Learning to Accept Public Taxes on Global Warming and Pollution : A Game of Two Cities

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Analysis plan

1 Introduction

The objective of this economic laboratory experiment is to assess the acceptability of environmental taxes on commuter mobility. To this end, we are building an experimental design in which residents of two cities are asked to vote in favor of environmental taxes that, by increasing the cost of mobility in private vehicles, encourage people to reduce their use of them in favor of non-polluting public transport. The originality of this research is its focus on identifying potential trade-offs among voters between a local tax on air pollution and a global tax on GHG emissions.

The proposed economic experiment is inspired by Janusch et al. (2021). The theoretical model used by Janusch et al. (2021) itself draws heavily on Hartman (2012), but focuses only on the congestion externality of private vehicle traffic.

The theoretical model presented in Hartman (2012) considers a fixed number of users who must choose between a bridge subject to traffic congestion and a freeway to commute. The travel time for the freeway is longer than for the bridge, but is not subject to fluctuations depending on the number of users choosing the freeway. For the bridge, travel time depends on a negative externality. The equilibrium traffic results in a number of users greater than the traffic that would minimize total transport costs. In the chosen specification, assuming homogeneous values of time, the optimum traffic is exactly half the equilibrium traffic (very close to the market entry game studied by Anderson et al. (2008)).

Our model is based on the aforementioned works. However, it does not consider a unique externality (ie. road traffic congestion) and also takes into consideration two environmental externalities : local pollution, which affects only the city where it is emitted, and global pollution, which has a global impact (here, two cities). A further distinction is that users are not presented with a choice between a slower but safer road route and a faster, potentially congested route, as in Hartman (2012), but between two modes of transport : fast, congested road transport, which emits local and global pollution, and slow, fluid and clean public transport.

The two cities are assumed to be identical in size. Transportation costs and local and global pollution costs are assumed to be the same for all users. It is further assumed that users are residents of each city and vice versa. Finally, it is assumed that congestion externalities are borne by road users and only by them, for each city. The local pollution externality, which depends on road traffic in city i, is borne by all residents of the concerned city, and the climate change externality, which depends on the aggregate of road traffic in both cities, is borne by all residents of both cities.

2 Notations, definitions and assumptions

- c_H^i : transportation costs arising from the use of public transport in the city i,
- c_B^i : transportation costs arising from private vehicle use in the city i,
- q_1, q_2 : PV traffic in city 1 and city 2 respectively, x_1, x_2 : public transport traffic in city 1 and city 2 respectively,
- n_1, n_2 : total number of transport users in cities 1 and 2 respectively,
- $N = n_1 + n_2 = 2n$: total number of transport users in the country made up of cities 1 and 2,
- t_H : temporal cost (constant) of using public transport for a user,
- t_B^i : temporal cost to a user of using a PV in the city i.,
- α : private fixed cost of private vehicle use,
- β : marginal cost of congestion externality linked to PV traffic,
- γ : marginal cost of local pollution externality linked to PV traffic,
- δ : marginal cost of global warming externality linked to PV traffic.

The users' choice is between a private vehicle, for which the total cost per user is c_B, and public transport, for which the cost is c_H.

Three hypothesis have been formulated :

1. the cost of local pollution and global warming is borne by transport users, regardless of their mode of transportation ;
2. the cost of traffic congestion is borne only by private vehicle users (option 1), and there is no congestion on public transport (option 2) ;
3. users are homogeneous, and the technologies used to produce external effects are identical in both cities.

The temporal (private) costs of using these modes are, for the city i :

$$t_B^i = \alpha + \beta q_i \tag{1}$$

$$t_H^i = t \tag{2}$$

The individual cost functions for private vehicle use for each city, including private and external costs, are as follows :

$$c_B^1 = \alpha + \beta q_1 + \gamma q_1 + \delta(q_1 + q_2) \tag{3}$$

$$c_B^2 = \alpha + \beta q_2 + \gamma q_2 + \delta(q_1 + q_2) \tag{4}$$

The individual cost functions for public transport use, including private and external costs in each city, are :

$$c_H^1 = t_H + \gamma q_1 + \delta(q_1 + q_2) \tag{5}$$

$$c_H^2 = t_H + \gamma q_2 + \delta(q_1 + q_2) \tag{6}$$

3 Balance without taxes

Following Hartman (2012) reasoning, at traffic equilibrium, transport costs must be equalized internally across all cities (Wardrop-Nash equilibrium). This principle gives :

$$\alpha + \beta q_1 + \gamma q_1 + \delta(q_1 + q_2) = t_H + \gamma q_1 + \delta(q_1 + q_2) \tag{7}$$

and

$$\alpha + \beta q_2 + \gamma q_2 + \delta(q_1 + q_2) = t_H + \gamma q_2 + \delta(q_1 + q_2) \tag{8}$$

