barrett, 1994; Wilson and Wildasin, 2004),[1] there are n ($n >= 2$) regions

[1] There are some excellent surveys, including Wilson (1999), Keen and Konard (2013), and Boadway and Tremblay (2012).

sharing a mobile productive resource base, which is the tax base as well. One widely used example of productive resources is capital, which is also the example used in this paper. Capital is assumed to flow freely across the regions, and thus earn the same return to capital in each region. The government in each region chooses tax policies on capital to maximize social welfare and uses capital tax revenue to finance public goods. The local social welfare depends on both public goods and private production output. To attract capital, governments have an incentive to choose sub-optimally low tax rates. The Nash equilibrium tax rate is lower than the efficient tax rate that maximizes total social welfare. Tax competition can be characterized as a social dilemma. When local governments pursue their local interests and choose inefficiently low tax rates, the overall interest will be harmed. The residents' welfare that results from the Nash equilibrium is below the Pareto optimal level.

I use the tax competition model to formalize the experiments and design treatments to test some main theoretical predictions: (1) the equilibrium tax rates are lower than efficient tax rates; (2) keeping the sensitivity of capital movement to tax rates constant, the number of competing regions does not directly affect equilibrium tax rates; (3) how sensitive the capital movement is to tax rates significantly negatively affects equilibrium tax rates. I also explore the effects of two policy instruments that have the potential to mitigate the inefficiency, namely a minimum tax rate constraint and communication. These policies have been proposed in the real world. The Ruding Committee (Report of the Committee of Independent Experts on Company Taxation, 1992) proposed setting a minimum corporate tax rate of 30% in the EU, and there has been continuous efforts on harmonization of corporate tax systems. As regards communication, there has been substantial efforts and conversations among governments in an attempt to reach partial tax harmonization. In this essay, the minimum tax rate constraint and communication are the two policies studied. The theoretical predictions for the two policies are: (4) when the minimum tax rate constraint is higher than equilibrium tax rate, regions choose the minimum tax rate; (5) communication does not change equilibrium tax policies.

I find that observed tax rates are significantly lower than efficient levels, and in some cases, they are even lower than predicted equilibrium tax rates. The sensitivity of capital movement has a significant effect on tax choices, and the relationship is negative, but the observed scale of the impact is much smaller than theoretical predictions. The number of competing regions, on the other hand, has a direct, significant, and large effect on tax rate choices. This effect has been generally overlooked in the theoretical literature. Minimum tax constraint increases tax rates mainly through compulsively pulling of tax rates to the binding minimum tax rates. Communication significantly increases tax rates and social welfare by promoting cooperative policies and adopting efficient tax rates among competing regions. Cooperation becomes harder to form with more competing regions.

A laboratory experiment is a powerful tool to examine the tax policies facing tax competition. One advantage of the lab experiment is that we can create a controlled environment in which the differences between treatments are the only factors that we intend to investigate. The effects of these factors are difficult to test using real-world data due to the lack of counterfactual data. Other econometric issues, such as endogeneity and missing variables, also disturbs the estimates. Moreover, using experimental data, we are able to compare the observed behaviors with predicted and efficient tax rates, which is an advantage compared with the empirical research where predicted and efficient tax rates are unknown.

As a first attempt to test tax competition model predictions in a laboratory experiment, I intend to design the experiment to be simple enough to capture the characteristics of tax competition. How governments change tax rates and make policies is a complicated process. The model and experiment used in this paper do not include some features, such as political institution and government structure, that play important roles in policymaking in the real world. I believe that the experiments' simplicity is able to reduce subjects' confusion. While I use the language of tax competition to describe the environment, the setup is applicable to other situations where competition distorts behaviors from efficient levels.

The results in this paper also have several implications for future research and policymaking. Regarding tax competition, it is necessary to take the effect of the number of competing regions into account for both empirical and theoretical works. The experimental observations and results help to motivate further theoretical developments to better fit observed facts. The new theories can then be tested with a new field or laboratory results. The limited effect of the sensitivity of capital movement also calls for an adjustment to and accommodation of theoretical work. Moreover, promoting better and more effective communication among governments would be beneficial in reconciling the inefficiencies caused by tax competition.

Tax competition can be characterized as a social dilemma. Other examples of social dilemma include public goods game, prisoner's dilemma, trust game, and others. Many experiments find players' behaviors are different from the Nash equilibrium predicted when assuming self-regarding (or *homo economicus*) preference. For example, in a public goods game, the contribution to public goods is significantly higher than *homo economicus* predictions (see Ledyard, 1994 and Chaudhuri, 2011 for review). Behavioral economic theory provides a wide range of models to explain the cooperation, such as inequality aversion (Fehr and Schmidt, 1999), reciprocal preferences (Dufwenberg and Kirchsteiger, 2004; Falk and Fischbacher, 2006; Cox *et al.*, 2008), and altruism (Andreoni, 1989; Andreoni, 1990).

There are other games and experiments that share similarity with tax competition. When competing governments use low tax rate to attract mobile tax base, such as capital, it's similar to a contest game. In a contest game, several rival parties expend resources in trying to secure a prize or rent for themselves (Abbink, *et al.*, 2010[2]). Tullock's (1967,

[2]Konrad (2007, 2009) provides recent surveys of the theoretical literature on contest models.

1980) lottery contest game is one of the most studied. Extensive experimental studies (Millner and Pratt, 1989, 1991; Sheremeta, 2010) have investigated the contest game and test whether the observed behavior is consistent with standard Nash equilibrium predictions. Many experiments find that the efforts and expenditures exceed theoretical predictions (i.e. overbidding). Possible explanations include non-monetary utility from winning (Sheremeta, 2010; Price and Sheremeta, 2011; Brookins and Ryvkin, 2014), and spiteful preferences and inequality aversion (Bartling *et al.*, 2009; Balafoutas *et al.*, 2012).

The rest of this essay proceeds as follows. Model setting and theoretical predictions are provided in section 2. Section 3 and 4 present experimental design and protocol. Section 5 lays out the results. Section 6 concludes. The appendix provides an example of subject instructions.

2.2 Theoretical Model

In this section, I lay out the primitives of the model and derive the equilibrium under the assumption that agents are purely selfish. The model is based on Zodrow and Mieszkowski (1986), Wildasin (1988), and Wilson (1991). In the model, consider $n > 1$ competing regions, indexed by $i = 1, 2 \ldots, n$. The competing regions face mobile capital and use a capital tax to finance public goods. The capital tax rate, in turn, affects the capital movement. I start by discussing the basic model in which there are two symmetric regions. Then I extend the basic model to consider the case where the number of regions is more than two.

2.2.1 Basic Model

Assume there are two regions $i = 1, 2$. The regions are symmetric and identical, which means they have the same number of identical residents, same production function and same technology. There is a fixed national total capital stock, and each region has the same initial capital endowment, $\overline{k_1} = \overline{k_2} = k^*$. Assume each region has one resident who participates in the production process. The production function[3] is $F(k_i, 1) = f(k_i)$. The government in each region levies taxes on capital, t_i. Capital flows freely across the two regions to earn the same net of tax return in each region, $f^{'}(k_1) - t_1 = f^{'}(k_2) - t_2$, where t_1, t_2 are the tax rate per unit of capital. Since the two regions are otherwise identical, more capital will flow to the region with the lower capital tax rate.

The government uses tax revenues from the capital tax to finance fully congested public services, g_i. Local governments face a hard budget constraint, $g_i = t_i * k_i$, and choose a capital tax rate to maximize the utility of a representative resident. The resident gets utility, $U_i(c_i, g_i)$, from both private goods, c_i, and public goods consumption, g_i. The resident spends all of his income on private goods, c_i. The tradeoff for governments is that it has incentives to lower tax rates in order to attract more capital, which produces more output. However, since tax revenue is the multiplication of tax rates and the amount of capital, lower tax rates do not necessarily increase the tax revenue and public goods provided. At the extreme, when the tax rate is zero, the region is able to attract a large amount of the capital, but there would be no tax revenue to finance public goods.

To be more specific, assume the production function to be $f(k_i) = \beta k_i - \alpha k_i^2$. We choose positive α, β so that the production function is positive, concave, twice differentiable and strictly increasing for all possible k_i.[4] The welfare function for a representative resident is $U_i(c_i, g_i) = c_i * g_i$, where $c_i = \beta k_i - t_i * k_i = (\beta - t_i) * k_i$. Since $c_i, k_i \geq 0$, $\beta - t_i \geq 0$.[5] The utility function is strictly increasing, concave, twice

[3]Model predictions and results are similar if we consider there to be L residents. Assume the production function to be $F(K, L)$ and the function has constant return to scale, $\frac{F(K,L)}{L} = F(\frac{K}{L}, 1) = F(k_i, 1) = f(k_i)$. In this setting, k_i is the capital per capita, and $f(k_i)$ is the output per capita.

[4]This means $k_i \epsilon [0, 2k^*]$.

[5]In the tax competition literature, we usually assume that each resident owns an identical share of the regional capital, k^*, and earns income through labor and capital. The income is thus, $[f(k_i) - f^{'}(k_i)k_i] + rk^* = [\beta k_i - \alpha k_i^2 - (\beta - 2\alpha k_i)k_i] + (\beta - 2\alpha k_i - t_i)k^* = \beta k_i - t_i k_i - \alpha k_i^2 + (k^* - k_i) * (\beta - 2\alpha - t_i)$. I simplify the consumption function to let the model be better used in the experiment without losing the key features of the game, $c_i = \beta k_i - t_i k_i$.

differentiable. Thus, the welfare function for a representative resident is:

$$U_i(c_i, g_i) = c_i * g_i = (\beta k_i - t_i k_i) * t_i k_i \tag{2.2.1}$$

2.2.2 Equilibrium Tax Rates

I now derive the indirect preferences of agents over tax rates and characterize the Nash equilibrium. Capital moves freely across regions to earn the same net return, $\beta - 2\alpha k_1 - t_1 = \beta - 2\alpha k_2 - t_2$, which can be simplified as: $2\alpha k_1 + t_1 = 2\alpha k_2 + t_2$. The total fixed capital supply is given by $k_1 + k_2 = \overline{k_1} + \overline{k_2} = 2k^*$. From the above two equations, we can derive the capital per capita function in region 1 follows:

$$k_1 = k^* + \frac{1}{4\alpha} * (t_2 - t_1) \tag{2.2.2}$$

The equation 2.2.2 shows that the capital in region 1 is directly determined by the tax rate difference between the competing regions. The intuition for this equation is straightforward. When the competing region (region 2) increases its tax rate, some capital will flow into the home region (region 1), which increases the capital per capita in home region. The same happens when the home region reduces its tax rates. The effect of a change in the home region tax rate on capital is given by:

$$\frac{\partial k_i}{/}\partial t_i = \frac{-1}{4\alpha} \quad i = 1, 2 \tag{2.2.3}$$

We call the effect of tax rate change on capital movement, $\frac{1}{4\alpha}$, as “the sensitivity of capital per capita to tax rate change.” I also “the sensitivity” and “sensitivity of capital movement” to refer to this effect for short. When α increases, the absolute value of this effect decreases, which means capital is less sensitive to a tax rate change. The sensitivity to the ax rate is an important dimension that I change in the experiment.

Inserting the capital function into the objective function, we have:

$Max_{t_i} : U_i(c_i, g_i) = c_i * g_i = (\beta(k^* + \frac{1}{4\alpha} * (t_j - t_i)) - t_i(k^* + \frac{1}{4\alpha} * (t_j - t_i))) * t_i(k^* + \frac{1}{4\alpha} * (t_j - t_i))$.

The Nash tax rate choices for region i is characterized by the first order condition:

$\frac{\partial U_i(c_i,g_i)}{\partial t_i} = \frac{\partial U_i(c_i,g_i)}{\partial c_i}\frac{\partial c_i}{\partial t_i} + \frac{\partial U_i(c_i,g_i)}{\partial g_i}\frac{\partial g_i}{\partial t_i} = -\phi\frac{\partial U_i(c_i,g_i)}{\partial c_i} + (k_i - t_i\frac{1}{4\alpha})\frac{\partial U_i(c_i,g_i)}{\partial g_i} = 0$, where

$\phi = k_i - t_i\frac{1}{4\alpha} + \beta\frac{1}{4\alpha}$ Rewrite this equation, we get:

$$\frac{\frac{\partial U_i(c_i,g_i)}{\partial c_i}}{\frac{\partial U_i(c_i,g_i)}{\partial g_i}} = \frac{k_i - t_i\frac{1}{4\alpha}}{\phi} \tag{2.2.4}$$

Solving the above equation 2.2.4 for both regions, we can derive the Nash equilibrium tax rates, t^N. Since $\beta, \alpha > 0$, then $\beta\frac{1}{4\alpha} > 0$. Thus $\frac{k_i - t_i\frac{1}{4\alpha}}{\phi} < 1$. It follows that

$\frac{\partial U_i(c_i,g_i)}{\partial c_i} < \frac{\partial U_i(c_i,g_i)}{\partial g_i}$, which means that the marginal utility of public goods consumption is larger than private goods consumption. While the optimal public goods provision, the g_i that maximizes social welfare, follows the first order condition, $\frac{\partial U_i(c_i,g_i)}{\partial c_i} = \frac{\partial U_i(c_i,g_i)}{\partial g_i}$. So, we know that public goods in the Nash equilibrium tax rates are less than the amount that maximizes social welfare. The under-provision of public goods also implies that the Nash equilibrium tax rate is lower than the optimal tax rate. We can derive the optimal tax rate by solving the first order condition in the optimum, which follows from

$\frac{\frac{(\partial U_i(c_i,g_i))}{\partial c_i}}{\frac{(\partial U_i(c_i,g_i))}{\partial g_i}} = \frac{t_i k_i}{\beta k_i - t_i k_i} = 1$. Thus, the optimal tax rate, denoted t^O, is $\beta/2$.

Moreover, the sensitivity of capital movement is related to tax rates and thus public goods provision.

$$\frac{\partial(\frac{k_i - t_i\frac{1}{4\alpha}}{\phi})}{\partial\frac{1}{4\alpha}} = \frac{-t_i}{\phi} - \frac{(k_i - t_i\frac{1}{4\alpha}) * (\beta - t_i)}{\phi^2} \tag{2.2.5}$$

Since $\beta - t_i \geq 0$, it follows that $\phi = k_i + \frac{1}{4\alpha} * (\beta - t_i) \geq 0$ and $(k_i - t_i\frac{1}{4\alpha}) * (\beta - t_i) > 0$. Thus the right hand of equation 2.2.5 is negative, which means that there is a inverse relationship between sensitivity and the equilibrium tax rate. The results here are also consistent with the predictions from Zodrow and Mieszkowski (1986) and Wilson (1991) that tax rates will be lower than optimal, so that the public good will be under-provided.

2.2.3 n-region Case

Following Wildasin (1988), I also extend the basic model to n regions. Based on the results in Wildasin (1988), in symmetric competition case with n identical regions, the respective effect of the tax rate in region 1 and region 2 on capital is as follows:

$$\frac{\partial k_1}{\partial t_1} = (\frac{\partial f'(k_1)}{\partial k_1})^{-1} * \frac{n-1}{n} \tag{2.2.6}$$

$$\frac{\partial k_1}{\partial t_2} = (\frac{\partial f'(k_2)}{\partial k_2})^{-1} * \frac{1}{n} \tag{2.2.7}$$

The sensitivity of capital to tax rates, i.e., the absolute value of $\frac{\partial k_i}{\partial t_i}$, is positively related with the number of regions, n. Keeping the production function parameters constant, if we increase the number of regions from 2 to 3, the sensitivity would increase from $|(\frac{\partial f'(k_1)}{\partial k_1})^{-1} * \frac{1}{2}|$ to $|(\frac{\partial f'(k_1)}{\partial k_1})^{-1} * \frac{2}{3}|$. Since there is a inverse relationship between the sensitivity and equilibrium tax rate, the higher sensitivity of capital movement results in a lower Nash equilibrium tax rate and public goods provision. On the other hand, if we increase the number of competing regions and keep the sensitivity constant through adjusting the production function parameters, the tax rate in equilibrium will not change with more competing regions (Wildasin, 1988).

