Tax Competition and Social Dilemma: A Laboratory Experiment

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Abstract

In this essay, I use 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.

Keywords: Tax Competition; Laboratory Experiment; Group Size; Sensitivity
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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 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

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

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

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.

2.1 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

[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.

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

$$U_i(c_i, g_i) = c_i * g_i = (\beta k_i - t_i k_i) * t_i k_i \tag{2.1}$$

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:

$$k_1 = k^* + \frac{1}{4\alpha} * (t_2 - t_1) \tag{2.2}$$

[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, $c_i = \beta k_i - t_i k_i$.

The equation 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:

$$\frac{\partial k_i}{/}\partial t_i = \frac{-1}{4\alpha} \quad i = 1, 2 \tag{2.3}$$

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:

$$\frac{\frac{\partial U_i(c_i,g_i)}{\partial c_i}}{\frac{\partial U_i(c_i,g_i)}{\partial g_i}} = \frac{k_i - t_i\frac{1}{4\alpha}}{\phi} \tag{2.4}$$

Solving the above equation 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.

$$\frac{\partial(\frac{k_i - t_i \frac{1}{4\alpha}}{\phi})}{\partial \frac{1}{4\alpha}} = \frac{-t_i}{\phi} - \frac{(k_i - t_i \frac{1}{4\alpha}) * (\beta - t_i)}{\phi^2} \tag{2.5}$$

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 2.5 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.

2.3 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:

$$\frac{\partial k_1}{\partial t_1} = (\frac{\partial f'(k_1)}{\partial k_1})^{-1} * \frac{n-1}{n} \tag{2.6}$$

$$\frac{\partial k_1}{\partial t_2} = (\frac{\partial f'(k_2)}{\partial k_2})^{-1} * \frac{1}{n} \tag{2.7}$$

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).

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.

3.1 Treatments

3.1.1 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:

$$\begin{gathered} t_1 = \frac{t_2}{4} - \frac{\sqrt{100t_2^2 - 20t_2 + 201}}{40} - \frac{19}{40} \quad if t_2 < 0.6596 \\ t_1 = t_2 - 0.4 \quad if t_2 >= 0.6596 \end{gathered} \tag{3.1}$$

The response function is shown in Fig. 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. The intersection, and thus the Nash equilibrium tax rate, is 16.15