Using Equations 7 and 8, we obtain the equilibrium for private vehicle traffic for city 1 and city 2 respectively :

$$\widehat{q_1} = \frac{t_H - \alpha}{\beta} \tag{9}$$

and

$$\widehat{q_2} = \frac{t_H - \alpha}{\beta} \tag{10}$$

4 Traffic optimum :

The social planner's objective is to minimize the sum of travel costs, which is written :

$$\begin{aligned} TTC =& q_1(\alpha + \beta q_1 + \gamma q_1 + \delta(q_1 + q_2))+ \\ & q_2(\alpha + \beta q_2 + \gamma q_2 + \delta(q_1 + q_2))+ \\ & (n - q_1)(t_H + \gamma q_1 + \delta(q_1 + q_2)) + (n - q_2)(t_H + \gamma q_2 + \delta(q_1 + q_2)) \end{aligned} \tag{11}$$

If we also consider the constraint that the sum of traffic be equal to $2n$, we also have :

$$q_1 + q_2 + x_1 + x_2 = 2n \tag{12}$$

The Lagrangian is written as :

$$\begin{aligned} \mathcal{L}(q_1, q_2, \lambda) =& q_1(\alpha + \beta q_1 + \gamma q_1 + \delta(q_1 + q_2))+ \\ & q_2(\alpha + \beta q_2 + \gamma q_2 + \delta(q_1 + q_2))+ \\ & (n - q_1)(t_H + \gamma q_1 + \delta(q_1 + q_2))+ \\ & (n - q_2)(t_H + \gamma q_2 + \delta(q_1 + q_2))+ \\ & \lambda(2n - q_1 - q_2 - x_1 - x_2) \end{aligned} \tag{13}$$

The first two partial derivatives of the Lagrangian with respect to q_1 and q_2, respectively, give, after simplification :

$$q_1 = \frac{-\alpha - 2\delta q_2}{2\beta + 2\gamma + 2\ \delta} \tag{14}$$

$$q_2 = \frac{-\alpha - 2\delta q_1}{2\beta + 2\gamma + 2\ \delta} \tag{15}$$

Using Equations 14 and15, we finally find :

$$q_1^* = \frac{t_H - \alpha - n\gamma - 2n\ \delta}{2\beta} < \widehat{q_1} \tag{16}$$

et

$$q_2^* = \frac{t_H - \alpha - n\gamma - 2n\ \delta}{2\beta} < \widehat{q_2} \tag{17}$$

Of course, we also note that :

$$q_1^* = q_2^* \tag{18}$$

5 Pigouvian taxes

To determine the value of the optimal taxes, we simply write that the total individual cost of transportation by private vehicle, including the optimal toll p, for the optimal total traffic level, must be equal to the total cost of transportation by public transport, i.e. in city 1 :

$$t_B(q_1^*, q_2^*, p) = \alpha + \beta q_1^* + \gamma q_1^* + \delta\,(q_1^* + q_2^*) + p = t_H + \gamma q_1^* + \delta\,(q_1^* + q_2^*) \tag{19}$$

Using Equations 16 and 17, we obtain :

$$p = \frac{(t_H - \alpha) + n(\gamma + 2\delta)}{2} \tag{20}$$

We can distinguish the toll from the congestion externality β on the one hand, from the local pollution externality γ on the other, from the toll from the global warming externality δ by writing (20) as follows :

$$p = \frac{t_H - \alpha}{2} + \frac{n\gamma}{2} + n\delta = p_C + p_L + p_G \tag{21}$$

6 Design, experimental treatments, calibration

6.1 Design and treatments

The previous game will be used repeatedly, as in Janusch et al. (2021). In each session, a total of twenty participants will be divided into four groups of five, with each group corresponding to one city. Thus, the session will have 20 participants, resulting in two independent observations (two cities per region and two regions that are completely independent of each other).

In the situation game, participants are given an endowment and the cost of their travel decision is deducted from the endowment. The cost of travel includes negative externalities : each participant suffers local pollution linked to his or her travel and that of others within his or her city, but also suffers global pollution linked to all travel in the two cities.

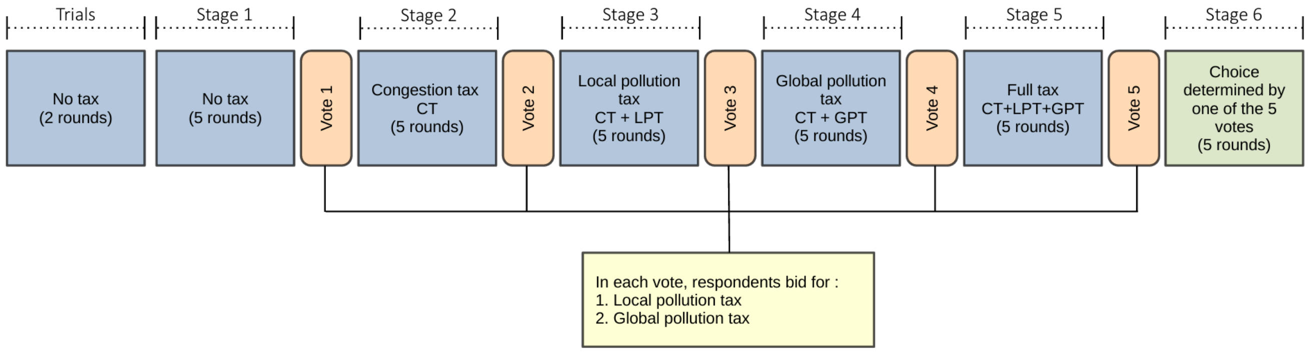

FIGURE 1 – Sequence for the experimental session (order 1)

The sequence (Figure 1) is inspired by Janusch et al. (2021).