2.3 Experimental Design and Predictions

I test the theoretical predictions through controlled laboratory experiments. I introduce subjects to a game that has the same structure as the one presented in the theoretical model. Every subject is randomly grouped with another anonymous subject, indexed by i =1, 2. Subjects are required to choose the tax rates on capital between 0 and 80%. Subjects' payoff depends on the welfare in their represented region, which is consistent with theoretical model where local governments' objective is to maximize welfare in its region. The parameters are set as $k^* = 120, \beta = 1$. The local welfare, i.e., the payoff function, thus is $U_i(c_i, g_i) = (k_i - t_i k_i) * t_i k_i$. The value of α differs across treatments in order to allow different sensitivity of capital movement to tax rates. From Section 2, we know the optimal tax rate is $t_i^O = \beta/2 = 50\%$, and the optimal public goods provision is 3600.

The treatments vary across the following dimensions: the number of competing regions (2 or 3) and the sensitivity of capital movement to tax rate. There are also two policy instrument treatments, namely a minimum tax rate constraint and communication. In total, we have seven treatments.

2.3.1 Treatments

2-Region Low Sensitivity Treatment

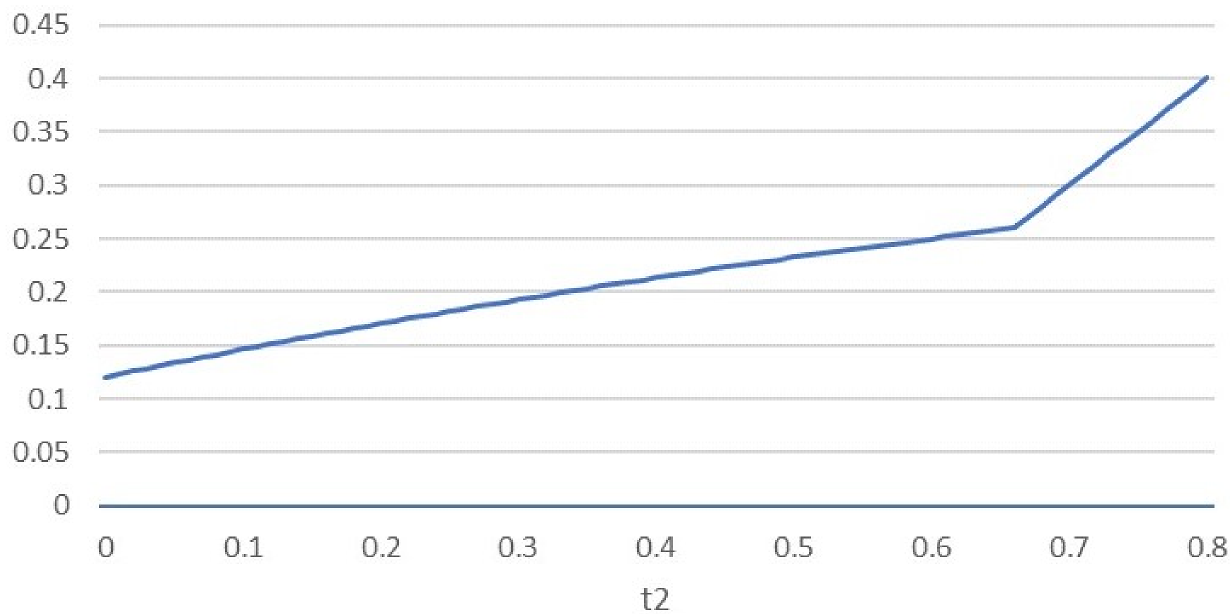
The first treatment is the *2-Region Low Sensitivity* treatment. In this treatment, $\alpha = 1/1200$, so that every 1 percentage point change in the local tax rate will cause $\frac{1}{4\alpha} * 0.01 = 300 * 0.01 = 3$ units of capital to move. With everything else constant, if region 1 increases its tax rate by 1 percentage point, 3 units of capital will move out from this region to the competing region, and vice versa. The sensitivity of capital movement to tax rate is 3.

The response function of region 1 to the tax rate of region 2 is:

$$t_1 = \frac{t_2}{4} - \frac{\sqrt{100t_2^2 - 20t_2 + 201}}{40} - \frac{19}{40} \quad if t_2 < 0.6596$$
$$t_1 = t_2 - 0.4 \quad if t_2 >= 0.6596 \qquad (2.3.1)$$

The response function is shown in Fig. 2.1. The horizontal axis is region 2's tax rates, and the vertical axis is region 1's tax rates that maximize its social welfare given region 2's tax rate. If we draw the both regions' responses functions in one graph, the intersection is the Nash equilibrium predicted tax rate, presented in Fig. 2.2. The intersection, and thus the Nash equilibrium tax rate, is 16.15

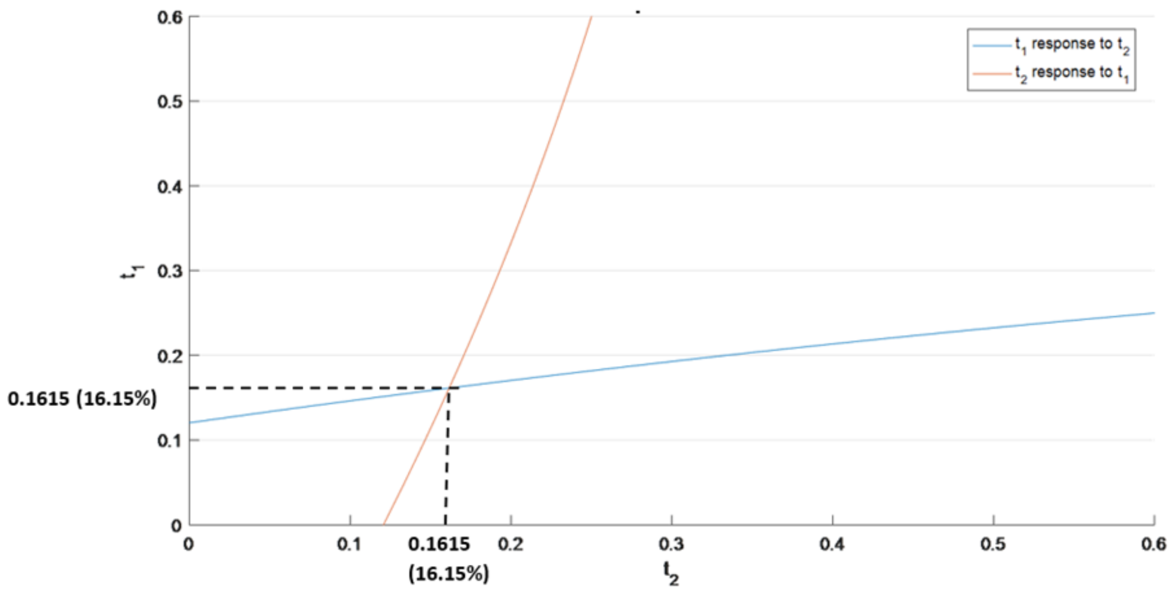
Figure 2.1: Response Functions



3-Region Low Sensitivity Treatment

The second treatment is the *3-Region Low Sensitivity* treatment. The main difference from the *2-Region Low Sensitivity* treatment is that there are 3 competing regions in a group instead of 2. The sensitivity of capital movement with respect to the tax rate is the same, which means that every one percentage point change in local tax rate will cause 3 units of the capital movement. Thus, the payoff function, Pareto-efficient level, and Nash equilibrium are also the same. To make the sensitivity of capital movement the same as

Figure 2.2: Response Functions and Equilibrium Tax Rates



with *2-Region Low Sensitivity* treatment, we need to change the parameter of the production function, α, and set $\alpha = \frac{3}{4} * \frac{1}{1200}$.

3-Region High Sensitivity Treatment

In the third treatment, the *3-Region High Sensitivity* treatment, we keep the production function constant and increase the number of competing regions. The sensitivity of capital movement to tax rate increases from 3 to 4, so every one percentage point change in the local tax rate will cause four units of capital to move. Other parameters stay the same as in the *2-Region Low Sensitivity* treatment. The Pareto-efficient tax rate level is still 50%. The Nash equilibrium tax rate decreases to 12.8%.

2-Region High Sensitivity Treatment

As I mentioned above, the increase in the number of competing regions also raises the capital movement sensitivity to tax rate changes. In order to disentangle the effects caused by changes in the sensitivity from the number of competing regions, I construct the fourth treatment, *2-Region High Sensitivity* treatment. The capital sensitivity is the same as the sensitivity in the *3-Region High Sensitivity* treatment, i.e., I set $\alpha = \frac{4}{3} * \frac{1}{1200}$). The number of competing regions is 2, which is the same as in the *2-Region Low Sensitivity* treatment. The Pareto-efficient tax rate level is still 50% and public goods provision is 25. The Nash equilibrium tax rate is the same as the *3-Region High Sensitivity* treatment, 12.8%.

From the above treatments, I disentangle the effects caused by the number of competing regions from the effects of capital sensitivity. If we keep the model parameters fixed, the increase in the number of competing regions raises capital sensitivity to the tax rate. The two factors change simultaneously. I thus set different parameters of the production function to change one factor at a time, 2 or 3 regions, low or high sensitivity of capital movement. This gives us four treatments. From the predictions of the theoretical models, sensitivity of capital movement directly affects the predicted equilibrium tax rates. If we increase the number of competing regions while keeping the sensitivity constant, the predicted tax rate is unchanged. Comparing the experimental results among the four treatments, we have a clear prediction of the effect of competition group size and sensitivity on equilibrium tax rates.

Race to the Bottom Treatment

The fifth treatment, *Race to the Bottom* (RTB), is an extreme case of very high capital sensitivity to tax rate change. The capital movement to tax rate change is so responsive that all the capital will move to the region with the lower capital tax rate. We set $\alpha = 0$ in this treatment. In order to attract capital, regions would choose the lowest possible tax rate to compete. In the experiment, the lowest possible tax rate is 0%. But when regions choose tax rates to be 0%, the payoff is 0 no matter what tax rates the competing region choose. When both regions choose 1%, the payoff is positive (238.56). If the competing region's tax rate is 1%, home region can not earn more by diverging from 1% and choosing 0% or higher tax rates. Both regions choosing 1% is the Nash equilibrium in this treatment.

Two Policy Instrument Treatments

We next consider the effects of two policies that have potentials to mitigate the inefficiency from tax competition, namely minimum tax rate constraint and communication. In the sixth treatment, Minimum Constraint treatment, a minimum capital tax rate constraint that governments can levy is added. In particular, subjects cannot choose a tax rate lower than 30%. Other characteristics and parameters are the same as with the *2-Region Low Sensitivity* treatment.

The last treatment, the *Communication* treatment, examines the effect of communication in reducing tax competition inefficiency. Before the competing regions make decisions on the capital tax rate, they have 60 seconds for cheap talk. During the 60 seconds, the regions in the same group are able to send messages to each other through computers, making suggestions regarding choices of tax rates and possibly agreeing to tax rates, but the agreement is not binding. Other characteristics and parameters are the same as with the *2-Region Low Sensitivity* treatment.

Table 1 specifies the parameters used in each treatment and lists the Nash equilibrium tax rate predictions for the regions. The first two columns shows the number and name of each treatment. The third column and fourth column present the number of regions in a group and the sensitivity of capital movement to tax rate change. A higher number represents higher sensitivity, which would cause lower Nash equilibrium tax rates. The number of competing regions, production function parameter α, and predicted Nash equilibrium tax rates are also shown here. The number of observations in each treatment are noted in the last columns. In each treatment, The Pareto-efficient tax rate level for all treatments is 50% and public goods provision is 25.

Table 2.1: Treatments, Parameters and Predictions

No.	Treatment	# of Regions	Capital Sensitivity	Parameter α	Predicted Tax Rates	# of Observations
1	2-Region Low Sensitivity	2	3	$\frac{1}{1200}$	16.15%	1950
2	3-Region Low Sensitivity	3	3	$\frac{3}{4} * \frac{1}{1200}$	16.15%	1305
3	3-Region High Sensitivity	3	4	$\frac{1}{1200}$	12.80%	585
4	2-Region High Sensitivity	2	4	$\frac{4}{3} * \frac{1}{1200}$	12.80%	1350
5	Race to the Bottom	2	120	0	1%	840
6	Minimum Constraint	2	3	$\frac{1}{1200}$	Minimum (30%)	330
7	Communication	2	3	$\frac{1}{1200}$	16.15%	600

2.3.2 Hypotheses

In this section, I distill the theoretical results into testable hypotheses. Hypothesis 1 compares predicted tax rates with efficient tax rates. Hypotheses 2-5 refer to the effect of different factors on equilibrium tax rates.

Hypothesis 1: the equilibrium tax rates are lower than efficient tax rates.

Hypothesis 2: keeping the sensitivity of capital movement to tax rates constant, the number of competing regions does not directly affect equilibrium tax rates.

Hypothesis 3: how sensitive the capital movement is to tax rates significantly affect equilibrium tax rates, and the relationship is negative.

Hypothesis 4: equilibrium tax rate is the same as a binding minimum tax constraint.

Hypothesis 5: communication does not change equilibrium tax policies.

2.4 Experimental Protocol

The subjects recruited for tne experiments are undergraduate students at Georgia State University. All the experiments were conducted at the GSU Experimental Economics Center. In each experiment session, subjects are exposed to two treatments. After finishing the two treatments, subjects' risk preference and distributional preferences are elicited. In total, there are four parts in each session. Twelve sessions were run. No subject participated in more than one session. I use both a between and within subject design.

The currency of payoff which subjects earned in this experiment is called tokens. The tokens were converted into dollars using the exchange rate: 300 Tokens = $1. Total earnings for a certain subject was the sum of earnings in each of the four parts. One period in every part was randomly selected at the end of each part, and the earning in the selected rounds was paid to the subjects at the end of the experiment. There is also a $5 show-up fee. Sessions lasted around 2 hours on average.

As mentioned, there are four parts in each experiment session. Part 1 and Part 2 of each session are two treatments out of the seven possible treatments discussed in Section 3. Each part lasted 15 identical periods. At the beginning of each part, subjects were divided randomly into groups of two or three depending on the treatments. The subjects in the same group represent competing regions. The group remains fixed within each part. At the beginning of each period, subjects are given 120 units of capital. The capital is mobile across subjects in the same group. Subjects simultaneously chose the capital tax rate without knowing what rate the competing subjects in the same group chose. The capital tax decision was allowed to be any whole number between 0 and 80 (%). After every subject in the same group has made the decision, capital moves freely between regions so that all capital earns the same net capital return.[6] This process is executed automatically by the computer.[7] Then the payoff, which is the welfare, is calculated. Subjects then received feedback that specified the following information of each subject in the same group: the tax rate decision, the final amount of capital, amount of public goods and

[6] As calculated in Section 2, capital in region 1 is $k_1 = k^* + \frac{1}{4\alpha} * (t_2 - t_1)$.

[7] One concern for the experiment is not using subjects to represent capital and residents. Our consideration is that using human subjects will add much complexity to the experiment. Besides, the results will be the confounding effect of capital mobility, resident's consumption decision and tax competition. Considering that our focus is tax competition, so for now we use computers to determine capital mobility and consumption decision, subjects only need to decide capital tax rate. Since using subjects for capital and residents is more realistic, it can be a future direction.

private goods, and payoff. After the period was over, subjects moved on to the next identical period. In all treatments, a built-in calculator was provided to help subjects calculate hypothetical earnings from different capital tax rate choices. The calculator appeared on subjects' monitors. Subjects can enter their own capital tax rate decision and a guess for the decision of the other competing region or regions. Then, the calculator will compute the payoff for the subject in this hypothetical scenario, taking capital mobility into account.

The third and fourth part are intended to elicit risk and distributional preferences of subjects. Each part lasted 10 periods. Part 3 uses the method of Holt and Laury (2002) to elicit risk preference. In each period of Part 3, subjects chose the preferred lottery to play between two lotteries. The two lotteries have the same probability distribution of winning a high prize or a low prize in a specific period. The key difference between the two lotteries is the gap among the high and low prizes. One lottery has 400 tokens as the high prize and 320 as the low prize. The other lottery has 770 tokens as the high prize and 20 as the low prize. The lottery with a small gap between high and low prizes is characterized as the low-risk lottery. The other one with a large gap is characterized as the high-risk lottery. Across periods, the high prize and low prize distributions of high-risk lottery and low-risk lottery were kept fixed respectively, but the probability of winning high prize or low prize differed. At the end of this part, one period was randomly selected, and the lottery in this period was played. Subjects' earning is the lottery prize earned in this selected prize.