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

Figure 1: Response Functions

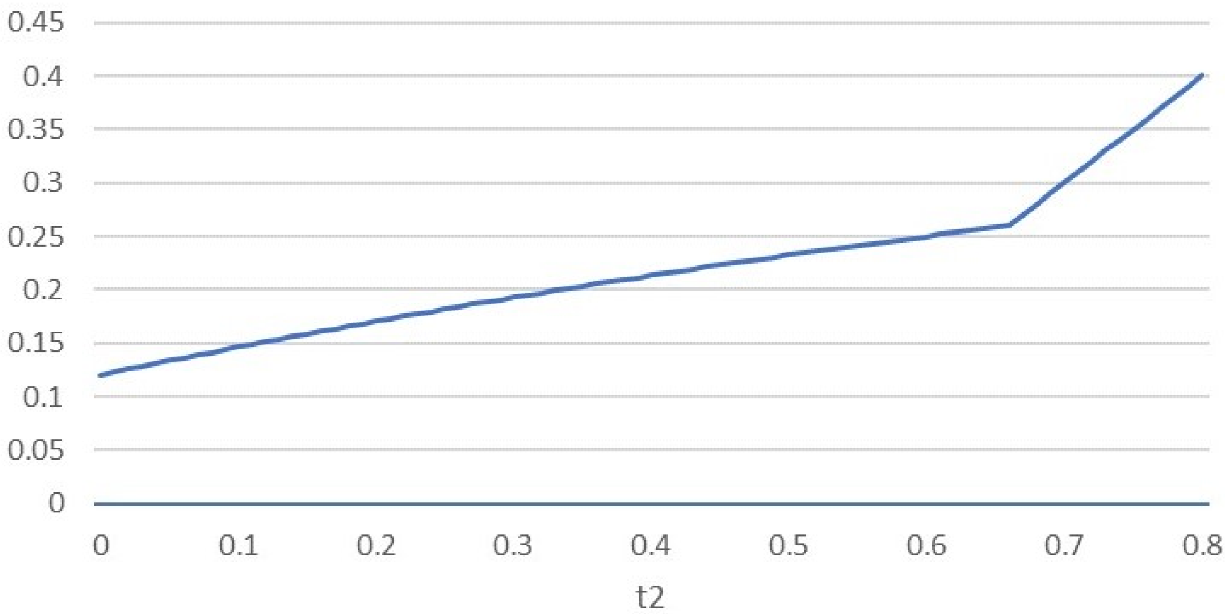
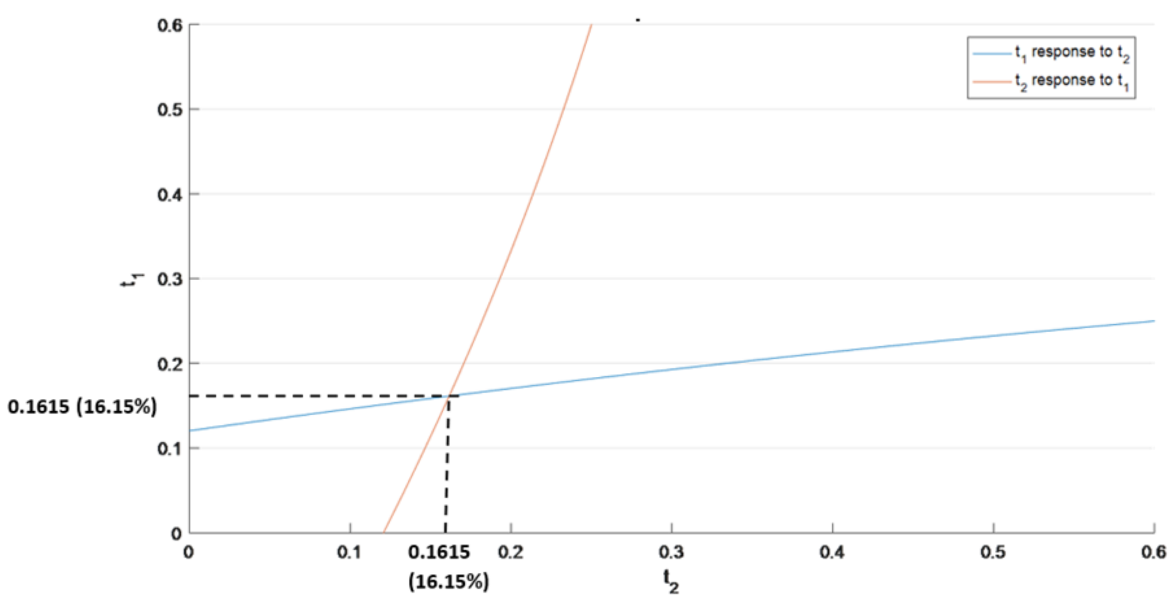


Figure 2: Response Functions and Equilibrium Tax Rates



3.1.3 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%.

3.1.4 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.

3.1.5 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.

3.1.6 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 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

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.

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 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.

[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.

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.

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.