One of the points not addressed by Janusch et al. (2021) is that of a possible order effect. The order adopted is a logical sequence, undoubtedly corresponds to a standard political agenda ("business as usual" first, then experimentation with a tax-like public policy, then a referendum on this tax).

However, in the sequence presented in Figure 1, it's hard to argue for a logical sequence. Not to mention that the gradual inclusion of taxes may further imply order effects. To overcome this problem, we propose to reverse the application of the local pollution tax and the global pollution tax.

The main idea of economic experimentation is to study the acceptability of pollution taxes and carbon taxes. In the theoretical model presented above, the Pigouvian tax that internalizes the two externalities is likely to be decomposed. into two taxes, the local tax p_L and the global tax p_G.

For the vote on the taxes, a simultaneous but repeated vote on each of the taxes taken in isolation is chosen. The "voting" procedure is not the usual majority voting procedure. In order to obtain more precise information on the acceptability of each tax, we use an auction mechanism (Messer et al., 2010), known as the Group Presentation Format.

This works as follows (see Figure 2) :

1. N bidders, each with an endowment of E, must offer an amount b_i in favor of a given policy (tax) — note that they do not vote for a certain tax amount —,
2. If the median value of the bids is greater than a computer-generated random number R between b_{min} and b_{max}, the policy is adopted, and each bidder pays R and wins $E - R$; otherwise the policy is rejected, no tax is collected and each bidder wins E.
3. if the tax is adopted, the tax revenue $R \times N$ is divided equally, i.e., each member of the group receives R.

In the session, for the voting phases and for each vote $E = 10$ Ecus are given and each participant must bid from 0 to 10 using integers.

The screen displaying the vote look like this (see Figure 3) :

Before that, they were given the cost of the tax that would apply to each externality :

As in Janusch et al. (2021), we randomly select which of the 6 votes applies to the final sequence (stage 6).

To test for a possible order effect, half of the groups (200 participants) are run with the local and global tax stages reversed (stage 3 and stage 4 in Figure 1). The sequence is as follows : Stage 1 : Tax-free ; Stage 2 : Road Congestion Tax ; Stage 3 : Global Pollution Tax ; Stage 4 : Local Pollution Tax ; Stage 5 : Full tax.

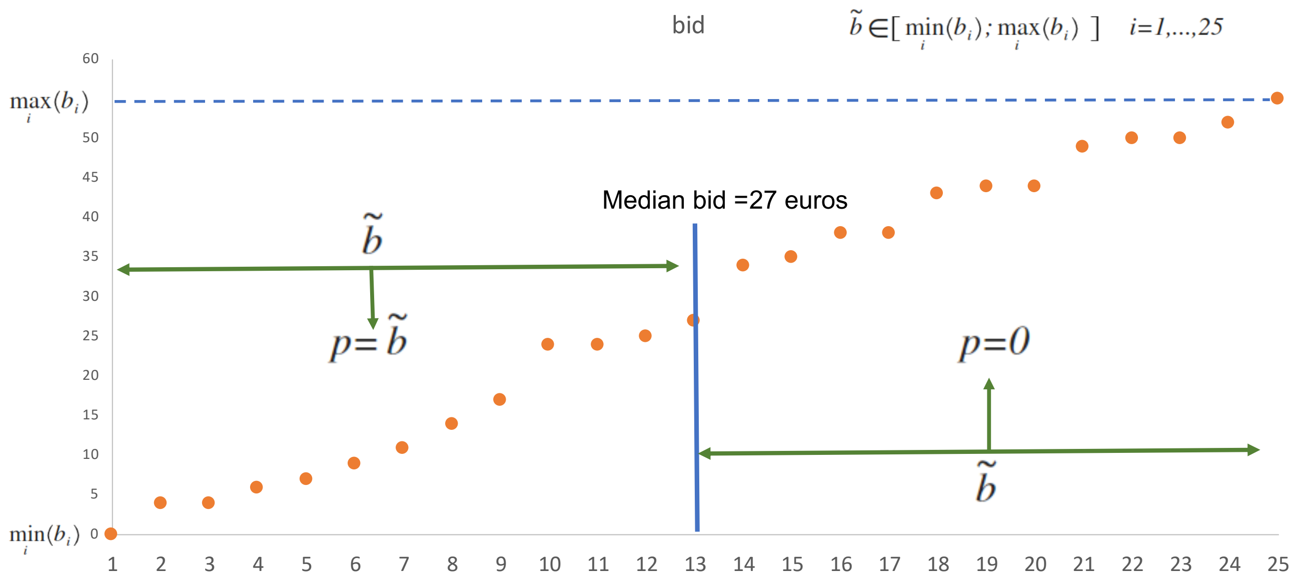

FIGURE 2 – Bid mechanism

TABLE 1 – Messages regarding taxes

Type of tax	Conditions under which you pay the tax	Tax amount
Traffic congestion tax	(1) paid if you choose PV AND (2) if the tax applies in your period	5 Ecus
Local pollution tax	(1)paid if you choose PV AND (2) if the tax applies in your period	2,5 Ecus
Global warming tax	(1) paid if you choose PV AND (2) if the tax applies in your period	2,5 Ecus

The assignment of participants to one of the two sequence orders will be done randomly.