In Part 4, I use the way of Fisman *et al.* (2007) and Fisman *et al.* (2017) to elicit distributional preferences. In each period, subjects were randomly grouped with an anonymous other subject, participated in a generalized dictator game, and divided an endowment between self and the other group member. The subject was free to allocate a unit endowment in any way she wishes within the budget constraint, $p_s\pi_s + p_o\pi_o = 1$, where π_s and π_o denote the payoffs to self and other, respectively, and $p = p_o/p_s$ is the relative price of redistribution. At the end of this part, one period was randomly selected, and subjects' earning was the sum of endowment allocated to self and the endowment received from the other group member.

Subjects also participated in 3 periods of practice before being engaged in the four parts in each experiment session. Practice periods are very similar to the *2-Region Low Sensitivity* treatment, except that the amount of capital is fixed, not mobile. Other characteristics are the same. The practice serves two main learning purposes. First is to learn to balance the provision of public good and private goods by setting the proper tax rate. The second is to learn the socially optimal tax rate, which is the same whether the capital is mobile or not. When the capital is not mobile as in the practice periods, the Nash equilibrium tax rate is the same as the optimal tax rate. This learning experience enables subjects to know the optimal tax rate that maximizes the national welfare before being exposed to the tax competition. Subjects were not paid for these periods.

At the end of the experiment, subjects were asked to complete a questionnaire. Basic demographic information of subjects, such as age, race, and gender, was collected. In addition, questions regarding their competition motives, winning goal, and understanding of the experiment were also asked. All the questions can be found in Appendix. In particular, subjects choose the degree of agreement with the following statements:

- Statement1: I choose the decision number low so that the number of resources will relatively large;
- Statement2: I concentrated more on getting more resources than earning of points;
- Statement3: I choose the decision number to get more resources than the other group member;
- Statement4: I choose the decision number to earn more than the other group member;
- Statement5: I increase decision number to increase the payment to the other group member;

- Statement6: I choose high decision number because my earning points will not be affected;
- Statement7: I did not understand well, so I choose randomly.

The wording in the instructions is neutral-framed without referral to tax, capital, or competition. I use "productive resources" to indicate capital. Subjects were asked to choose a "decision number" instead of the tax rate. In addition, the word "competition" is not mentioned at all in the instructions. I used neutral wording to prevent subjects' pre-experiment perceptions on tax or competition or capital from contaminating the experiments' results. The results of this experiment can be applied to other scenarios with similar game characteristics. The instructions for the experiment are included in the Appendix.

2.5 Results

I report the results of the experiments in the following order. First, I examine the effect of group size on tax choices. To answer this question, I compare the 2-Region Low Sensitivity with the 3-Region Low Sensitivity treatments and compare the 2-Region High Sensitivity with the 3-Region High Sensitivity treatments. Second, I explore the effect of the sensitivity of capital movement to tax rate change keeping the group size constant. I compare the 2-Region Low Sensitivity with the 2-Region High Sensitivity and the Race to the Bottom treatments. 3-Region Low Sensitivity and 3-Region High Sensitivity treatments are also analyzed. Finally, I consider the policy interventions.

2.5.1 The Effect of Group Size

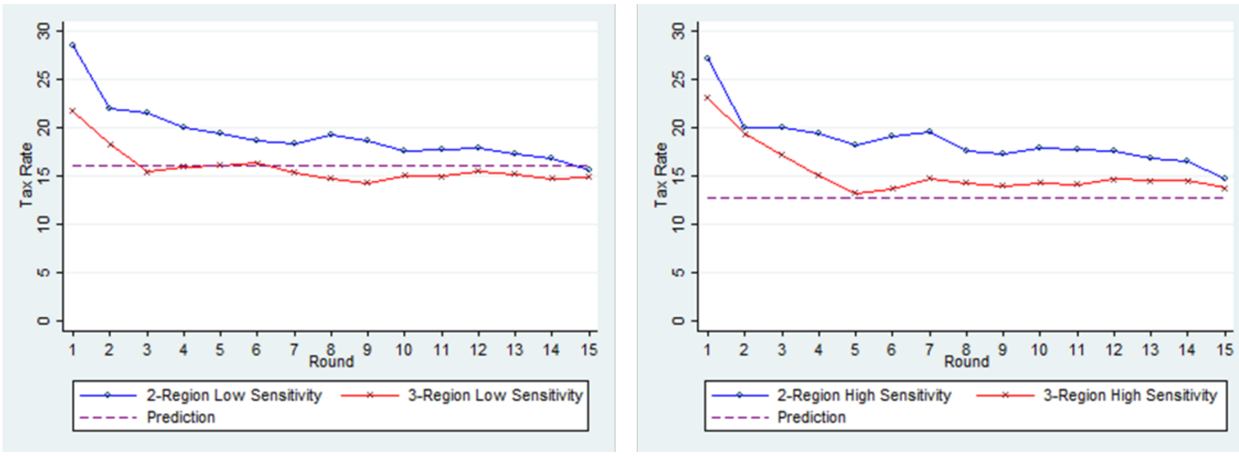
One of the most interesting results is the statistically significant and large effect of group size. As shown in Section 2, when the sensitivity of capital movement to tax rate is fixed, the number of competing regions should not affect equilibrium tax rates. Hence, the theory predicts that we would observe the same tax rates in the 2-Region Low Sensitivity and 3-Region Low Sensitivity treatments, and also same tax rates in the 2-Region High Sensitivity and 3-Region High Sensitivity treatments. Table 2.2 presents the average observed tax rates and predicted tax rates for the four treatments. The first column shows the Nash equilibrium predicted tax rates. The following columns display the average tax rates in all periods, period 1, period 1 to 5, period 6 to 10, and period 11 to 15. Fig. 2.3 depicts the evolution of the tax choices as subjects gain more experience with the game. The dashed line represents the model prediction, while the data observed in the experiments are marked as the circles and stars. Fig. 2.4 presents histograms of tax choices in the last 5 period in the four treatments. I also regress tax choices on the competing group size using the data from treatments 1-4 (2-Region and 3-Region Low/High Sensitivity treatments). The results of the random effect regression model controlling for period fixed effects can be found in the column (1) of Table 2.3.

Table 2.2: Predicted and Observed Tax Rates (%)

Treatments	Nash Equilibrium	Average Tax Rates (st err) in Different Periods				
		All periods	1	1 to 5	6 to 10	11 to 15
2-Region Low Sensitivity	16.15	19.29	28.56	22.29	18.48	17.11
		(0.28)	(1.28)	(0.53)	(0.46)	(0.43)
3-Region Low Sensitivity	16.15	15.90	21.70	17.50	15.15	15.06
		(0.20)	(1.23)	(0.41)	(0.24)	(0.35)
2-Region High Sensitivity	12.8	18.10	27.74	20.46	17.78	16.07
		(0.30)	(1.27)	(0.54)	(0.54)	(0.48)
3-Region High Sensitivity	12.8	15.24	21.29	16.99	14.33	14.41
		(0.32)	(1.59)	(0.61)	(0.50)	(0.56)

When the number of competing regions increase from 2 to 3, the observed tax rates decrease substantially even though the Nash equilibrium prediction stays fixed. In the low sensitivity treatments, an increase in the number of competing regions reduces the all-period average tax rates from 19.29% to 15.9%, a decrease of 3.39%. The null

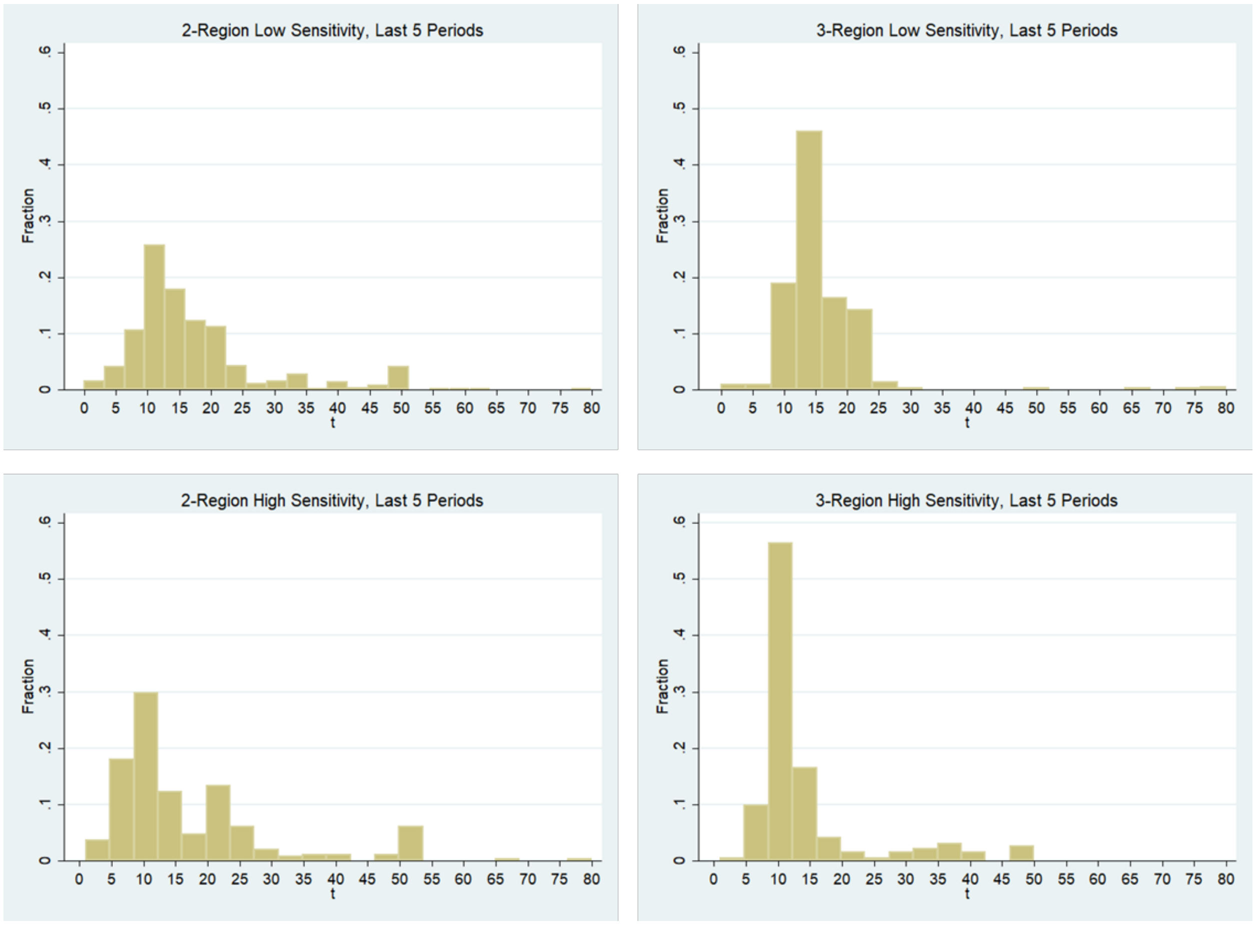
Figure 2.3: Dynamics of Tax Rates over Periods Comparing Different Group Size



hypothesis that tax choices are the same given the sensitivity of capital is rejected (Mann-Whitney, $z = 4.550, p < 0.01$). Similar results are found in high sensitivity treatments (Mann-Whitney, $z = 4.653, p < 0.01$). Presented in Table 2.3, the coefficients on Group Size are statistically significant in all 3 regressions. Increasing the group size from 2 to 3 reduces the tax rates by around 2.6%. The histograms in Fig. 2.4 show that when group size is 2, the distribution of tax choices is more spread out than the distributions when group size is 3. And some subjects did pick the optimum tax rate, 50%, even in the presence of tax competition. The dynamics of tax rates choices also show that there is a decreasing trend over the periods, and the standard error also tends to get smaller as the experiment proceeds. The results reveal that subjects adjust behaviors to converge to equilibrium as they are more experienced.

Consistent with Hypothesis 1, the observed tax rates are lower than Pareto-efficient tax rates. While the observed tax rates are not consistent with the model predictions. Except for the 3-Region Low Sensitivity treatment, the average tax rates in the other three treatments are statistically significantly higher than the theoretical predictions. The p-values of the three t-tests are 0.000. When we use the data of the last 5 periods, i.e., period 11 to 15, the results are equivalent. The p-values of t-tests using last the 5 periods in the three treatments are 0.013, 0.000, and 0.000, respectively. In the 3-Region Low

Figure 2.4: Histograms of Tax Choices in the Last Five Periods



Sensitivity treatment, the observed tax rates are consistently lower than the model prediction in the last 8 periods. This means that when group size increases, the inefficiency and under-provision of public goods are underestimated in theoretical tax competition literature.

Conclusion 1: Consistent with Hypothesis 1, observed tax rates are lower than the efficient tax rate, which demonstrates the inefficiency caused by tax competition. Inconsistent with Hypothesis 2, tax rates are significantly lower when the group size increases and sensitivity to capital movement stays fixed. The direct effect of group size is underestimated in the theoretical literature, which is one main reason why the observed behaviors are not consistent with the Nash equilibrium predictions.

Table 2.3: The Effect of Group Size and Sensitivity

	(1)	(2)	(3)
		Observed Tax Rates	
Group Size	-2.638***	-2.640***	-2.668***
	(0.299)	(0.300)	(0.302)
Sensitivity		-0.167	-0.057***
		(0.296)	(0.004)
Constant	26.861***	27.427***	27.042***
	(1.102)	(1.562)	(0.901)
Period Dummies	YES	YES	YES
# of subjects	253	253	277
# of observations	5190	5190	6030

Notes: Standard errors clustered at the session level in parentheses * $p < 0.10, **p < 0.05, ***p < 0.01$. Random effects regression with clustering at the experimental session level. Column 1 and 2 show the results of using data of Treatments 1-4. Column 3 shows the results of using data of Treatments 1-4 and Race to the Bottom treatment.

This raises the question, why group size have such significant effect on tax choices. One potential reason is that besides personal payoff, region also cares about attracting for more capital, i.e., "winning" the game. Increasing group size make the competition more fierce, and lower tax rates are needed to achieve the goal of more capital and winning. To explore this explanation, I add regions' previous period capital resources rank to the regression. The rank variable is larger for regions that earn relatively more capital resources. For regions that received the least amount of resources, the rank variable is 0. For regions that received the most amount of resources compared with other competitors in the previous period, the rank variable is 1 if the group size is two, and the rank is 2 if the group size is three. I also include the variables regarding tax decision motive statements asked in the questionnaire. For the seven Statement variables added to the regression, higher values mean that subjects agree more with the motive statements. Results are presented in Table 2.4[8].

[8]Statement1: I choose the decision number low so that the number of resources will relatively large; Statement2: I Concentrated more on getting more resources than earning of points; Statement3: I choose the decision number to get more resources than the other group member; Statement4: I choose the decision number to earn more than the other group member; Statement5: I increase decision number to increase the

Table 2.4: The Effect of Previous Resources Rank and Competition Motives

	(1)	(2)
	Observed Tax Rates	
Previous Rank	0.315*	0.349**
	(0.172)	0.165)
Group Size	-2.729***	-2.793***
	(0.424)	(0.430)
Sensitivity	-0.326	-0.142
	(0.444)	(0.461)
Statement 1		-1.006**
		(0.511)
Statement 2		-0.324
		(0.748)
Statement 3		-2.249***
		(0.684)
Statement 4		0.354
		(0.575)
Statement 5		0.840**
		(0.349)
Statement 6		-0.221
		(0.674)
Statement 7		0.286
		(0.790)
Constant	28.784***	30.774***
	(1.837)	(3.720)
Demographic Variables	NO	YES
Period Dummies	YES	YES
# of subjects	253	253
# of observations	4434	4434

Notes: Standard errors clustered at the session level in parentheses * $p < 0.10, **p < 0.05, ***p < 0.01$. Random effects regression with clustering at the experimental session level. Column 1 and 2 show the results of using data of Treatments 1-4. Variable "Previous Rank" measures regions' previous period capital resources rank in the group. The rank variable is larger for region who earn relatively more capital resources. The seven statement variables corresponds to seven motive statements asked in the questionnaire. Higher variable values represent that subjects more agree with the statement.