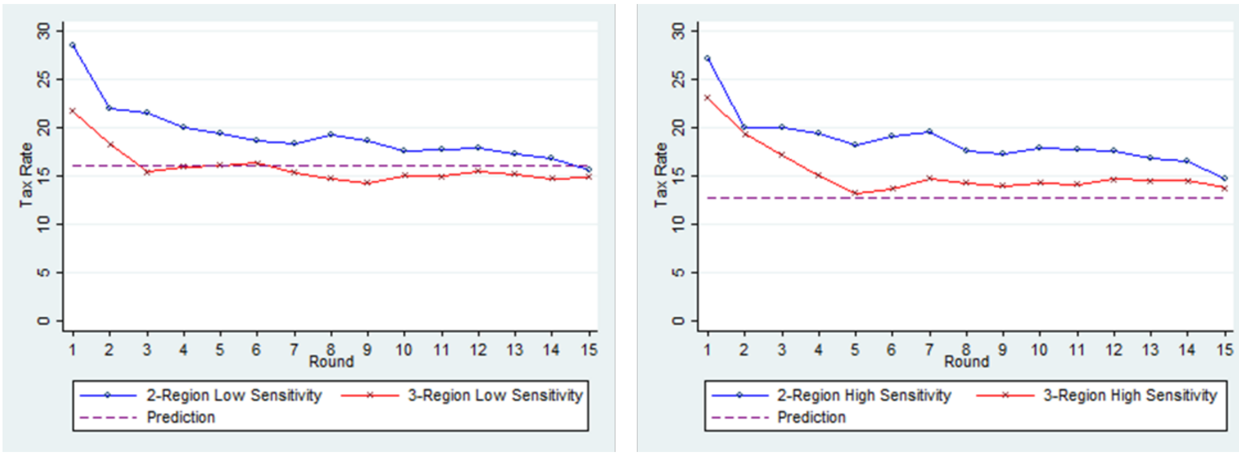
5.1 The Effect of Group Size

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 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. 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. 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 3.

Table 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)

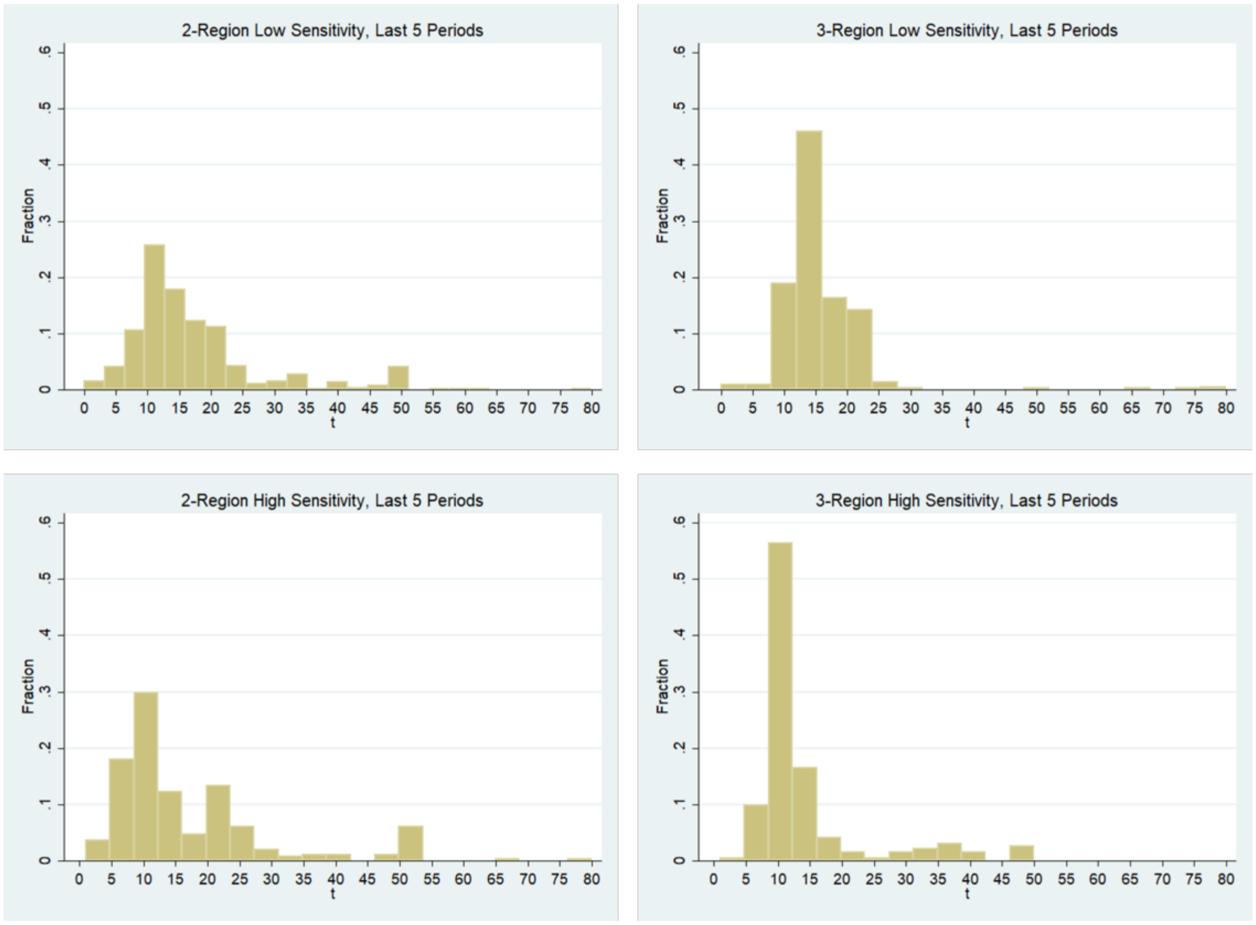
Figure 3: Dynamics of Tax Rates over Periods Comparing Different Group Size