Each city votes separately for the taxes. If one adopts the global tax and the other does not, the other city benefits from the vote of the first.

The cost of the tax does not affect efficiency, as the **amount of revenue is distributed uniformly to the residents of each city**.

6.2 Calibration

The calibration should be sufficiently simple and understandable for the participants, and as far as possible, give integer numbers for equilibrium, optimum and taxes. The following calculations are based on the theoretical model described above.

We propose the following calibration (see Table 2) :

For the calibration below, the traffic equilibrium is $\widehat{q_1} = \widehat{q_2} = 5$, and the traffic optimum is $q_1^* =$

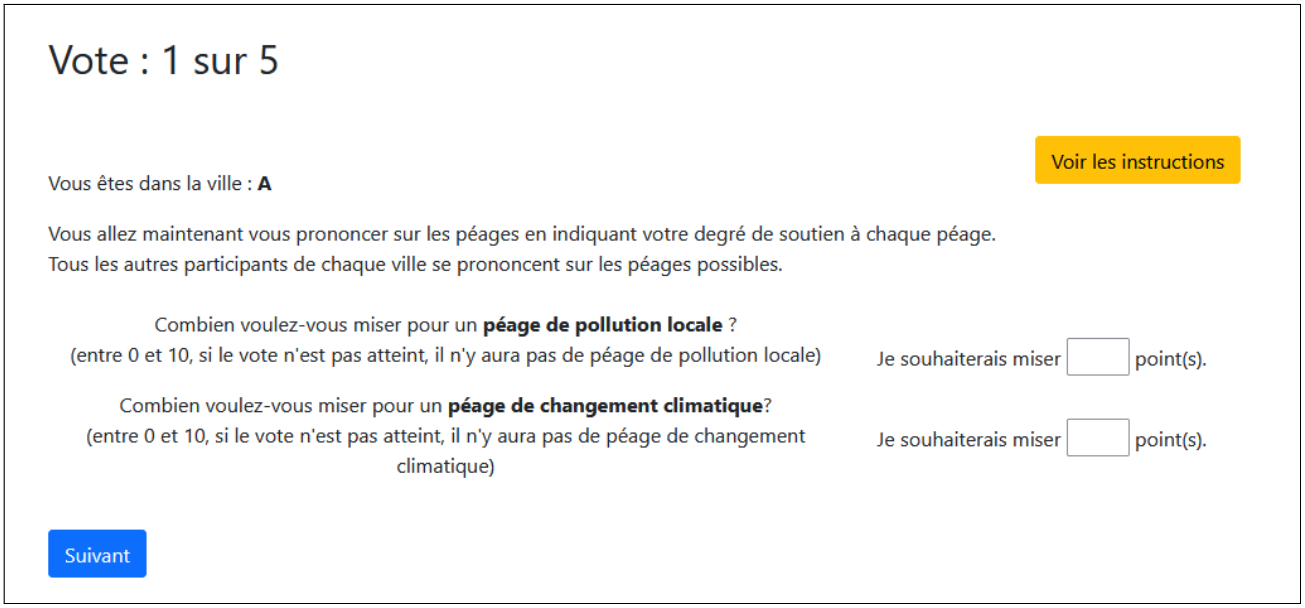

FIGURE 3 – Auction selection screen for taxes

$q_2^* = 0$. Under these conditions, the Pigouvian toll (full tax) is $p = 10$, with a possible decomposition into $p_C = 5$, $p_L = 2.5$ and $p_G = 2.5$. For the initial endowment for each game period (excluding the voting phase), and to avoid losses, we give each choice period E =30, since the maximum transport cost (excluding tolls) is 30 $(10 + 2 \times (5) + 1 \times (5) + 0.5 \times (5 + 5))$.

In terms of payouts to participants, there are 30 non-voting play periods. At the end of the game, we draw 5 of the 30 periods for each participant and add up their winnings.

TABLE 2 – Calibration of experimental parameters

n	t_H		t_B			q_e	q_o	p_c	p_{PL}	p_{GES}	Full Tax
		α	β	γ	δ						
5	**20**	**10**	**2**	**1**	**0.5**	**5**	**1**	**5**	**2.5**	**2.5**	**10**

6.3 Experimental controls

— Inequality Aversion at the individual level (Blanco et al., 2011),
— CRT : Cognitive Reflection Test,
— Sociodemographic characteristics of respondents

6.3.1 Psycho-social constructs

We propose psycho-social constructs to explain different taxes acceptance. These constructs are assessed through blocks of different items :

A. Environmental self-identity

Environmental self-identity refers to the extent to which people see themselves as the type of person who engages in environmentally friendly behavior. This variable has been identified as a strong predictor of pro-environmental preferences, intentions and behaviors (van der Werff et al., 2013).