Table 2.4 shows that the resource rank in the previous period has a positive and statistically significant effect on the tax choices in current period. Regions tend to reduce tax rates to attract more capital resources when their resource rank is low in the previous previous period. Regions adjust their tax choices based on capital resources rank. The second column of Table 2.4 shows that subjects' motives for making tax decisions, many have statistically significant effect. In particular, the effect of variable Statement 3, "I choose the decision number to get more resources than the other group member", is pretty large. Subjects who have stronger motives of getting more resources than the competitors tend to choose lower tax rates. When they face more competitors and larger group size, they choose even lower tax rates to achieve the aim of more resources and winning the game.

Another potential explanation for the significant effect of group size is that subjects may learn the strategies from competitors more quickly when the group size is larger. Thus, they are able to reach the equilibrium tax rates faster. I explore this explanation by using only the data from last 5 and 2 periods to estimate the effect of group size. The results are presented in Table 2.5.

Only using the last 2 periods of data to estimate the regressions, we also find a statistically significant effect of group size on tax decisions. In the last a few periods, the scale of effect is smaller, which may reflect that subjects learn and reach their equilibrium strategies more quickly in larger group. Learning can only partly explain the behavior divergence.

One might also think that risk aversion helps to explain the tax choices difference in different group size. Table 2.6 presents the results of estimating the effect of risk preferences. Risk Pref. is the risk preference variable measured by frequency of choosing risky options in the lotteries. Lower values of this variable means more risk averse. Table 2.6 shows that risk averse subjects tend to choose lower tax rates. However, in two of

payment to the other group member; Statement6: I choose high decision number because my earning points will not be affected; Statement7: I did not understand well, so I choose randomly.

Table 2.5: The Effect of Group Size Using Data from Last 5 and 2 Periods

	(1)	(2)
	Observed Tax Rates	
Group Size	-1.268***	-0.849*
	(0.399)	(0.468)
Sensitivity	-0.587	-0.369
	(0.507)	(0.575)
Constant	19.149***	17.554***
	(1.543)	(1.703)
Period Dummies	YES	YES
# of subjects	253	253
# of observations	1730	692

Notes: Standard errors clustered at the session level in parentheses * $p < 0.10, **p < 0.05, ***p < 0.01$. Random effects regression with clustering at the experimental session level. Column 1 and 2 show the results of using last 5 and 2 periods data of Treatments 1-4 respectively.

regressions, the coefficients on risk preference are not statistically significant. Distributional Pref. is measured by percentage of tokens that are saved for self. Higher values of this variable represents being more selfish. Table 2.6 shows that more selfish subjects tend to choose lower tax rates. However, similar to the effect of risk preferences, distributional preferences do not have significant effect on tax choices.

2.5.2 The Effect of the Sensitivity of Capital Movement

We have seen that increasing group size has a significant impact on tax rates. In this section, I investigate the effect of the sensitivity of capital movement. The hypothesis is that the more sensitive capital movement is to tax rate, the lower the equilibrium tax rate is, everything else holds fixed. Hence, compared to 2-Region Low Sensitivity treatment, we expect to observe lower tax rates in the 2-Region High Sensitivity treatment and much lower rate in the Race to the bottom treatment. We also expect that the tax rates in the 3-Region High Sensitivity will be lower than the rates in the 3-Region Low Sensitivity.

Table 2.6: The Effect of Risk and Distributional Preferences

	(1)	(2)	(3)
		Observed Tax Rates	
Group Size	-2.616***	-2.641***	-2.675***
	(0.339)	(0.338)	(0.355)
Sensitivity	-0.18	-0.083	-0.056***
	(0.629)	(0.619)	(0.005)
Risk Pref.	0.477	0.543*	0.38
	(0.319)	(0.314)	(0.327)
Distributional Pref.	-2.947	-0.541	-1.403
	(2.455)	(3.296)	(3.287)
Statement1		-0.946**	-0.321
		(0.477)	(0.504)
Statement2		-0.33	-0.739
		(0.583)	(0.584)
Statement3		-2.414***	-2.421***
		(0.612)	(0.651)
Statement4		0.439	-0.047
		(0.667)	(0.695)
Statement5		0.638	0.694
		(0.595)	(0.599)
Statement6		-0.208	-0.426
		(0.642)	(0.668)
Statement7		0.244	-0.259
		(0.677)	(0.725)
Male		1.555	0.882
		(1.182)	(1.205)
School Year		0.221	0.223
		(0.529)	(0.546)
GPA		-1.914**	-1.752**
		(0.783)	(0.815)
Smoke		0.239	-1.137
		(1.985)	(2.17)
Self-rated Ranking		-1.471**	-1.182
		(0.715)	(0.734)
Understanding		0.92	1.680**
		(0.658)	(0.693)
Constant	27.721***	28.413***	25.365***
	(3.298)	(4.69)	(4.254)
Period Dummies	YES	YES	YES
# of subjects	253	253	277
# of observations	5190	5190	6030

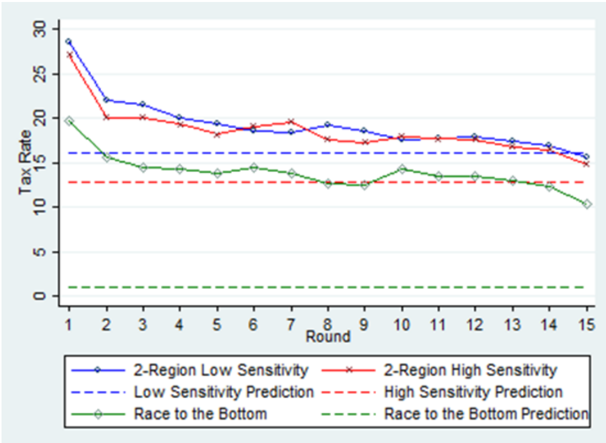
Notes: Risk Pref. is the risk preference variable measured by frequency of choosing risky options in the lotteries. Lower values of this variable means more risk averse. Distributional Pref. is measured by percentage of tokens that are saved for self. Higher values of this variable represents being more selfish. Standard errors clustered at the session level in parentheses * $p < 0.10, **p < 0.05, ***p < 0.01$. Random effects regression with clustering at the experimental session level. Column 1 and 2 show the results of using data of Treatments 1-4. Column 3 shows the results of using data of Treatment 1-5.

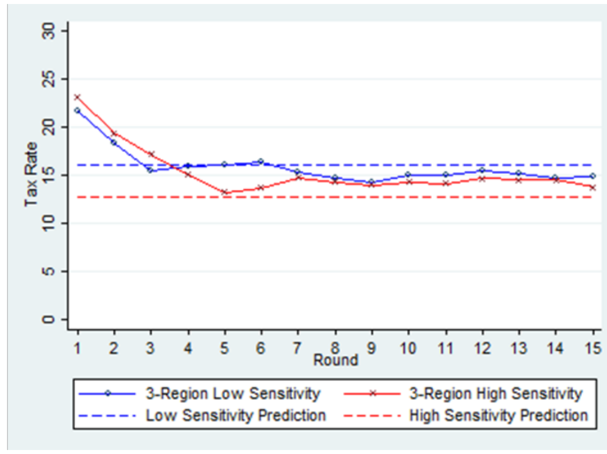
Table 2.7 presents summary statistics of observed tax rates and predicted tax rates in the five treatments. Fig. 2.5 depicts the trend of tax rates over time for the five treatments. The results are consistent with the null hypothesis that tax rates are lower in treatments with higher sensitivity. In the 2-Region treatments, an increase in the sensitivity reduces the all-period average tax rates from 19.29% to 18.10%, a decrease of 1.19%. Mann-Whitney tests reject that tax rates in 2-Region Low Sensitivity and 2-Region High Sensitivity treatment are the same ($z = 2.775, p < 0.01$). Similar results can be found when there are 3 regions in the group ($z = 7.368, p < 0.01$). Although the negative effect of sensitivity on tax rates goes in the direction predicted by theory, the scale of the effect is well below theoretical predictions. Regressing tax rates on capital movement sensitivity and group size, we find that the effect of sensitivity is not statistically significant (see results in Column 2 of Table 2.3). One potential reason for the insignificant effects is that the sensitivity difference between High Sensitivity and Low Sensitivity treatments is not large enough to induce behavior distinctions. The results of including Race to the Bottom data in the regression is presented in Column 3 of Table 2.3. The effect is statistically significant at the 1% level; however, the scale of the effect is much smaller than predictions.

Table 2.7: Predicted and Observed Tax Rates with Race to the Bottom Treatment(%)

Treatments	Predicted Taxes	Average Tax Rates (st err) in Different Periods				
		All periods	1	1 to 5	6 to 10	11 to 15
2-Region Low Sensitivity	16.15	19.29	28.56	22.29	18.48	17.11
		(0.28)	(1.28)	(0.53)	(0.46)	(0.43)
2-Region High Sensitivity	12.8	18.10	27.74	20.46	17.78	16.07
		(0.30)	(1.27)	(0.54)	(0.54)	(0.48)
Race to the bottom	1	13.90	19.70	15.64	13.55	12.52
		(0.55)	(2.08)	(0.90)	(0.95)	(0.98)
3-Region Low Sensitivity	16.15	15.90	21.70	17.50	15.15	15.06
		(0.20)	(1.23)	(0.41)	(0.24)	(0.35)
3-Region High Sensitivity	12.8	15.24	21.29	16.99	14.33	14.41
		(0.32)	(1.59)	(0.61)	(0.50)	(0.56)

Figure 2.5: Dynamics of Tax Rates over Periods Comparing Different Sensitivity





Conclusion 2: The effect of the sensitivity of capital movement is statistically significant in some regressions, but the scale of effect is much smaller than predictions.

2.5.3 Response Function

The above shows that the effects of group size and sensitivity diverge from the model predictions. These divergences raise one question regarding behaviors, whether these behaviors are caused by subjects' confusion and indiscretion or whether they reflect some phenomenon that has been neglected in the literature. To answer the question, this section examines whether subjects behave strategically.

I estimate how subjects respond to the competitor's tax choices and confront the response with model predictions. As shown in section 2, the predicted response function for Low Sensitivity treatments is $t_1 = \frac{t_2}{4} - \frac{\sqrt{100t_2^2 - 20t_2 + 201}}{40} - \frac{19}{40}$ if $t_2 < 0.6596$. The function is close to a line with the slope as around 0.21. In a given round, subjects choose tax rates simultaneously and can not observe the competitor's tax choice. They need to predict competitor's behavior and respond correspondingly. To measure the prediction on the other group member's behaviors, I use the previous round tax rates of the other group member and construct the variable "Prediction". In 3-Region treatments, "Prediction" is constructed by using the average of the other two group members' tax rates in the pervious round . The effect of the variable "Prediction" reflects how subjects react to others' tax choices, thus the subjects' response function. Table 2.8 presents the estimated response function results using random effect regressions. In Column 2 of Table 2.8, the interaction term of prediction and sensitivity is added to the regression, which measures how the response may changes with different sensitivity of capital movement.

The results show that subjects do positively respond to others' predicted tax rates as predicted. When subjects project that others' tax rate will reduce by 1%, they decrease their own tax rates by around 0.3% in response. The scale of the effect is a little bit larger than suggested by predictions as noted above (0.21). The sensitivity does not statistically significantly move the reaction function, which is consistent with the limited effect of sensitivity found in Tables 2.3 and 2.7.

Table 2.8: Estimating the Response Function

	(1)	(2)
	Observed Tax Rates	
Prediction	0.341***	0.317***
	(0.041)	(0.026)
Prediction * Sensitivity		0.053
		(0.077)
Group Size	-1.626***	-1.653***
	(0.221)	(0.243)
Sensitivity	-0.253	-1.150
	(0.377)	(1.131)
Constant	11.038***	14.127***
	(1.837)	(3.720)
Period Dummies	YES	YES
# of subjects	253	253
# of observations	5190	5190

Notes: Standard errors clustered at the session level in parentheses $* \ p < 0.10, **p < 0.05, ***p < 0.01$. Random effects regression with clustering at the experimental session level. Column 1 and 2 show the results of using data of Treatments 1-4. Variable "Prediction" measures how subjects predict the competitor's behaviors, and I use the competitor's pervious round behaviors to construct it.

Conclusion 3: subjects behave strategically and respond to competitor's behaviors in the same direction as predicted.

2.5.4 The Effect of Policy intervention

Considering the inefficiency caused by tax competition, proper policy interventions are needed to improve tax choices. I consider two potential policy interventions, minimum tax rate constraint, and communication. Table 2.9 shows the results of tax rates with and without policy interventions. Fig. 2.6 and Fig. 2.7 show the evolution of tax choices over periods. Fig. 2.8 compares the histograms of tax choices in last five periods. Both policy interventions significantly increase tax rates (Mann-Whitney tests comparing minimum constraint treatment and 2-Region Low Sensitivity treatment are $z = 21.682, p < 0.01$; Mann-Whitney tests comparing communication treatment treatment and 2-Region Low Sensitivity treatment are $z = 19.505, p < 0.01$.)

When we set the minimum tax rate constraint to be 30%, observed average tax rate is 34.03%. Most of the tax rate choices, around 63.6 percent, are close to the constraint level (30% or 31%). This policy instrument does have an effect on increasing the tax rates and reducing inefficiency, though the impact is mainly caused by the binding constraint.

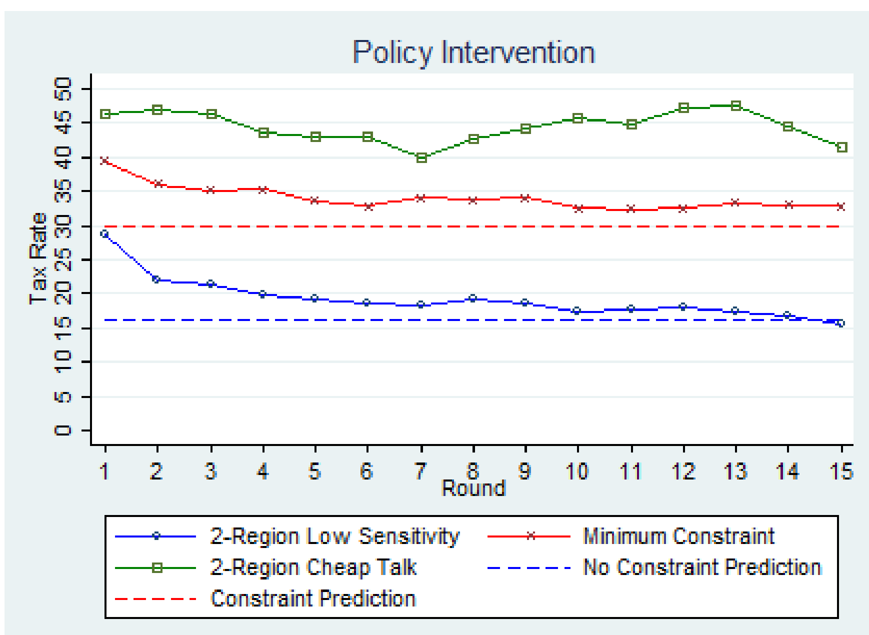
Table 2.9: Predicted and Observed Tax Rates in Policy Intervention treatments

Treatments	Prediction	Average tax rates (st err) in different periods				
		All periods	1	1 to 5	6 to 10	11 to 15
Minimum Constraint	30	34.03	39.36	35.86	33.43	32.78
		(0.36)	(1.73)	(0.65)	(0.60)	(0.59)
2-Region Communication	16.15	44.48	46.45	45.27	43.07	45.09
		(0.98)	(3.31)	(1.73)	(1.73)	(1.62)
3-Region Communication	16.15	34.80	38.33	37.42	34.86	32.13
		(1.13)	(4.93)	(2.04)	(1.89)	(1.93)
2-Region Low Sensitivity	16.15	19.29	28.56	22.29	18.48	17.11
		(0.28)	(1.28)	(0.53)	(0.46)	(0.43)

On the other hand, communication is able to improve the tax rates substantially, even without the binding constraint. The average tax rate in 2-Region Communication treatment is 44.48%, which is close to the optimal tax rate, 50%. This substantial effect also lasts through the 15 periods, and in the last few periods, the tax rates are even getting higher. Around 58.8% of tax choices are optimal tax rates, compared to only 4.6% in the 2-Region Low Sensitivity treatment.