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 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 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. 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

Figure 4: Histograms of Tax Choices in the Last Five Periods



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 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

Table 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.

in the theoretical literature, which is one main reason why the observed behaviors are not consistent with the Nash equilibrium predictions.

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 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

Table 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 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 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 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 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 6 shows that risk averse subjects tend to choose lower tax rates. However, in two of regressions, the coefficients on risk preference are not statistically significant. Distributional Pref. is measured by per-

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.

Table 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.

centage of tokens that are saved for self. Higher values of this variable represents being more selfish. Table 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.

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 7 presents summary statistics of observed tax rates and predicted tax rates in the five treatments. Fig. 5 depicts the trend of tax rates over time for the five treatments. The

Table 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.

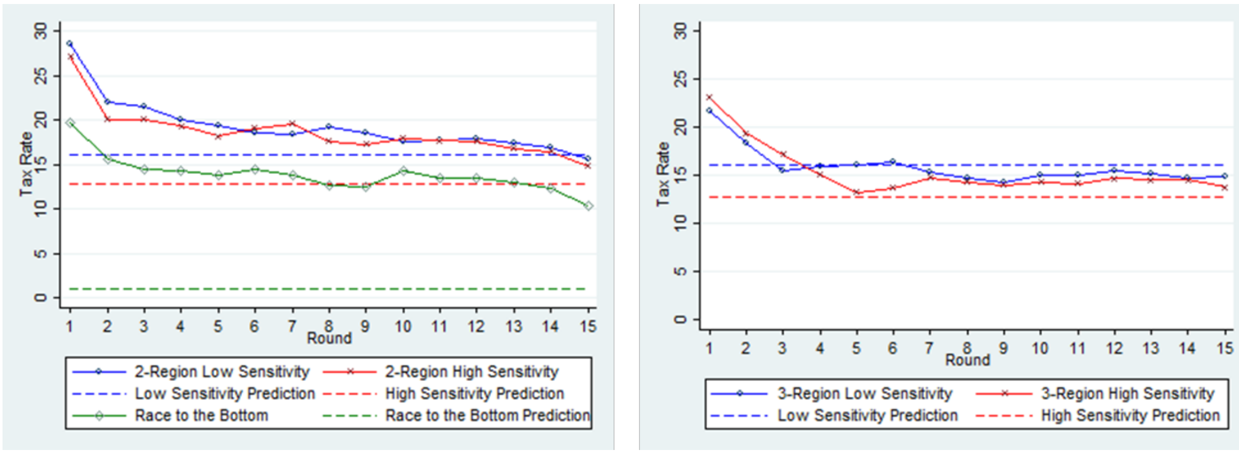
results are consistent with the null hypothesis that tax rates are lower in treatments with higher sensitivity. In the 2-Region treatments, an increase in the sensitivity reduces the all-period average tax rates from 19.29% to 18.10%, a decrease of 1.19%. Mann-Whitney tests reject that tax rates in 2-Region 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 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 3. The effect is statistically significant at the 1% level; however, the scale of the effect is much smaller than predictions.