B. Consideration of future consequences

These items seek to assess whether individuals act on the basis of the immediate consequences of their actions, or on the basis of their long-term consequences (Strathman et al., 1994). Demarque et al. (2010) provides a validated French version of the scale.

C. Environmental concerns

Inspired by the Norm activation model, (Schwartz, 1997) and the transtheoretical model of behavioural change (Prochaska and DiClemente, 1983), we propose to assess "Environmental concern" by dividing it into two parts : local air pollution and global climate change.

D. Perceived legitimacy of taxes

We propose a list of items to assess tax perception and, more specifically, perceived legitimacy, based on two published articles on the perceived legitimacy of road safety rules (Laurent et al., 2023; Varet et al., 2024). According to these articles, the feeling of legitimacy towards traffic rules can be broken down into four psychological parameters. These are effectiveness, efficiency, fairness and moral alignment. The proposed items correspond to these different dimensions with an additional one : the belief in a fair redistribution of taxes.

E. Habits and attitude towards cars and public transport

In line with a forthcoming article from Philipps-Bertin et al. (2024) we propose 6 items to assess habits on car usage. Inspired by the works of Steg et al. (2001) and Hunecke et al. (2007) (2007) we assess attachment to the car through the notion of pleasure in using it (2 items), but also evaluate the notion of freedom and independence associated with the car (3 items).

We aggregate the different items by blocks to create a score. The reliability and internal consistency of the score (average of the items) are assessed by the Crombach alpha. When the latter is greater than .7, it is possible to aggregate the responses to the various construct items to calculate a score.

7 Hypothesis

We will test four main hypothesis :

H0 : a. The acceptance of the tax on local pollution will increase after the congestion tax implementation.
b. The acceptance of the tax on global pollution will increase after the congestion tax implementation.

H1 : a. The acceptance of the tax on local pollution will increase after its implementation.
b. The acceptance of the tax on global pollution will increase after its implementation.

H2 : a. Acceptance of the tax on local pollution decrease after the implementation of the tax on global pollution.
b. Acceptance of the tax on global pollution decrease after the implementation of the tax on local pollution.

H3 (order effect) : a. The acceptance of the local pollution tax after its implementation (in stage 4) is higher if the global pollution tax has been implemented before (in stage 3).
b. The acceptance of the global pollution tax after its implementation is higher (in stage 4) if the local pollution tax has been implemented before (in stage 3).

H4 : a. The private vehicle usage is lower when all three taxes are implemented, than when none are.
b. It is lower with the local pollution tax and the congestion tax than with only the congestion tax.
c. It is lower with the global pollution tax and the congestion tax than with only the congestion tax.
d. It is lower with the congestion tax than with no tax.

8 Statistical Method and Power Analysis

The two main outcomes are the share of private vehicle use and the participants' bid for the implementation of a tax. The aim is to test the effects of the different treatments on these outcomes. To select the best number of participants, a power analysis is performed for the two outcomes.

To test hypothesis H4, we will use a Wilcoxon signed-rank test.

The other hypothesis will be tested using Tobit modeling with random effects. Acceptance is considered through individual bids for a given tax. The limit on the value of the bids could lead to censored data, which explains the use of a Tobit model. To this modeling, we will add several controls described in the section on experimental controls (Section 6.3).

This means that there are four different Wilcoxon tests and eight different tests for Tobit parameter models.

First, we define the smallest effect size of interest for both outcomes. For the share of private car users, we consider as interesting a difference if one participant per city (20% of the population) changes his mode. This corresponds to two participants at the group level (two cities). For the tax implementation offer, 10 Ecus are given to each participant, we will consider a minimum effect of 10% (1 Ecus), i.e. a difference of 10 Ecus for the whole group.

To calculate the power of a test, we need different information :

1. The variable(s) to be tested, and an a priori idea of its (their) distribution(s).
2. The test we are going to use.

To gain insight into the distribution of the private vehicle use, we initially rely on experiments analogous to our own, i.e. Hartman (2012) and Janusch et al. (2021) (see first version of the Analysis plan). Since our experiment differs significantly from this two studies, we have conducted a pilot study to improve our previous power analysis.

We consider a value of $\alpha = 0.05$ as a first error risk (ie : maximum p-value to reject H0). To account for the twelve tests, we use a Bonferroni correction in our analysis.

8.1 Wilcoxon signed-rank test

To perform the different Wilcoxon signed-rank tests, we use a similar method as we have done in our previous analysis. We only correct the standard deviation to match our pilot sample data.

We conduct our power analysis using Monte Carlo simulation. Our main objective is to determine the effect of the different treatments with a within-subjects Design. Therefore, we will test the whole population in one treatment against the whole population in another treatment. This analysis is performed for these tests.

We consider the variance per stage. The average of these variances is ≈ 1.02. We will consider a variance of 1.5 in the Monte Carlo simulation. In addition the expected value, without the treatment effect, is set to 6, which corresponds to the mean of the first stage of our pilot data.