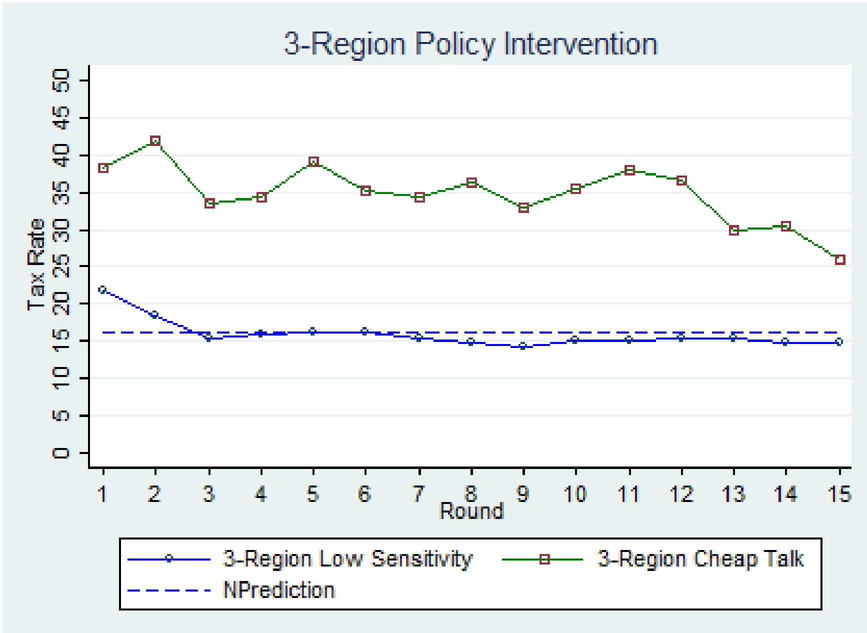
The effect of communication can also be found when the group size is 3. The average tax rate is 34.80%. This rate is substantially higher than the treatment without communication. Compared to the case of group size to be 2, the average tax rate is lower. Fig. 2.8 presents the histograms of tax rates in the 2-Region and 3-Region treatments. There are substantially fewer regions choosing optimal tax rates when group size is 3 (26.3%). This is likely the results of larger group size increasing the difficulty of forming an agreement when there is no punishment.

Figure 2.6: Dynamics of Tax Rates over Periods Comparing Policy Interventions



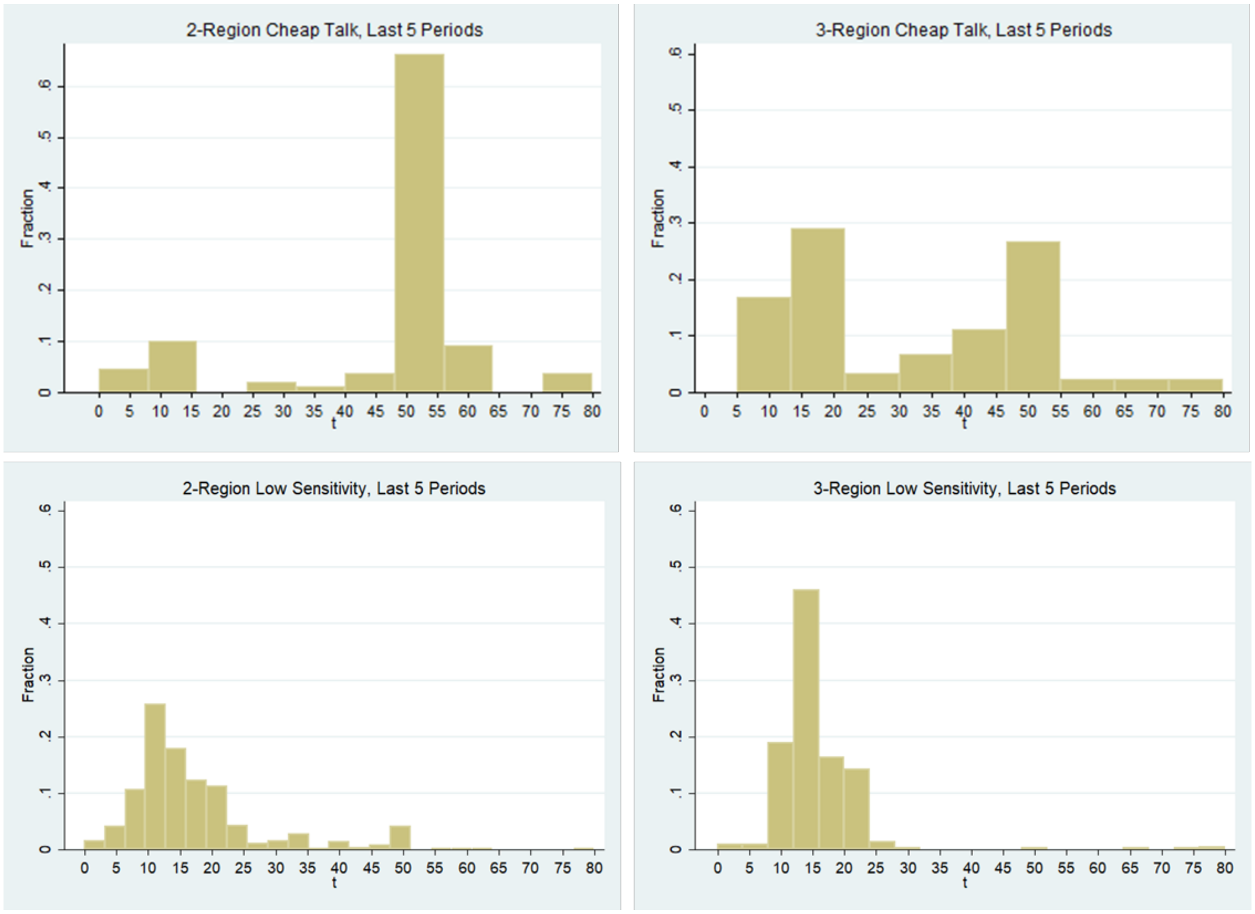
Conclusion 4: Minimum tax constraint increases tax rates mainly through their compulsion to increasing tax rates to the binding minimum tax rates. Communication

Figure 2.7: Dynamics of Tax Rates over Periods Comparing Policy Interventions in 3-Region treatments



significantly increases tax rates and social welfare by promoting cooperative policies and adopting efficient tax rates among competing regions. The cooperation becomes harder to form with more competing regions.

Figure 2.8: Histograms of Tax Choices in the Last Five Periods Comparing Different Policy Interventions



2.6 Discussion and Conclusion

This essay uses a controlled laboratory experiment to study the effect of tax competition. I design several experimental treatments to test the predictions of different tax competition models. The treatments vary across the following dimensions: the number of competing regions, the elasticity of capital movement to the tax rate. I also explore the effects of two policy instruments that could mitigate the potential inefficiency, namely minimum tax rate constraint and communication. Results show that the effect of several factors is not consistent with the model predictions even though regions behave strategically. Particularly, the direct impact of the number of competing regions on tax rates has been overlooked in the tax competition model and literature.

This paper is a first attempt of using an experimental method to test tax competition model predictions. Many features that are present in the tax competition are not considered in the experiment. Other interesting predictions and phenomena in the literature call for further investigations and studies in the future. The competition game and the social dilemma presented in this paper may prove interesting to be further explored in experimental works.

2.7 Appendices

I provide an example of the experiment instruction of 2-Region Low Sensitivity treatment.

Welcome!

You are about to participate in an experiment in decision-making. Please read these instructions carefully, as the money you earn may depend on how well you understand them.

No Talking Allowed

Please DO NOT talk to other participants. If you have any questions after you finish reading the instructions, please raise your hand, the experimenter will approach you and answer your question in private.

Turn Off Personal Electronics

Please take a minute and turn off all of your electronic devices, especially phones.

Anonymity

Your decisions will be completely anonymous to other participants. No participant will be able to link your choices to your identity.

Decision Tasks

The experiment includes 4 parts. Before the beginning of each part, we will explain the decision tasks about that part and the computer screen.

Payment

The currency in this experiment is called tokens. All earnings are denominated in this currency. At the end of the experiment, you will be paid. The tokens you earn in the experiment will be converted into dollars using the exchange rate: **300 Tokens = $1**. One round in every part will be randomly selected at the end of the each part, and your earning in the selected rounds will be paid to you at the end of the experiment.

2.7.1 Practice

Before the experiment, you have 3 practice rounds. These rounds are for *practice* to let you have a better understanding of the experiment. These 3 practice rounds will **NOT** be paid.

At the beginning of each round, you will be given a certain amount of "**productive resources**". Your task for each round is to split the productive resources into two accounts, **Account x and Account y**. Your earning in this round is determined by multiplying resources in Account x by resources in Account y:

Your Earning = Resources in Account x times Resources in Account y

For example, if you have 40 resources in Account x and 80 resources in Account y, then your earning is $40 * 80 = 3200$ Tokens.

To split the resources, you need to choose a "**decision number**" between 0 and 80. Your decision number is the percentage of the productive resources you decide to put into Account x. For example, if your decision number is 40%, you will put 40% of the total resources into Account x, and the rest of the resources (60%) will be automatically allocated to Account y.

Example:

Suppose you are given 120 resources, and you choose 40% as the decision number. This means that you put $48(48 = 120 * 40\%)$ resources into Account x. And the rest of resources $72(72 = 120 - 48)$ are automatically put into Account y. So, your earning is $48 * 72 = 3456$ Tokens.

Calculator

To assist in your decision, a built-in calculator on the computer screen is provided. See the computer screen image below. At the top of the screen, there is a slider with an orange box. By dragging the orange box on the slider to different decision numbers, you can see the amount of resources that are allocated to the two accounts and your earning for a given decision number. The decision number is shown above the slider. Below the slider, on the left, you can find the resources that would be allocated to the two accounts and your earning. Your total amount of resources is shown by the orange text. The green line is all the possible allocations of the resources into the two accounts. When you slide the decision number on the slider, the green box will change accordingly. The width of the green box is the amount of resources in Account x. The height of the green box is the amount of resources in Account y. The size of the box is the earning you will get. For example, the computer interface below is an example for which the total amount of resources is 120. When you drag the orange box to 40 and pick the decision number to be 40, you will allocate 40% (48) resources into Account x. As you can see, the width of the green box is 48. The rest of resources, 72, will be allocated in Account y. The height of the green box is 72. The size the box is 3456 Tokens. Once you made your decision, enter your decision number on the right lower box and press the "Submit your decision" button.

Time Limit

For each round, you have 1 minute (60 seconds) to choose the decision number. If you run out of the time and did not submit decision, your earning will be 0 in this round.

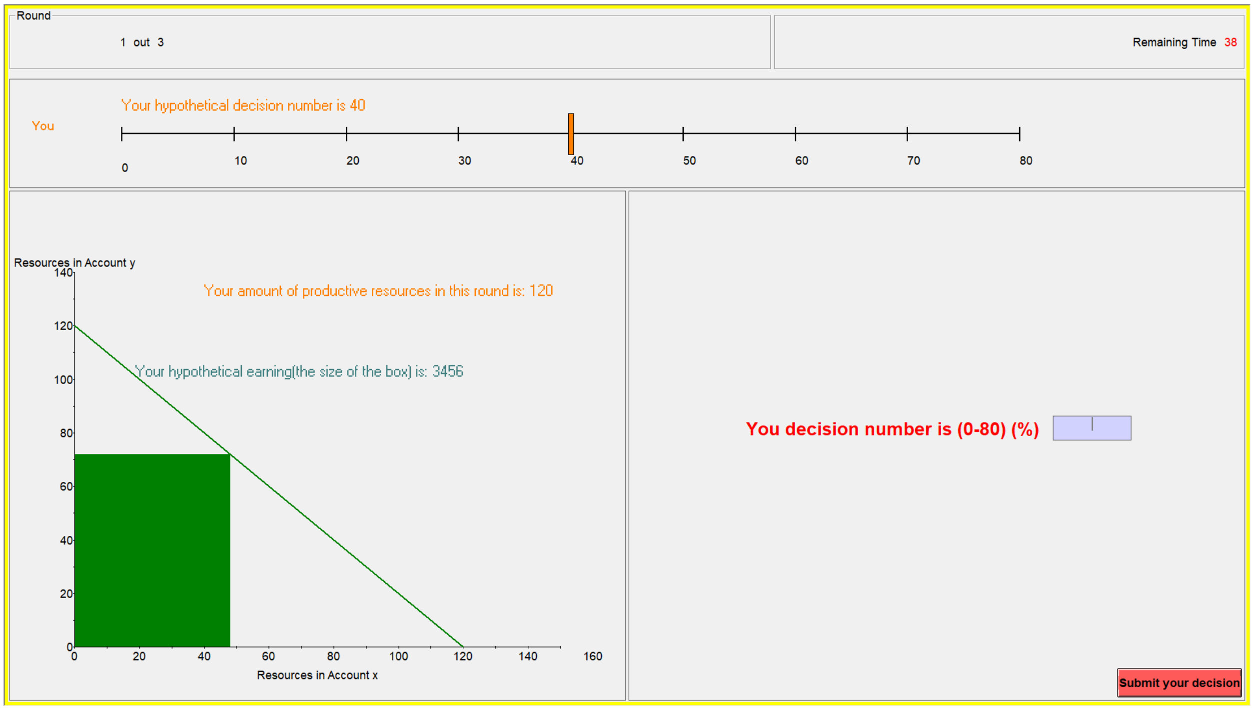
2.7.2 2-Region Low Sensitivity Treatment

This part of the experiment consists of 15 identical rounds. One round will be randomly selected at the end of the experiment, and your earning in this selected round will be paid to you. As in the practice rounds, your task for each round is to choose a decision number to split the productive resources. **The difference is that your amount of productive resources is not fixed. It depends on your decision number and the decision number of the other participant in your group.**

Fixed Matching and Anonymity

At the beginning of this part of this experiment, you will be randomly matched with one other participant in the room to form a group of two. The group remain fixed for all 15

Figure 2.9: Practice Part Computer Screen



rounds in this part. No one will learn the identity of the other participant in your group. Your decisions will be completely anonymous to other participants. No participant will be able to link your choices to your identity.

Amount of productive resources

You originally have 120 productive resources at the beginning of each round. The productive resources are mobile in the group. Both your decision number and the other group member's decision number will affect the final amount of your productive resources. The lower your decision number is, the more resources you are able to attract.

To be more specific, suppose you choose the same decision number as the other group member, then the resources will not be reallocated. Both you and the other group member will have 120 productive resources in the end. For every 1 point **higher** your decision number is than the other group member's, your productive resource will **fall** by 3 from 120. For every 1 point **lower** your decision number is than the other group member's, your productive resource will **increase** by 3 from 120. The following table gives two examples:

Table 2.10: Two Examples

	Your decision number	The other group member's decision number	Decision number difference	Your amount of productive resources	The other's amount of productive resources
Example 1	20%	24%	$24 - 20 = 4$	$120 + 3 * 4 = 132$	$120 - 3 * 4 = 108$
Example 2	30%	20%	$20 - 30 = -10$	$120 + 3 * (-10) = 90$	$120 + 3 * 10 = 150$

Steps for each round:

- At the beginning of each round, you and the other group member **choose decision number simultaneously and privately**.
- Then, your final amount of productive resources will be determined.
- Then, your resources in Account x and Account y will be calculated.
- At the end, your earning (resources in Account x x resources in Account y) will be calculated and shown on the screen. You will also see the other group member's decision number and earning on the screen.

The Calculator

A built-in calculator on the computer screen is provided. At the top of the screen, there are two sliders. You can pick your guess decision number by dragging the orange box on the top slider. You can also pick the other group member's hypothetical decision number by dragging the black box on the second slider. The black text above the slider will show the other group member's decision number you choose. Notice that these decision number you picked are **hypothetical decisions**, and the real decision numbers could be different. You cannot decide other's decision number.