Table 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)

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.

Figure 5: Dynamics of Tax Rates over Periods Comparing Different Sensitivity



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 8 presents the estimated response function results using random effect regressions. In Column 2 of Table 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 3 and 7.

Table 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.

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 9 shows the results of tax rates with and without policy interventions. Fig. 6 and Fig. 7 show the evolution of tax choices over periods. Fig. 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.

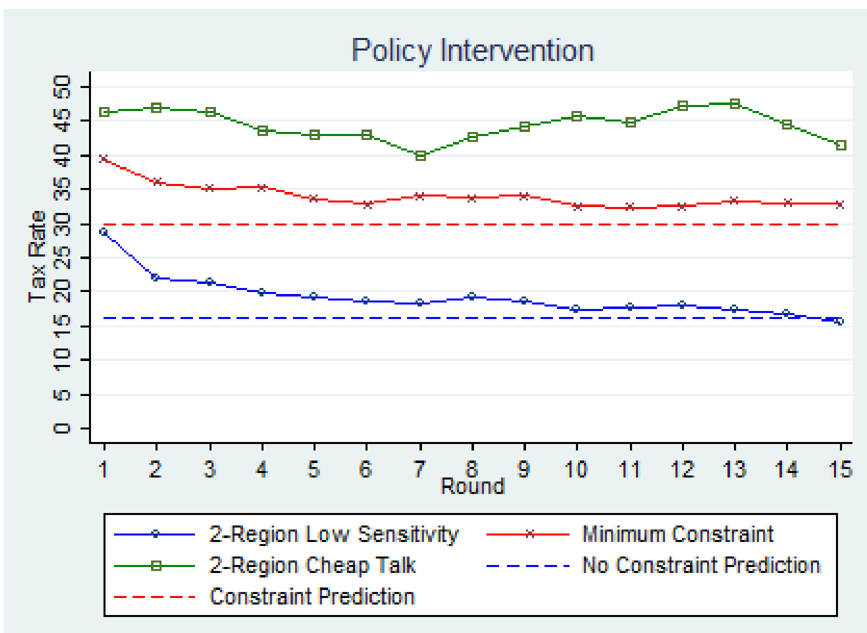
Table 9: Predicted and Observed Tax Rates in Policy Intervention treatments

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.