We test several classical distributions : Normal, Laplace, Uniform and Binomial. Two are unbounded laws (the Normal and Laplace laws), and so cannot be the true law. However, we can hope that multiplying laws, even unbounded ones, will give us an idea of the effect of distribution variation on the required number of people. We test the equality of the distribution laws of the average number of VP users. We will get richer results (at turn-by-turn level), but with panel effects. We adopt a unique average value for each stage (5 turns) and use a Wilcoxon signed-rank test.

The variation in estimated test power is illustrated in the following Figure 4.

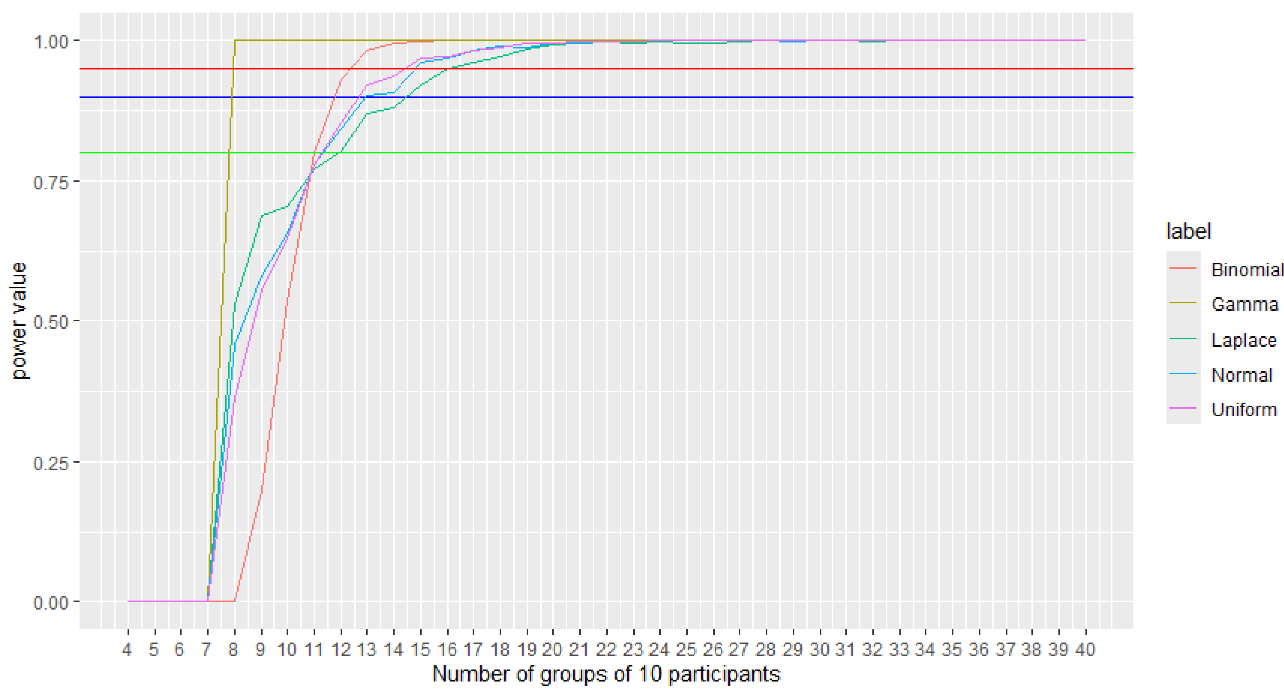

FIGURE 4 – Tests' power for a mean deviation of 2 and a standard deviation of 1.5
The orange horizontal line corresponds to a threshold of 0.99, the red line corresponds to a threshold of 0.95, the blue line corresponds to a threshold of 0.9, and the green line corresponds to a threshold of 0.8.

With a total of 12 groups of 10 participants, we have a power above 0.8 for all laws. A minimum of 130 respondents should be sufficient to have a probability of 80% to successfully detect an effect over a difference of 2 respondents.

8.2 Tobit models

Initially, we were unable to perform a power analysis on the Tobit model because we lacked information on the bid distribution. With the pilot data, we have a way to access a distribution. The data structure is complex : each participant votes five times and interacts with each other. We will not be able to maintain this structure completely. Therefore, we suggest four different and imperfect solutions to evaluate our hypothesis testing :

1. Pure simulation : simulation using the mean and variance of the pilot data. We cannot replicate interactions this way.

2. "Wild" group bootstrap : the correct way to use the bootstrap method with aggregated data is to bootstrap at the highest level of aggregation. In our case, this level would be the group of 10 respondents. But since we only have two groups in the pilot data, we cannot just use classical bootstrapping. So we add a random component to the bootstrap samples.
3. "Wild" city bootstrap : bootstrap at the city level, while still adding a random component.
4. Individual bootstrap : bootstrap in two steps, first we draw one city (among the four in the pilot data), then within the city we draw five individuals (with replacement). In this case, we don't add a random component.

For each number of groups, we simulate/draw 100 samples of the required length for each of the four solutions. The different power estimates are displayed in the following Figures 5 , 6 , 7 and 8.