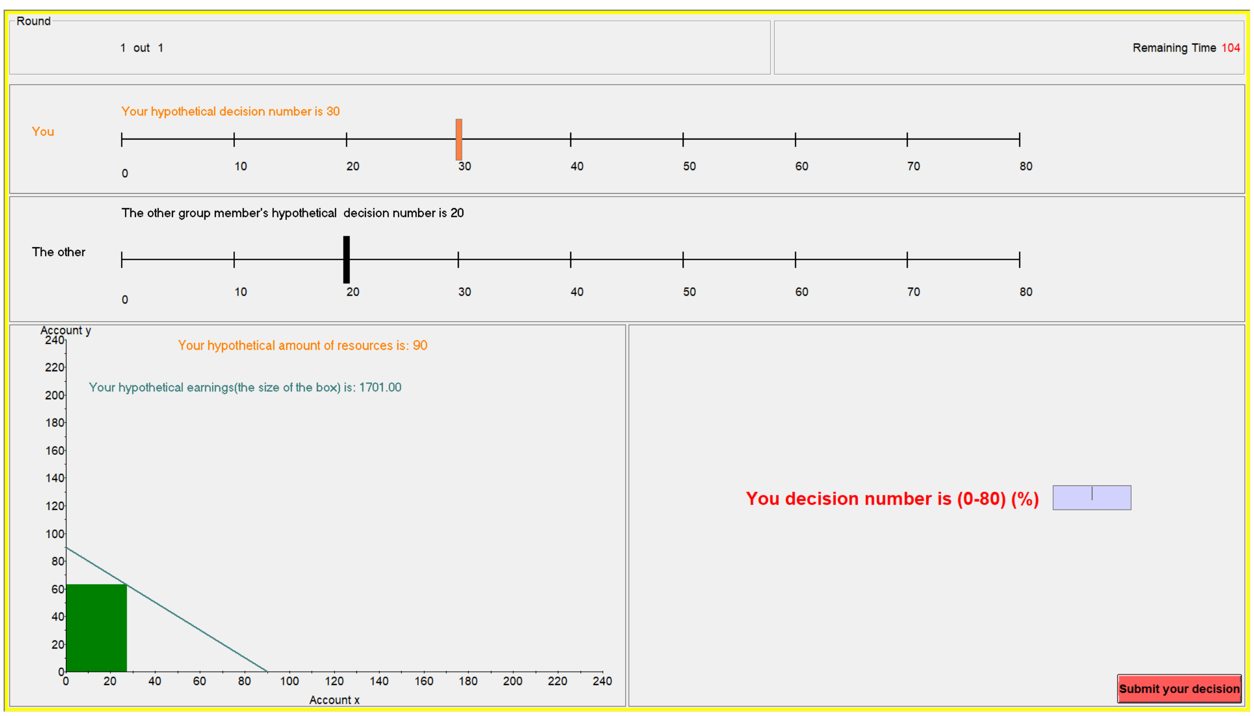
As in the practice rounds, below the slider, the green line shows all the possible allocations of the resources into the two accounts. The green box shows your earning.

For example, the below computer interface shows when you choose the decision number to 30 and the other choose the decision number to be 20. Then your amount of resources is 90. Since your decision number is 30, you allocate 30% of the resources into Account x, which is $90 * 30\% = 27$. The rest of the resources, $90 - 27 = 63$, will be allocated to Account y. So your earning is $27 * 63 = 1701$.

Time Limit

For each round, you have 2 minutes (120 seconds) to choose the decision number. Once you made your decision, enter your decision number on the right lower box and press the "Submit your decision" button.

Figure 2.10: Part 1 Computer Screen



2.7.3 Questionnaire

1. What is your class standing?

- Freshman
- Sophomore
- Junior
- Senior

2. What is your intended or declared major?
3. On a 4-point scale, what is your current GPA?

- Between 3.75 and 4.0 GPA (mostly A's)
- Between 3.25 and 3.74 GPA (about half A's and half B's)
- Between 2.75 and 3.24 GPA (mostly B's)
- Between 2.25 and 2.74 GPA (about half B's and half C's)
- Between 1.75 and 2.24 GPA (mostly C's)
- Other

4. In what year were you born?
5. What is your gender?
6. What is your race?
7. How / would you characterize your religious beliefs? Please check the one / that best represents them.

- Atheism
- Buddhism

- Christianity – Baptist
- Christianity – Catholic
- Christianity - Methodist
- Christianity - Other
- Hinduism
- Islam
- Judaism
- Nonreligious or Agnostic
- Other
- Prefer not to answer

Do you agree with the following statement? (Strongly disagree, disagree, not sure, agree, strongly agree)

- Statement 1. I choose the decision number low so that the number of resources will relatively large.
- Statement 2. I Concentrated more on getting more resources than earning of points.
- Statement 3. I choose the decision number to get more resources than the other group member.
- Statement 4. I choose the decision number to earn more than the other group member.
- Statement 5. I increase decision number to increase the payment to the other group member.

- Statement 6. I choose high decision number because my earning points will not be affected.
- Statement 7. I did not understand well, so I choose randomly.

15. How did you feel about the 120s time limit?

- Too short
- Short
- Appropriate
- Long
- Too long

16. How would you rank your total earnings among all the participants?

- Top 5
- Top 25
- Average
- Bottom 25
- Lowest 5

17. On a scale of 1 to 5, how would you rate your understanding of the INFORMATION presented in the experiment?

18. Were there any problems you ran into during the course of the experiment? If there were problems, please write a brief explanation below.

19. Was there anything that could have been made clearer to help you make tax rate decisions? If something could have been made clearer, please write a brief explanation below

Essay 3

Multi Prizes for Multi Tasks: Externalities and the Optimal Design of Tournaments

3.1 Introduction

In the principal-agent problem, the principal needs to use certain mechanisms to induce the optimal effort levels from the agents. The design of incentive schemes is an important issue to explore. Tournament is such a scheme(Lazear and Rosen, 1981). A tournament involves several agents with each undertaking one task to produce a single product. It awards the participating agents on the basis of the ordinal ranking of their performances. In equilibrium, the effort levels that agent make are optimal. The optimum property with agents performing one task and producing one output can also be preserved when the model is extended to the setting in which agents undertake multiple tasks and produce multiple outputs (see, for example, Holmstrom and Milgrom, 1991; Barlevy and Neal, 2012; Liu and Xu, 2018).

In the tournament settings discussed above, there are no *inter-agent externalities* in which an agent's actions may affect the performances of other competing agents, nor are there effects of one task's performance on other tasks' performances of the same agent. It has been noted that, in many situations, there are various externalities in the performances of competing agents. These externalities can take various forms. For example, agents may engage in sabotage activities to increase the probability of winning by reducing their opponents' measured output (Lazear, 1989), or an agent may help co-workers 'as with on-the-job training of junior by senior employees' (Drago and Garvey, 1998), or due to team externalities, greater efforts by one agent increase another agent's output (Drago and Turnbull, 1988). In multi-task environments, in some cases, an agent's effort on one task may affect the performance of this agent as well as other agents on other tasks. One example is the research management problem (Bardsley,1999). Agents (scientist) allocate effort and resources among multiple tasks (a portfolio of projects), and the principal (the central research manager) uses the allocation of funds as the incentive to achieve policy objectives. Scientists engage in a tournament to get funds. Some projects may have external effects on other projects due to the spillover of scientific knowledge. Political competition and election is another example. Voters, as the principal, elect the 'best' candidate for the office or position. Political candidates are agents and perform multiple tasks to get elected. The externalities across tasks and across candidates may exist, e.g., the introduction of a refinery factory promotes local economic development, but may damage the local environment and the environment of the neighboring districts.

In the literature on tournaments with a single task and a single output, it has been shown that, in the presence of inter-agent externalities, tournaments often fail to achieve their intended goals (see Lazear, 1989, Drago and Turnbull, 1988, for some early contributions, and Chowdhury and Guertler, 2015, and Connelly, Tihanyi, Crook, and Gangloff, 2014 for surveys on the related contributions). On the other hand, there seems no study in the literature that explores tournaments with multi tasks and multi outputs in the presence of inter-agent externalities. This paper tries to fill this gap and studies tournaments in which there are inter-agent externalities.

In our set-up, each agent has two tasks to undertake, and one of the tasks produce inter-agent externalities. It has effect on the performances of the other task of the self agent and the competing agents as well. We examine the problem of designing tournaments to induce the optimal effort levels from the agents, and show that, in the presence of inter-agent externalities, there is no single-prized tournament that can be used to elicit the optimal effort levels. We thus propose the task-specific, multi-prized tournaments, which can accomplish the intended goal in this case. In our design, for each task, agents are ranked according to their performances along this task, and task-specific prizes are awarded to the agents based on their performances on each task. Each agent receive multiple prizes from multiple tasks. Through adjusting the spread of the prizes for different tasks, optimal effort levels from the agent can be induced. The intuition that task-specific multi-prized tournaments can induce optimal effort levels may be explained as follows. In a tournament with multiple tasks, competing agents exert effort to increase the rank of their performances and balance the efforts among different tasks. If a task has spillover effects on the performance of other competing agents, the incentive of tournaments is distorted due to that agents do not internalize such externalities. To increase performance rank, an agent tends to put too much (or too little) efforts on tasks that have negative (or positive) externalities on other agents to reduce their measured output. The task-specific, multi-prized tournaments can resolve this distortion by adjusting the prizes for different tasks. A low (high) winning prize for a task with negative externalities reduces (increases) the agents' efforts and adjust efforts levels to the optimum.

The remainder of the paper is organized as follows. In Section 1, we introduce and set up our model. Section 2 discusses the design of the tournaments and presents our main results. Section 3 contains a few concluding remarks.

3.2 The Model

3.2.1 The setup

In this section, we present our basic model. Consider two competing agents, 1 and 2, in a tournament. The agents choose their efforts for two tasks: a task with externality, to be called e, and a task without externality, to be called t. For each agent $i \in \{1,2\}$, let e_i and t_i be the effort levels i spends on e and on t, respectively. Agent i's ($i \in \{1,2\}$) 'production functions' are assumed to take the following forms:

$$E_i = e_i + \epsilon_i \tag{3.2.1}$$

$$T_i = \alpha t_i + \beta e_i + \beta' e_j + \xi_i \tag{3.2.2}$$

where E_i and T_i, respectively, measure agent i's performance on e and t. $\alpha(>0)$, β and β' are given parameters. ϵ_1, ϵ_2, ξ_1 and ξ_2 are random variables with zero means and are assumed to be independently and identically distributed (i.i.d.).

It may be remarked that, in the above production functions, the parameter β captures the effect incurred by an agent's effort in task e on the performance of the same agent's task t. β' captures the *inter-agent externality* and represents externalities imposed by an agent's effort in task e on the other agent's performance of task t.

For each agent $i \in \{1,2\}$, let $C(e_i, t_i)$ be the cost function when i exerts effort levels e_i and t_i. We assume that the cost function is the same for both agents. The cost function $C(\cdot,\cdot)$ is assumed to be strictly increasing in each of its arguments, strictly convex, $C(0,0) = 0$, $C_{e_i}(0,a) = C_{t_i}(b,0) = 0$ for all $a \geq 0, b \geq 0$, and $\lim_{a\to\infty} C_{e_i}(a,t_i) \to \infty$ for all $t_i > 0$ and $\lim_{b\to\infty} C_{t_i}(e_i,b) \to \infty$ for all $e_i > 0$.

3.2.2 Optimal choices of effort levels

We first consider socially optimal choices of effort levels by the agents. For this purpose, we consider the principal's problem where the principal chooses agents' effort levels to maximize the expected value of a simple sum of outputs net the costs of exerting such efforts:

$$\max_{e_1,e_2,t_1,t_2} E[E_1 + T_1 + E_2 + T_2 - C(e_1,t_1) - C(e_2,t_2)] \tag{3.2.3}$$

Substituting the outputs and taking the expectation, we have

$$\max_{e_1,e_2,t_1,t_2} (1+\beta+\beta')(e_1+e_2)+\alpha(t_1+t_2)-C(e_1,t_1)-C(e_2,t_2) \tag{3.2.4}$$

Let e_1^*, e_2^*, t_1^* and t_2^* be the solutions to the above problem. Then, noting that the objective function of problem (3.2.4) is strictly concave in e_i and t_i, the following first order conditions are both necessary and sufficient for $i = 1, 2$:

$$\begin{aligned} (1+\beta+\beta') - C_{e_i}(e_i^*, t_i^*) &\leq 0 \quad (= 0 \text{ if } e_i^* > 0) \\ \alpha - C_{t_i}(e_i^*, t_i^*) &\leq 0 \quad (= 0 \text{ if } t_i^* > 0) \end{aligned}$$

It may be noted that, if $(1+\beta+\beta') \leq 0$, then $e_1^* = 0 = e_2^*$. That is, the optimal choices of effort levels for task e are 0 for the agents. The intuition is fairly straightforward: when externalities inflicted on task t in performing task e by the agents are destructive and large (so that $\beta+\beta' \leq -1$), it is optimal for the principal to ask the agents to perform just one task, task t, which causes no externalities. In this case, the problem is reduced to the conventional single task problem. In the subsequent discussions, therefore, we consider the case in which $1+\beta+\beta' > 0$.

Proposition 1. *Let $1+\beta+\beta' > 0$. Then, there exists a unique set of effort levels, $(e_1^*, e_2^*, t_1^*, t_2^*)$, to the problem (3.2.4) such that $e_1^* > 0, e_2^* > 0, t_1^* > 0$ and $t_2^* > 0$.*

Proof. Let $1+\beta+\beta' > 0$.

For each $i = 1, 2$, define a function $h(e_i, t_i) = (1+\beta+\beta')e_i + \alpha t_i - C(e_i, t_i)$. Since $C(e_i, t_i)$ is strictly convex, $h(e_i, t_i)$ is strictly concave. Note that $C_{e_i}(0, t_i) = 0$ for all $t_i \geq 0$, $C_{t_i}(e_i, 0) = 0$ for all $e_i \geq 0$, $\lim_{a\to\infty} C_{e_i}(a, t_i) \to \infty$ for all $t_i > 0$ and $\lim_{b\to\infty} C_{e_i}(e_i, b) \to \infty$ for all $e_i > 0$.

Let $U = \{\mathbf{u} \in \mathbb{R}_+^2 : u_1 + u_2 = 1\}$. Any vector (e_i, t_i) can be uniquely expressed as $\lambda\mathbf{u}$ for some $\lambda \geq 0$ and some $\mathbf{u} \in U$. Given our assumptions on $C(e_i, t_i)$, for any given vector

$\mathbf{u} \in U$, it must be the case that $C(\lambda \mathbf{u})$ is increasing and convex in λ, and $\lim_{\lambda \to \infty} C_\lambda(\lambda \mathbf{u}) = \infty$. Since $(1 + \beta + \beta')\lambda e_i + \alpha \lambda t_i$ is concave in λ, for any $\mathbf{u} \in U$, there exists a finite cutoff value, λ_u, of λ such that $h(e_i, t_i)$ evaluated at $(e_i, t_i) = \lambda \mathbf{u}$ will be negative for all $\lambda \geq \lambda_u$. Let $\lambda^* = sup\{\lambda_u : \mathbf{u} \in U\}$. Since U is compact, λ^* is well defined and finite. It follows that the global maximum for $h(e_i, t_i)$ lies in the bounded set $[0, \lambda^*]^2$.