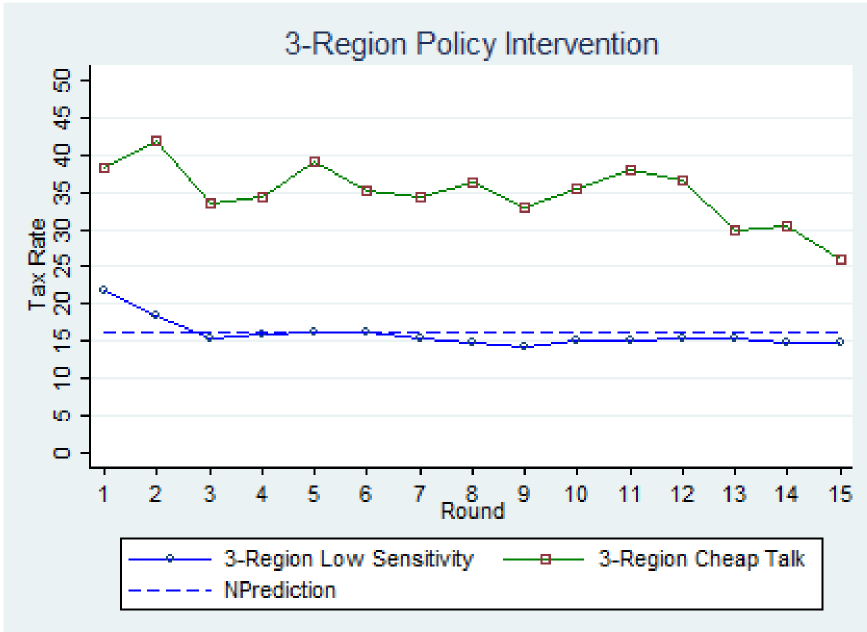
The effect of communication can also be found when the group size is 3. The average tax rate is 34.80%. This rate is substantially higher than the treatment without communication. Compared to the case of group size to be 2, the average tax rate is lower. Fig. 8 presents the histograms of tax rates in 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 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 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 7: Dynamics of Tax Rates over Periods Comparing Policy Interventions in 3-Region treatments