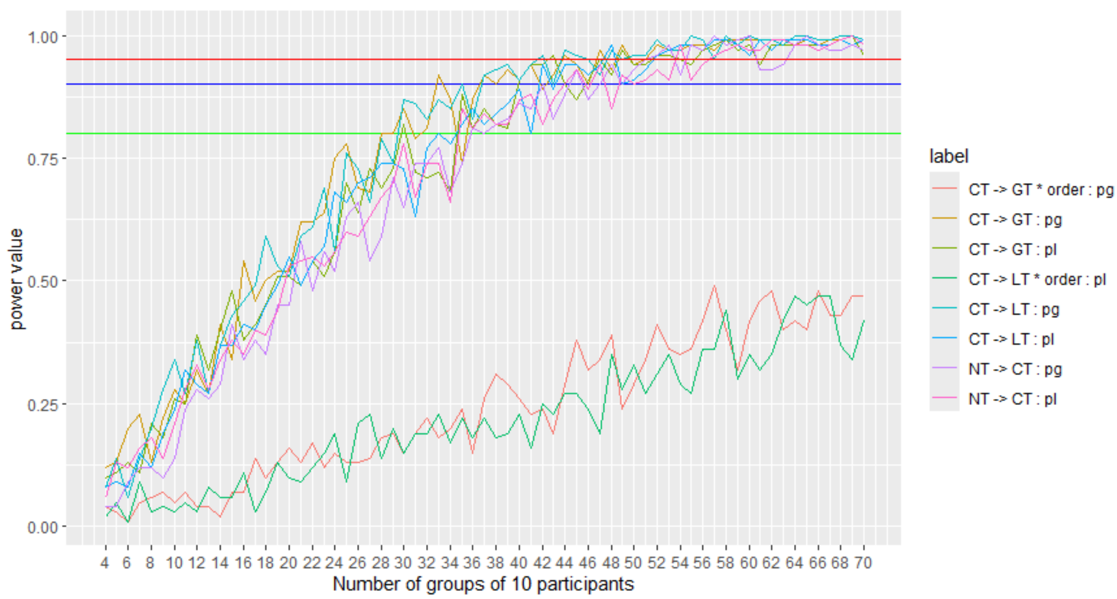

FIGURE 5 – Tests' power for the "Pure simulation" solution

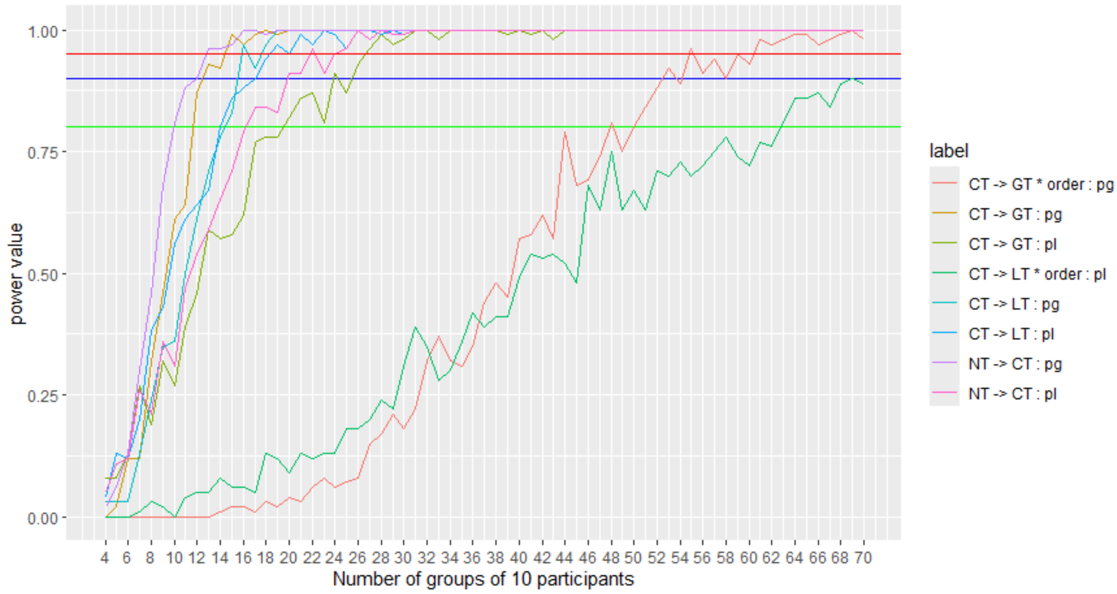

FIGURE 6 – Tests' power for the "Wild group bootstrap" solution

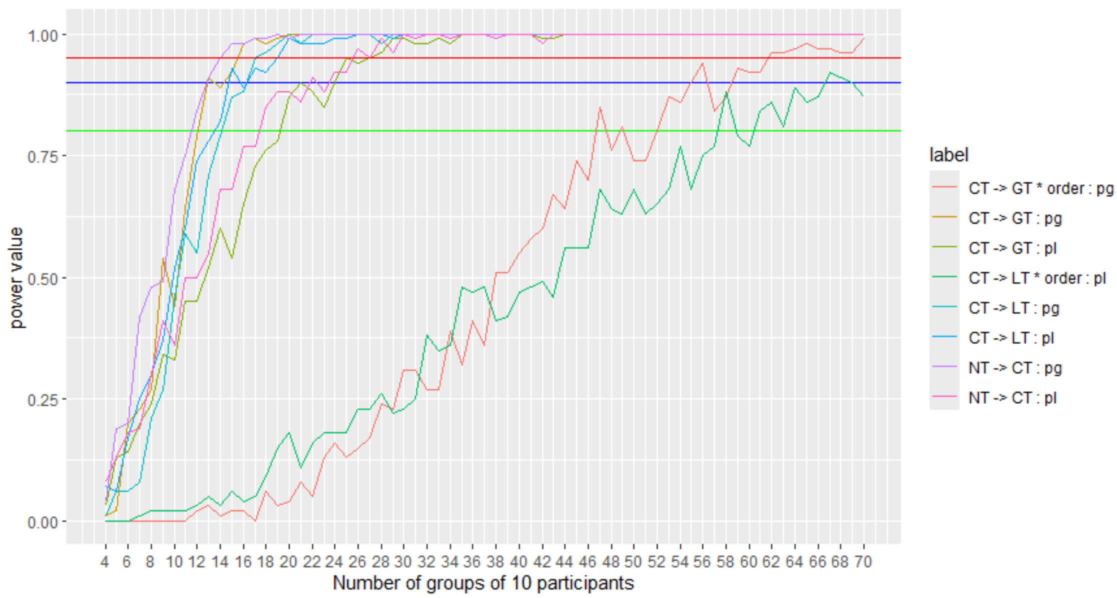

FIGURE 7 – Tests' power for the "Wild city bootstrap" solution

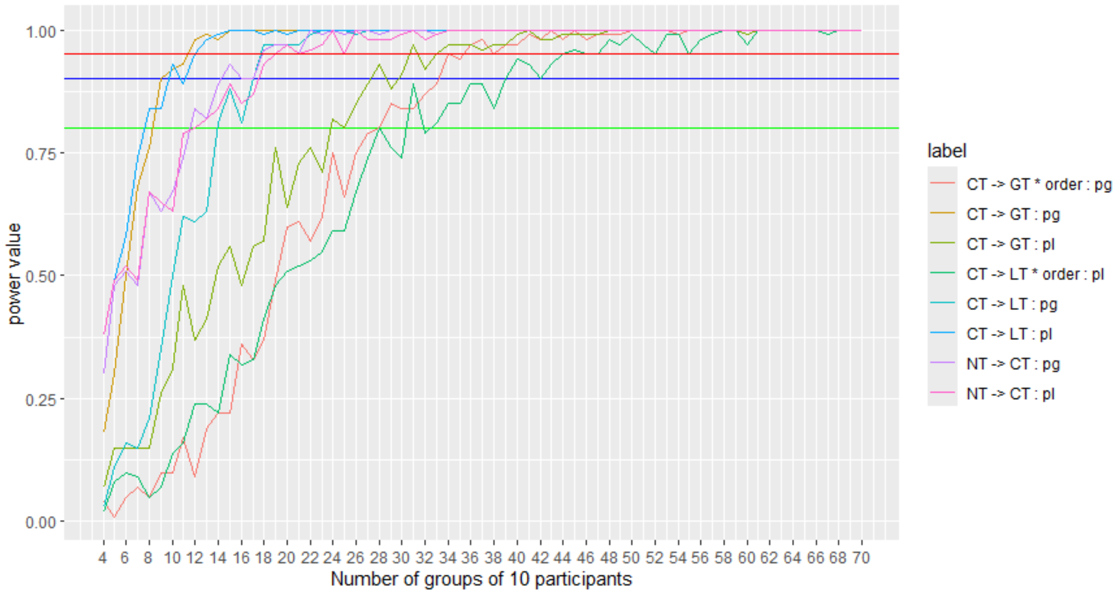

FIGURE 8 – Tests' power for the "Individual bootstrap" solution

The orange horizontal line corresponds to a threshold of 0.99, the red line corresponds to a threshold of 0.95, the blue line corresponds to a threshold of 0.9, and the green line corresponds to a threshold of 0.8. The upper-case correspond to experienced tax : NT : no tax CT : congestion tax LT : local pollution tax GT : global pollution tax

The lower-case correspond to tax bidding : pl : local pollution tax pg : global pollution tax

*order : correspond to the order effect (half the sample experience the local tax before the global tax, the other half do the opposite).

the label should be read : "CT -> GT : pg" effect of experiencing the global pollution tax (+the congestion tax) in comparison of experiencing only the congestion tax on global pollution bid value.

The two tests on the order effect are different from the rest, which is not surprising considering that these tests compare a half-sample with another half-sample, and not the whole sample with itself as in other tests. These two hypotheses have lower power. The power doesn't pass over 0.8 for the simulation, it needs over 65 groups the bootstrap solutions, only 35 if considering bootstrap at the individual level. For the other tests, with 40 groups we obtain a power above 0.8 in all cases. If we consider the different bootstrap solutions, the requirement is much lower.

Considering 40 groups gives us enough power for the four Wilcoxon tests, and the Tobit models if the order test is not considered.

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