Since the function $h(e_i, t_i)$ is strictly concave, it is also strictly concave over $[0, \lambda^*]^2$, which is the region that contains the global optimum. This ensures that the following first-order conditions are both necessary and sufficient a global maximum:

$$
\begin{aligned}
(1 + \beta + \beta') - C_{e_i}(e_i^*, t_i^*) &\leq 0 (= 0 \text{ if } e_i^* > 0) \\
\alpha - C_{t_i}(e_i^*, t_i^*) &\leq 0 (= 0 \text{ if } t_i^* > 0)
\end{aligned}
$$

The boundary conditions on C and subsequently on h, together with the assumptions that $(1 + \beta + \beta') > 0$ and $\alpha > 0$, ensure the maximum of h being achieved at an interior point so that $e_i^* > 0$ and $t_i^* > 0$. Therefore, there exist $e_i^* > 0, t_i^* > 0$ $(i = 1, 2)$ satisfying the following equations:

$$
\begin{aligned}
(1 + \beta + \beta') - C_{e_i}(e_i^*, t_i^*) &= 0 \\
\alpha - C_{t_i}(e_i^*, t_i^*) &= 0
\end{aligned}
$$

These are necessary and sufficient conditions for the problem (3.2.4). Since h is strictly concave, $e_i^*, t_i^* (i = 1, 2)$ are unique. □

Subsequently, we shall call $(e_1^*, t_1^*, e_2^*, t_2^*)$ that solves the problem (3.2.4) as the 'social optimum'. Since the principal does not observe the agents' choices of effort levels, we shall introduce incentive schemes needed to induce the social optimum in the next section.

3.3 Tournaments

In this section, we discuss the design of tournaments to achieve social optimum characterized in the last section. Two different forms of tournament will be explored: a single-prized tournament and a multi-prized tournament. In a single-prized tournament, there is one tournament for both tasks combined and a single prize will be given to the winner, while in a multi-prized tournament, there is a tournament for each task and a prize will be given to the winner of each tournament.

3.3.1 Single-prized tournament

In this subsection, we discuss single-prized tournaments. A single-prized tournament involves a *bonus*, to be denoted by B, and a base pay, to be denoted by B_0. In our discussion, we do not restrict B to be positive only. The bonus B is given to the agent who has a bigger total output than the other agent where the total output is the simple sum of the agent's performances on the two tasks. We first discuss the design of B by the principal.

We model the two agents as playing a simultaneous move game. Agent i's ($i \in \{1, 2\}$) objective is to solve the following maximization problem given the other agent's choices:

$$\max_{e_i, t_i} \quad B_0 + BPr[E_i + T_i > E_j + T_j] - C(e_i, t_i) \tag{3.3.1}$$

Note that

$$E_i + T_i > E_j + T_j \Leftrightarrow \epsilon_j + \xi_j - \epsilon_i - \xi_i < (1 + \beta - \beta')(e_i - e_j) + \alpha(t_i - t_j)$$

Then, the above optimization problem (3.3.1) can be rewritten as follows:

$$\max_{e_i, t_i} \quad B_0 + BPr[\epsilon_j + \xi_j - \epsilon_i - \xi_i < (1 + \beta - \beta')(e_i - e_j) + \alpha(t_i - t_j)] - C(e_i, t_i) \tag{3.3.2}$$

Let $G(\cdot)$ be the cumulative distribution function (cdf) of the random variable $\epsilon_i + \xi_i - \epsilon_j - \xi_j$. Then the optimization problem for agent i ($i \in \{1, 2\}$ is:

$$\max_{e_i, t_i} \quad B_0 + BG[(1 + \beta - \beta')(e_i - e_j) + \alpha(t_i - t_j)] - C(e_i, t_i) \tag{3.3.3}$$

Let $G(\cdot)$ be differentiable with $G'(\cdot) = g(\cdot)$. Agent i's best responses to the competing agent's efforts can be characterized by the following first order conditions:

$$(1 + \beta - \beta')Bg[(1 + \beta - \beta')(e_i - e_j) + \alpha(t_i - t_j)] - C_{e_i}(e_i, t_i) \leq 0 (= 0 \text{ if } e_i > 0) \tag{3.3.4}$$

$$\alpha Bg[(1 + \beta - \beta')(e_i - e_j) + \alpha(t_i - t_j)] - C_{t_i}(e_i, t_i) \leq 0 (= 0 \text{ if } t_i > 0) \tag{3.3.5}$$

Let $((e_1^s, t_1^s), (e_2^s, t_2^s))$ denote a Nash equilibrium pair of efforts chosen by the two agents.

Proposition 2. *For each B, there exists a symmetric Nash equilibrium pair of efforts which involves both agents choosing the same effort levels: $e_1^s = e_2^s \geq 0, t_1^s = t_2^s \geq 0$.*

Proof. For a given B, a Nash equilibrium, $((e_1^s, t_1^s), (e_2^s, e_2^s))$, is a solution that solves the agents' best responses, (3.3.4), (3.3.5). Being symmetric, the solution is such that $e_1^s = e_2^s, t_1^s = t_2^s$ and satisfies

$$(1 + \beta - \beta')Bg(0) - C_{e_1}(e_1, t_1) \leq 0 (= 0 \text{ if } e_1 > 0) \tag{3.3.6}$$

$$\alpha Bg(0) - C_{t_1}(e_1, t_1) \leq 0 (= 0 \text{ if } t_1 > 0) \tag{3.3.7}$$

When $B = 0$, from the above, $e_1^s = e_2^s = 0$ and $t_1^s = t_2^s = 0$ solve the problem.

When $B < 0$, from equation (3.3.7), we have $t_1^s = 0$. If $(1 + \beta - \beta') \geq 0$, then ($e_1^s = 0, t_1^s = 0$) satisfies (3.3.6) and (3.3.7). When $1 + \beta - \beta' < 0$, (3.3.6) becomes

$$(1 + \beta + \beta')Bg(0) - C_{e_1}(e_1, 0) = 0$$

Note that $(1 + \beta + \beta')Bg(0) > 0$. Given the boundary conditions of $C(e_1, t_2)$, there is $e_1^s > 0$ satisfying the above condition. Hence, in this case, there exists a pair $(e_1^s > 0, t_1^s = 0)$ satisfying (3.3.6) and (3.3.7).

Consider $B > 0$. Suppose first $1 + \beta - \beta' > 0$. Then, following a similar proof strategy to that of Proposition 1, we can show that there exist $e_1^s > 0$, $t_1^s > 0$ satisfying (3.3.6) and (3.3.7). If $1 + \beta - \beta' \leq 0$, then, from (3.3.6), $e_1^s = 0$. Given the conditions on $C(e_1, t_1)$, from (3.3.7), there exists $t_1^s \geq 0$ that satisfies (3.3.7). □

Proposition 2 informs us the existence of a symmetric Nash equilibrium. As we have seen in the process of proving Proposition 2, the question whether a single-prized tournament will be able to elicit optimal efforts from the agents lingers, and the answer to this question may depend on the parameters β and β'. In the rest of this subsection, we discuss whether a single-prized tournament can accomplish its intended goal of eliciting optimal efforts from the agents.

Proposition 3. *Let $1 + \beta + \beta' > 0$. If $\beta' = 0$, then there exists a $B > 0$ such that the symmetric Nash equilibrium of the single-prized tournament is the social optimum, e.g., $(e_i^s, t_i^s) = (e_i^*, t_i^*)$ for $i = 1, 2$.*

Proof. When $\beta' = 0$, $1 + \beta + \beta' = 1 + \beta > 0$. The first order conditions (3.3.6) and (3.3.7) for an interior symmetric Nash equilibrium become: for each $i = 1, 2$,

$$\begin{aligned} (1+\beta)Bg[0] - C_{e_i}(e_i^s, t_i^s) &= 0 \\ \alpha Bg[0] - C_{t_i}(e_i^s, t_i^s) &= 0 \end{aligned}$$

On the other hand, the social optimum, $(e_i^*, t_i^*)(i = 1, 2)$, is characterized by the following:

$$\begin{aligned} (1+\beta) - C_{e_i}(e_i^*, t_i^*) &= 0 \\ \alpha - C_{t_i}(e_i^*, t_i^*) &= 0 \end{aligned}$$

By setting $B = 1/g[0]$ and from the proof of Proposition 1 that the social optimum is unique, we must have $(e_i^s, t_i^s) = (e_i^*, t_i^*)$ for $i = 1, 2$. □

Proposition 3 stats that, if there is no cross-agent externality, a single-prized tournament can achieve the social optimum. The optimum is obtained by the agents' internalization of the cross-task externalies. However, when there are cross-agent externalities, a single-prized tournament fails to induce social optimal efforts, as shown by the following proposition.

Proposition 4. *Let $1 + \beta + \beta' > 0$. If $\beta' \neq 0$, then there exists no B such that the symmetric Nash equilibrium of the single-prized tournament is the social optimum.*

Proof. Let $(1 + \beta + \beta') > 0$ and $\beta' \neq 0$. We note that if there was a B such that $(e_i^s, t_i^s) = (e_i^*, t_i^*)$ for $i = 1, 2$. Then, we would have

$$\begin{aligned} (1+\beta-\beta')Bg[0] - C_{e_i}(e_i^s, t_i^s) = 0 \\ \alpha Bg[0] - C_{t_i}(e_i^s, t_i^s) = 0 \end{aligned}$$

and

$$\begin{aligned} (1+\beta+\beta') - C_{e_i}(e_i^*, t_i^*) &= 0 \\ \alpha - C_{t_i}(e_i^*, t_i^*) &= 0 \end{aligned}$$

From the above, we would then obtain

$$(1+\beta+\beta') = C_{e_i}(e_i^*, t_i^*) = C_{e_i}(e_i^s, t_i^s) = (1+\beta-\beta')Bg[0] \tag{3.3.8}$$

$$\alpha = C_{t_i}(e_i^*, t_i^*) = C_{t_i}(e_i^s, t_i^s) = \alpha Bg[0] \tag{3.3.9}$$

(3.3.8) would imply

$$1+\beta+\beta' = (1+\beta-\beta')Bg[0]. \tag{3.3.10}$$

and (3.3.9) would imply

$$1 = Bg[0] \tag{3.3.11}$$

(3.3.10) and (3.3.11) would be in contradiction with $\beta' \neq 0$. Therefore, there is no B such that $(e_i^s, t_i^s) = (e_i^*, t_i^*)$ for $i = 1, 2$ □

When there are externalities across competing agents, i.e., when $\beta' \neq 0$, a single-prized tournament cannot achieve the social optimum. To understand the intuition behind this result, we note that, in a single-prized tournament, the winning agent is the one who produces the greatest 'total output', the total output being the simple sum of the performances of the two tasks. In the production functions of the agent, the task t has no externalities while the task e creates externalities on the agent's performance in task t and the competing agent's task t as well. The social optimum is obtained by internalizing these externalities. However, when the agents are engaged in a single tournament, though the agent can internalize externalities across tasks, the externalities across the agents are ignored in calculating Nash equilibrium choices of efforts. As a consequence, the externalities across the agents cannot be internalized, and consequently, a single-prized tournament cannot achieve the social optimum.

3.3.2 Multi-prized tournament

As shown in Section 3.1, there is a difficulty in using a single-prized tournament to achieve the social optimum in the presence of cross-agent externalities (i.e., when $\beta' \neq 0$). In this Section, we introduce and consider an alternative tournament scheme, a multi-prized tournament, and examine whether it can be used by the principal to achieve the social optimum.

A multi-prized tournament consists of two separate 'tournaments', to be called an e-tournament and a t-tournament, for the two agents to compete for. An e-tournament is for the performance of task e and a t-tournament is designed for the performance of task t. The winner of each tournament is determined by the relative performance of each task. Let B_e and B_t, respectively, be the prizes for the e-tournament and t-tournament. Again, let B_0 be the base payment to the agent.[1]

The two agents play a simultaneous-move game in which they each choose a pair of efforts (e_i, t_i) $(i = 1, 2)$ to maximize the expected payoffs. Specifically, each agent i $(i = 1, 2)$ solves the following problem:

$$\max_{e_i, t_i} \quad B_0 + B_e Pr[E_i > E_j] + B_t Pr[T_i > T_j] - C(e_i, t_i) \tag{3.3.12}$$

Let $((e_1^m, t_1^m), (e_2^m, t_2^m))$ denote a Nash equilibrium pair of choices of efforts by the two agents when they play the game in this Section. Then, we obtain the following results summarized in Propositions 5 and 6.

Proposition 5. *For suitably chosen B_e and B_t, there exists a unique symmetric Nash equilibrium pair of choices of efforts which involves both agent choosing the same effort levels $e_1^m = e_2^m > 0, t_1^m = t_2^m > 0$.*

[1] In this paper, we focus on the design of B_e and B_t. The choice of B_0 is done by considering the participation constraints of the agents once B_e and B_t are determined.

Proof. Note that

$$E_i > E_j \Leftrightarrow \epsilon_j - \epsilon_i < e_i - e_j$$

and

$$T_i > T_j \Leftrightarrow \xi_j - \xi_i < \alpha(t_i - t_j) + (\beta - \beta')(e_i - e_j)$$

So, the above problem (3.3.12) can be rewritten as follows:

$$\max_{e_i,t_i} \quad B_e Pr[\epsilon_j - \epsilon_i - < e_i - e_j] + B_t Pr[\xi_j - \xi_i < \alpha(t_i - t_j) + (\beta - \beta')(e_i - e_j)] - C(e_i, t_i)$$

Let $H_E(\cdot)$ be the cdf of the random variable $\epsilon_j - \epsilon_i$ and $H_T(\cdot)$ be the cdf of the random variable $\xi_j - \xi_i$. Then, the above can be rewritten as the following:

$$\max_{e_i,t_i} \quad B_e H_E[e_i - e_j] + B_t H_T[\alpha(t_i - t_j) + (\beta - \beta')(e_i - e_j)] - C(e_i, t_i)$$

Let $H'_E(\cdot) = h_E(\cdot)$ and $H'_T(\cdot) = h_T(\cdot)$. Considering symmetric equilibrium choices of effort levels, we obtain the following

$$B_e h_E[0] + (\beta - \beta')B_t h_T[0] - \frac{\partial C(e_i, t_i)}{\partial e_i} \quad \leq \quad 0 (= 0 \text{ if } e_i > 0) \tag{3.3.13}$$

$$\alpha B_t h_T[0] - \frac{\partial C(e_i, t_i)}{\partial t_i} \quad \leq \quad 0 (= 0 \text{ if } t_i > 0) \tag{3.3.14}$$

Following a similar proof strategy to that of Proposition 2, it can be shown that, if B_e and B_T are chosen such that $B_e h_E[0] + (\beta - \beta')B_t h_T[0] > 0$, then there are
$e_1^m = e_2^m > 0, t_1^m = t_2^m > 0$ such that

$$B_e h_E[0] + (\beta - \beta')B_t h_T[0] = \frac{\partial C(e_i^m, t_i^m)}{\partial e_i} \tag{3.3.15}$$

$$\alpha B_t h_T[0] = \frac{\partial C(e_i^m, t_i^m)}{\partial t_i} \tag{3.3.16}$$

It may be noted (as in the proof of Proposition 2) that the solution to the system of equations, (3.3.15) and (3.3.16), is unique. □

Proposition 6. *There exist B_e and B_t such that $(e_i^m, t_i^m) = (e_i^*, e_i^*)$ for $i = 1, 2$.*

Proof. From proposition 5, there are $e_1^m = e_2^m > 0, t_1^m = t_2^m > 0$ satisfying (3.3.15) and (3.3.16). On the other hand, we have

$$(1 + \beta + \beta') = C_{e_i}(e_i^*, t_i^*)$$
$$\alpha = C_{t_i}(e_i^*, t_i^*)$$

If we set $B_e h_E[0] = 1 + 2\beta'$ and $B_t h_T[0] = 1$, then,
$B_e h_E[0] + (\beta - \beta')B_t h_T[0] = 1 + 2\beta' + (\beta - \beta') = 1 + \beta + \beta' > 0$, and consequently, $(e_i^m, t_i^m) = (e_i^*, e_i^*)$ for $i = 1, 2$. □

Therefore, a multi-prized tournament can be used by the principal to induce the optimal effort levels from the agents. From the proof of Proposition 3.3.17, the choices of task-specific 'prizes' are:

$$B_t = \frac{1}{h_T(0)} \quad \text{for the T task,}$$

$$B_e = \frac{1+2\beta'}{h_E(0)} \quad \text{for the E task}$$

It may be noted that $B_t > 0$, while B_e can be positive, or negative, or zero depending on the parameter β' of the cross-agent externalities:

$$\beta' \geq -1/2 \text{ if and only if } B_e \geq 0.$$

Note that the sign and size of B_e depend on β', the parameter capturing the cross-agent externalities. This can be intuitively understood as a way that the principal internalizes such externalities. In particular, if such externalities are negative and significant, then, in the design of B_e, the principal uses a task-specific negative prize to curb such detrimental activities to achieve optimality. The flexibility of choosing both prizes, B_t and B_e, enables the principal to internalize cross-agent externalities. This is in sharp contrast to a single-prized tournament where the principal does not have this kind of flexibility, and, as a consequence, when $\beta' \neq 0$, a single-prized tournament cannot induce the optimal effort levels from the agents.