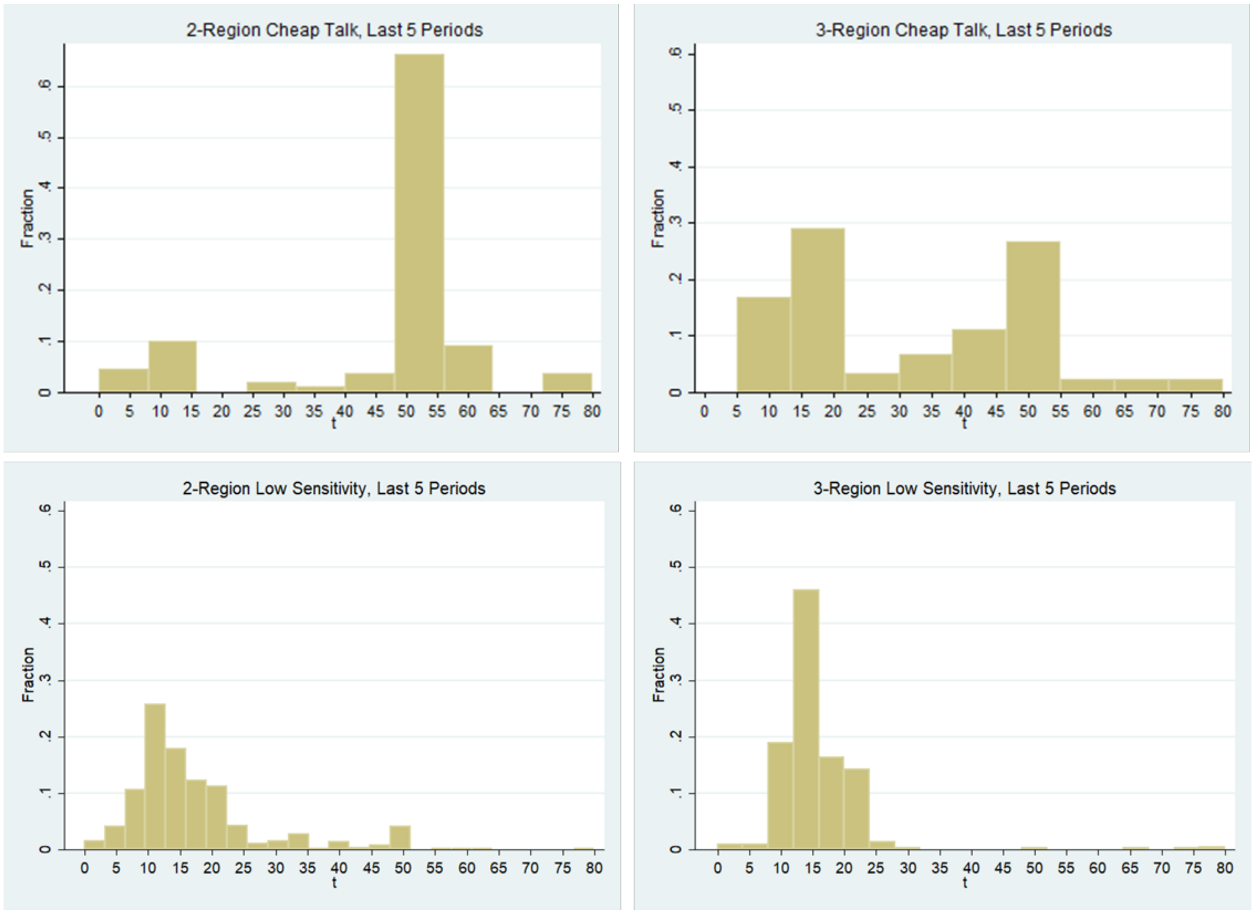


6 Discussion and Conclusion

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

Figure 8: Histograms of Tax Choices in the Last Five Periods Comparing Different Policy Interventions



presented in this paper may prove interesting to be further explored in experimental works.

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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.

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.

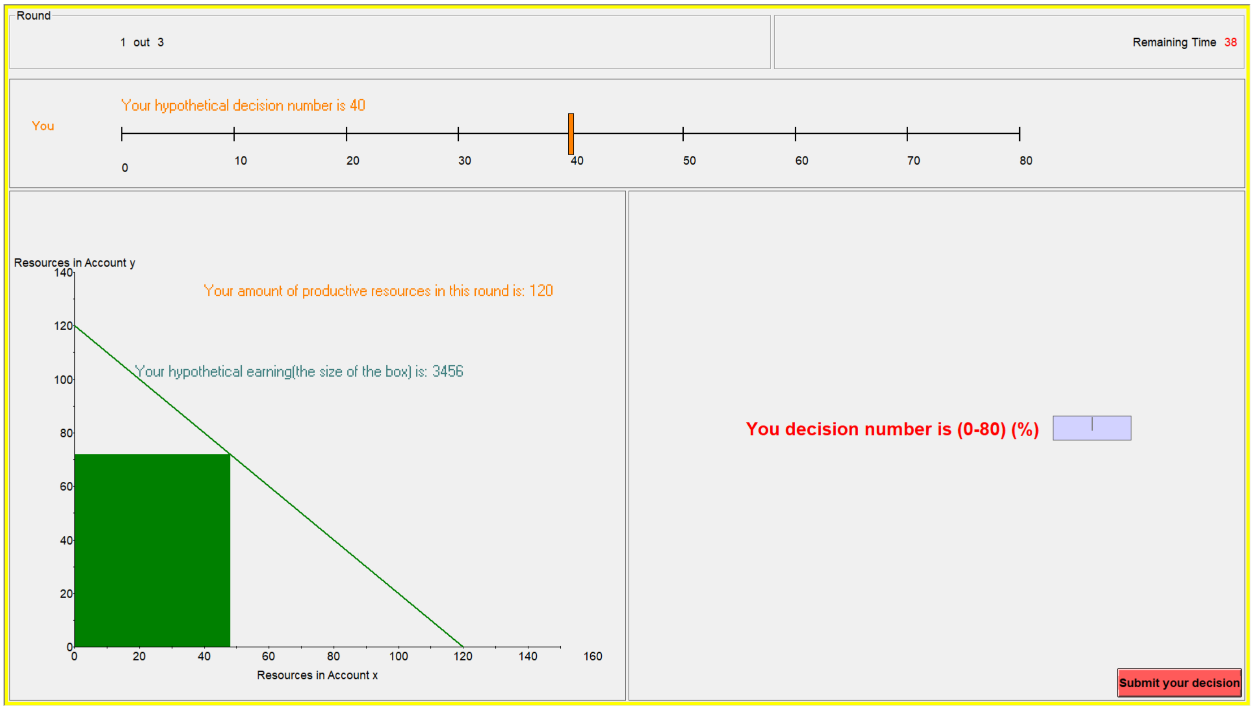
7.2 2-Region Low Sensitivity Treatment

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 rounds in this part. No one will learn the identity of the other participant in your group.