3.4 Conclusion

In this paper, we consider the problem of designing tournaments to induce the optimal effort levels from competing agents. Agents perform multiple tasks and produce multiple outputs, and there are inter-agent externalities. We have shown that, in such environments, a single-prized tournament fails to induce the optimal effort levels from the agents, while task-specific multi-prized tournaments can be used to induce the agents to choose the optimal levels of effort.

An implication of our analysis and results is that when agents perform multiple tasks and produce multiple outputs, and when there are inter-agent externalities, the principal should not use a single-prized tournament for the purpose of inducing the optimal levels of efforts from the agents. Single-prized tournament 'bundles' the tasks and outputs together, and such a tournament will not work in general. Instead, the principal should use task-specific multi-prized tournaments that are tailored for each task. The main reason that this tournament design works in these contexts is that the principal has extra degrees of freedom to adjust the sizes of the prizes needed for delegating the right incentives to the agents.

Our study is theoretical. As we have already noted in the Introduction, there are several occasions where the contexts similar to those modeled in this paper arise. It would be interesting to see how our model and theoretical results fare in such occasions.

References

Abbink, Klaus, Jordi Brandts, Benedikt Herrmann, and Karina Whitehead. 2007. "Inter-Group Conflict and Intra-Group Punishment in an Experimental Contest Game about the Centre or contact." *Experimental Economics*, 100: 420–447.

Albrizio, Silvia, Tomasz Kozluk, and Vera Zipperer. 2017. "Environmental policies and productivity growth: Evidence across industries and firms." *Journal of Environmental Economics and Management*, 81: 209–226.

Andreoni, James. 1989. "Giving with Impure Altruism : Applications to Charity and Ricardian Equivalence." *Journal of Political Economy*, 97(6): 1447–1458.

Andreoni, James. 1990. "Impure Altruism and Donations to Public Goods: A Theory of Warm-Glow Giving." *The Economic Journal*, 100(401): 464.

Anselin, Luc. 1988. *Spatial econometrics : methods and models.* Kluwer Academic Publishers.

Balafoutas, Loukas, Rudolf Kerschbamer, and Matthias Sutter. 2012. "Distributional Preferences and Competitive Behavior." *Journal of Economic Behavior and Organization*, 83(1): 125–135.

Bardsley, Peter. 1999. "The Optimal Management of Research Portfolios." *Australian Journal of Agricultural and Resource Economics*, 43(3): 323–335.

Barlevy, Gadi, and Derek Neal. 2012. "Pay for Percentile." *American Economic Review*, 102(5): 1805–1831.

Bartling, Björn, Ernst Fehr, Michel André Maréchal, and Daniel Schunk. 2009. "Egalitarianism and Competitiveness." *American Economic Review*, 99(2): 93–98.

Beck, T., George Clarke, Alberto Groff, Philip Keefer, and Patrick Walsh. 2001. "New Tools in Comparative Political Economy: The Database of Political Institutions." *The World Bank Economic Review*, 15(1): 165–176.

Besley, Timothy, and Anne Case. 1995. "Incumbent Behavior: Vote-Seeking, Tax-Setting, and Yardstick Competition." *The American Economic Review*, 85(1): 25–45.

Boadway, Robin, and Jean-François Tremblay. 2012. "Reassessment of the Tiebout model." *Journal of Public Economics*, 96(11–12): 1063–1078.

Boockmann, Bernhard, and Axel Dreher. 2003. “The contribution of the IMF and the World Bank to economic freedom.” *European Journal of Political Economy*, 19(3): 633–649.

Botta, Enrico, and Tomasz Kozluk. 2014. “Measuring Environmental Policy Stringency in OECD Countries: A Composite Index Approach.”

Brueckner, Jan K. 2003. “Strategic Interaction Among Governments: An Overview of Empirical Studies.” *International Regional Science Review*, 26(2): 175–188.

Brunel, Claire, and Arik Levinson. 2013. “Measuring Environmental Regulatory Stringency.” *OECD Trade and Environment Working Papers 2013/05*, 42.

Carruthers, Bruce G, and Naomi R Lamoreaux. 2016. “Regulatory Races: The Effects of Jurisdictional Competition on Regulatory Standards.” *Journal of Economic Literature*, 54(1): 52–97.

Case, Anne C, S Rosen, and James R Hines. 1993. “Budget Spillovers Interdependence: Evidence and Fiscal Policy from the States.” *Journal of Public Economics*, 52: 285–307.

Cerny, G P. 1994. “The Dynamics of Financial Globalization: Technology, Market Structure and Policy Response.” *Policy Sciences*, 27(4): 319–342.

Chinn, Menzie D., and Hiro Ito. 2006. “What matters for financial development? Capital controls, institutions, and interactions.” *Journal of Development Economics*, 81(1): 163–192.

Chowdhury, Subhasish M., and Oliver Gürtler. 2015. “Sabotage in Contests: a Survey.” *Public Choice*, 164(1-2): 135–155.

Cole, Matthew A., and Per G. Fredriksson. 2009. “Institutionalized pollution havens.” *Ecological Economics*, 68(4): 1239–1256.

Cole, Matthew A., Robert J R Elliott, and Per G. Fredriksson. 2006. “Endogenous pollution havens: Does FDI influence environmental regulations?” *Scandinavian Journal of Economics*, 108(1): 157–178.

Connelly, Brian L., Laszlo Tihanyi, T. Russell Crook, and K. Ashley Gangloff. 2014. “Tournament Theory: Thirty Years of Contests and Competitions.” *Journal of Management*, 40(1): 16–47.

Cox, James C., Daniel Friedman, and Vjollca Sadiraj. 2008. “Revealed Altruism.” *Econometrica*, 76(1): 31–69.

Dahlberg, Matz, and Karin Edmark. 2008. “Is there a ”race-to-the-bottom” in the setting of welfare benefit levels? Evidence from a policy intervention.” *Journal of Public Economics*, 92(5-6): 1193–1209.

Davies, Ronald B., and Helen T. Naughton. 2013. "Cooperation in environmental policy: a spatial approach." *International Tax and Public Finance*, 21(5): 923–954.

Davies, Ronald B., and Krishna Chaitanya Vadlamannati. 2013. "A race to the bottom in labor standards? An empirical investigation." *Journal of Development Economics*, 103(1): 1–14.

Devereux, Michael P., Ben Lockwood, and Michela Redoano. 2008. "Do countries compete over corporate tax rates?" *Journal of Public Economics*, 92(5-6): 1210–1235.

Drago, Robert, and Geoffrey K. Turnbull. 1988. "The Incentive Effects of Tournaments with Positive Externalities among Workers." *Southern Economic Journal*, 55(1): 100.

Drago, Robert, and Gerald T. Garvey. 1998. "Incentives for Helping on the Job: Theory and Evidence." *Journal of Labor Economics*, 16(1): 1–25.

Drezner, Daniel W. 2001. "Globalization and Policy Convergence." *International Studies Review*, 3(1): 53–78.

Dufwenberg, Martin, and Georg Kirchsteiger. 2004. "A Theory of Sequential Reciprocity." *Games and Economic Behavior*, 47(2): 268–298.

Eliassen, Anton, and Jørgen Saltbones. 1983. "Modelling of long-range transport of sulphur over Europe: A two-year model run and some model experiments." *Atmospheric Environment (1967)*, 17(8): 1457–1473.

Fisman, Raymond, Pamela Jakiela, and Shachar Kariv. 2017. "Distributional Preferences and Political Behavior." *Journal of Public Economics*, 155: 1–10.

Fisman, Raymond, Shachar Kariv, and Daniel Markovits. 2007. "Individual Preferences for Giving." *American Economic Review*, 97(5): 1858–1876.

Fredriksson, Per G., and Daniel L. Millimet. 2002. "Strategic Interaction and the Determination of Environmental Policy across U.S. States." *Journal of Urban Economics*, 51(1): 101–122.

Fredriksson, Per G., John A. List, and Daniel L. Millimet. 2004. "Chasing the smokestack: Strategic policymaking with multiple instruments." *Regional Science and Urban Economics*, 34(4): 387–410.

Genschel, Philipp, and Peter Schwarz. 2011. "Tax competition: A literature review." *Socio-Economic Review*, 9(2): 339–370.

Hahn, Jinyong, Jerry Hausman, and Guido Kuersteiner. 2004. "Estimation with weak instruments: Accuracy of higher-order bias and MSE approximations." *The Econometrics Journal*, 7(1): 272–306.

Hansen, L. 1982. "Large sample properties of generalized method of moments estimators." *Econometrica*, 50(4): 1029–1054.

Hansen, Lars Peter, John Heaton, and Amir Yaron. 1996. "Finite-Sample Properties of Some Alternative GMM Estimators." *Journal of Business & Economic Statistics*, 14(3): 262–280.

Henisz, W. J. 2000. "The Institutional Environment for Economic Growth." *Economics and Politics*, 12(1): 1–31.

Holmstrom, Bengt, and Paul Milgrom. 1991. "Multitask Principal-Agent Analyses: Incentive Contracts, Asset Ownership, and Job Design." *Journal of Law Economics, & Organization*, 745(18): 24–52.

Holt, Charles A, and Susan K Laury. 2002. "Risk Aversion and Incentive Effects." *American Economic Review*, 92(5): 1644–1655.

Holzinger, Katharina, and Thomas Sommerer. 2011. "'Race to the Bottom' or 'Race to Brussels'? Environmental Competition in Europe." *Journal of Common Market Studies*, 49(2): 315–339.

Keen, Michael, and Kai a. Konrad. 2013. *The Theory of International Tax Competition and Coordination.* Vol. 5, Elsevier B.V.

Kellenberg, Derek K. 2009. "An empirical investigation of the pollution haven effect with strategic environment and trade policy." *Journal of International Economics*, 78(2): 242–255.

Kennedy, Peter W. 1994. "Eqiulibrium pollution taxes in open economies with imperfect competition." *Journal of Environmental Economics and Management*, 27: 49–63.

Kirkpatrick, Colin, and Kenichi Shimamoto. 2008. "The effect of environmental regulation on the locational choice of Japanese foreign direct investment." *Applied Economics*, 40(11): 1399–1409.

Kleibergen, Frank, and Richard Paap. 2006. "Generalized reduced rank tests using the singular value decomposition." *Journal of Econometrics*, 133(1): 97–126.

Konrad, Kai A. 2007. "Strategy in Contests: An Introduction."

Konrad, Kai Andreas. 2009. *Strategy and Dynamics in Contests.* Oxford University Press.

Lazear, Edward P. 1989. "Pay Equality and Industrial Politics." *Journal of Political Economy*, 97(3): 561–580.

Lazear, Edward P., and Sherwin Rosen. 1981. "Rank-Order Tournaments as Optimum Labor Contracts." *Journal of Political Economy*, 89(5): 841–864.

Levinson, Arik. 2003. "Environmental Regulatory Competition: A Status Report and Some New Evidence." *National Tax Journal*, 56(1): 91–106.

Liu, Yongzheng, and Yongsheng Xu. 2018. "Rawlsian vs. Utilitarian : Teachers' Incentives and the Distribution of Student Performance." *Journal of Institutional and Theoretical Economics*, 174(3), 548-569.

Markusen, James R., Edward R. Morey, and Nancy Olewiler. 1995. "Competition in regional environmental policies when plant locations are endogenous." *Journal of Public Economics*, 56(1): 55–77.

Millimet, Daniel L. 2014. "Environmental federalism: a survey of the empirical literature." *Case Western Reserve Law Review*, 64(4): 1669–1758.

Millner, Edward L., and Michael D. Pratt. 1989. "An Experimental Investigation of Efficient Rent-Seeking." *Public Choice*, 62(2): 139–151.

Millner, Edward L., and Michael D. Pratt. 1991. "Risk Aversion and Rent-Seeking: An Extension and some Experimental Evidence." *Public Choice*, 69(1): 81–92.

Mulatu, Abay, Reyer Gerlagh, Dan Rigby, and Ada Wossink. 2010. "Environmental regulation and industry location in Europe." *Environmental and Resource Economics*, 45(4): 459–479.

Murdoch, James C, Morteza Rahmatian, and Mark A Thayer. 1993. "A Spatially Autoregressive Median Voter Model of Recreation Expenditures." *Public Finance Quarterly*, 21(3): 334–350.

Murdoch, James C, Todd Sandler, and Keith Sargent. 1997. "A tale of two collectives: Sulphur versus nitrogen oxides emission reduction in Europe." *Economica*, 64(254): 281.

Murdoch, James C., Todd Sandler, and Wim P M Vijverberg. 2003. "The participation decision versus the level of participation in an environmental treaty: A spatial probit analysis." *Journal of Public Economics*, 87(2): 337–362.

Murphy, Dale D. 2006. *The Structure of Regulatory Competition: Corporations and Public Policies in a Global Economy.* Oxford University Press.

Oates, Wallace E. 1972. *Fiscal Federalism.* New York:Harcourt Brace Jovanovich.

Oates, Wallace E., and Robert M. Schwab. 1988. "Economic competition among jurisdictions: efficiency enhancing or distortion inducing?" *Journal of Public Economics*, 35(3): 333–354.

Olney, William W. 2013. "A race to the bottom? Employment protection and foreign direct investment." *Journal of International Economics*, 91(2): 191–203.

Price, Curtis R., and Roman M. Sheremeta. 2011. "Endowment Effects in Contests." *Economics Letters*, 111(3): 217–219.

Sheremeta, Roman M. 2010. "Experimental Comparison of Multi-Stage and One-Stage Contests." *Games and Economic Behavior*, 68(2): 731–747.

Sigman, Hilary. 2002. “International spillovers and water quality in rivers: Do countries free ride?” *American Economic Review*, 92(4): 1152–1159.

Tullock, Gordon. 1967. “The Welfare Costs of Tariffs, Monopolies, and Theft.” *Economic Inquiry*, 5(3): 224–232.

Tullock, Gordon. 1980. *Toward a Theory of the Rent-Seeking Society.* Texas A & M University.

Wildasin, David E. 1988. “Nash Equilibria in Models of Fiscal Competition.” *Journal of Public Economics*, 35(2): 229–240.

Wilson, John D., and David E. Wildasin. 2004. “Capital Tax Competition: Bane or Boon.” *Journal of Public Economics*, 88(6): 1065–1091.

Wilson, John Douglas. 1986. “A Theory of Interregional Tax Competition.” *Journal of Urban Economics*, 19: 296–315.

Wilson, John Douglas. 1991. “Tax Competition with Interregional Differences in Factor Endowments.” *Regional Science and Urban Economics*, 21(3): 423–451.

Wilson, John Douglas. 1999. “Theories of Tax Competition.” *National Tax Journal*, 52(2): 269–304.

Zodrow, George R., and Peter Mieszkowski. 1986. “Pigou, Tiebout, Property Taxation, and the Underprovision of Local Public goods.” *Journal of Urban Economics*, 19(3): 356–370.

Vita

Susan Xu Tang was born in Shandong in the People's Republic of China. She studied at the Central University of Finance and Economics, where she received a BA in Economics in July, 2013. Susan began pursuing a PhD in Economics in August, 2013. Her primary research interests are in public economics, environmental economics and behavioral economics.

During her graduate studies in the Andrew Young School of Policy Studies, Susan worked as a Graduate Research Assistant for Dr. Yongsheng Xu, Dr. Daniel Kreisman, and Dr. John Gibson. She was also an instructor for Principles of Microeconomics at GSU. Susan received several awards and grants throughout her graduate studies at Georgia State University including the E.D. (Jack) Dunn Fellowship, the GSU Dissertation Grant, and Andrew Young School Dissertation Fellowship.

Susan was awarded his Ph.D. in Economics in August, 2018. She has accepted a Lecturer position at Bloomsburg University of Pennsylvania.