Figure 9: Practice Part Computer Screen



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:

Steps for each round:

Table 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%	$20 - 30 = -10$	$120 + 3 * (-10) = 90$	$120 + 3 * 10 = 150$

- 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.

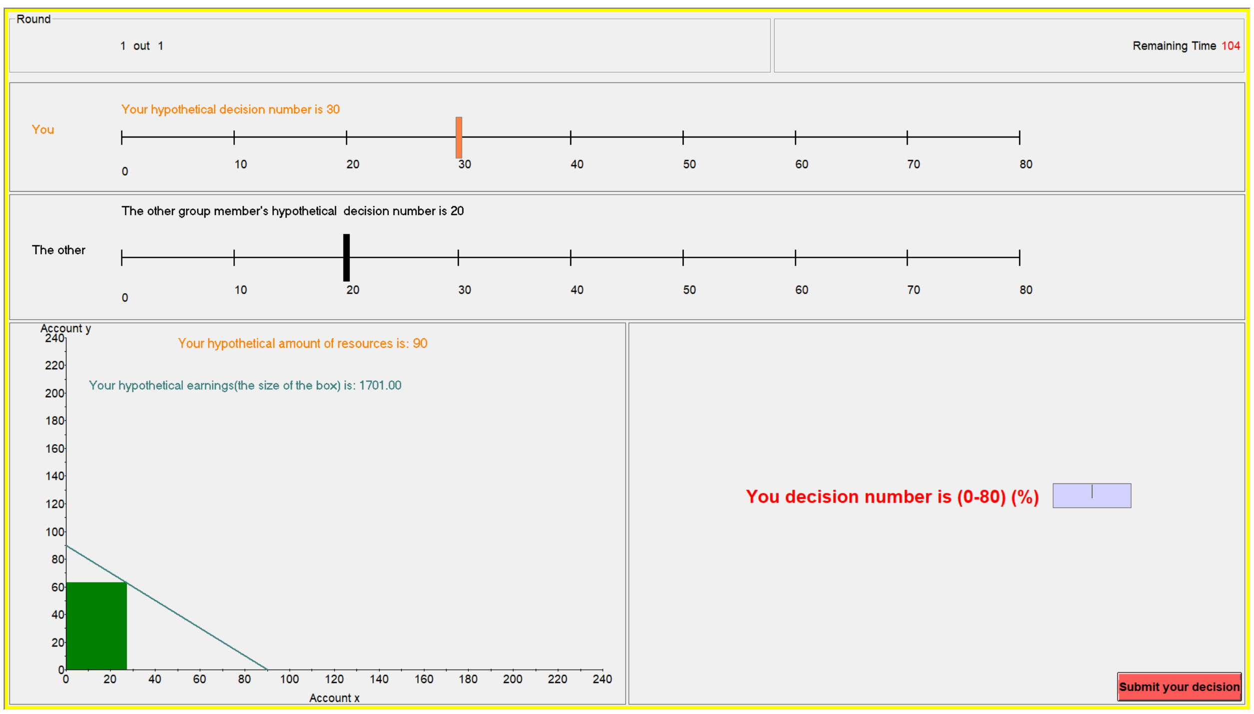
As in the practice rounds, below the slider, the green line shows all the possible allocations of the resources into the two accounts. The green box shows your earning.

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 10: Part 1 Computer Screen



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