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Tax evasion behavior using finite automata: Experiments in Chile and Italy

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ABSTRACT

In this paper, we use a Moore Automata with Binary Stochastic Output Function in order to capture the extensive decision regarding tax evasion made by subjects in experiments run in Chile and Italy. Firstly, we show how an hypothesis about subject behavior is converted into an automaton, and how we compute the probabilities of evading for every state of an automaton. We use this procedure in order to look for the automaton which is able to anticipate the highest number of decisions made by the subjects during the experiments. Finally, we show that automata with few states perform better than automata with many states, and that the bomb-crater effect described in Mittone (2006) is a well identified pattern of behavior in a subset of subjects.

1. Introduction

In this paper we use the theory of finite automata in order of describing behavioral data collected in two set of experiments on tax evasion run in Italy and in Chile.

In economic, the neoclassical theory of tax evasion in Allingham and Sandmo (1972), Yitzhaki (1974), is based on the assumption of a traditional fully-rational agent who decides her level of tax compliance accordingly to a standard process of expected utility maximization. This theoretical approach has been widely criticized on the basis of an experimental empirical ground. The extraordinarily wide latitude of the experimental economics literature in this field, makes it impossible to summarize here the wealth of the empirical findings (for a recent survey see Kirchler (2007)).

In utmost synthesis, one could say that the standard theory fails to account for the agents' reactions induced by the standard parameters of the decisional problem – a typical example of this kind is the weakness of the theory in explaining the tax payers reactions to an increase in the tax rate. Moreover the standard theory is inadequate for forecasting the tax payers' response to the inclusion of psychological factors in the task problem – e.g. including a social blame effect or other forms of psychological constraint.

Some quite recent attempts to overcome the limits of the standard approach to tax evasion have been carried out by substituting the Expected Utility Maximization Theory (EUMT) with the Prospect Theory (PT) by Kahneman and Tversky (1979). In spite of its behavioral foundations, the Prospect Theory still belongs to the class of theories based on a perfectly rational agent. The only apparent concession to bounded rationality in the theoretical machinery of PT, is limited to the allowance of some inconsistency in the risk attitudes. The PT agent re-models her risk attitude according to a reference point which works as a psychological dividing wall between risk aversion and risk propensity.

The psychological–behavioral foundations of PT, can help to explain the tax payers' inconstancy reported by many repeated-choice experiments, but it is still unable to forecast in a satisfactory way the full complexity of the factors that can affect the decisional process. This is clearly a paradox: on the one hand, both the two most important among the general parsimonious theories applied to tax evasion fail to take into account the complexity of the decisional process and, on the other hand, these theories are grounded in a substantially perfectly-rational agent who does not exist in the real world.

In this paper, we assume an agent who is strongly rationally bounded, even more limited than the real agents are. Using finite automata to explain human decision-making, is equivalent to saying that participants' decisions depend on their current conditions or state. An individual has different states, and she changes from one state to another, according to external events. This idea closely resembles the original Simonian definition of bounded rational agent.

To decide in accordance with a bounded "local" set of information, implies discarding the standard view of a perfectly rational optimizing homo economics. If an individual has evaded, but she has not been audited, the next time she might be less willing to evade than a subject who has been audited and punished. It is worth noting that this shifting of the agent's attitude towards evasion due to past experiences, is not compatible with a standard view of perfect rationality. What has happened in the previous round should not affect the tax payer's decision process because, if she were perfectly rational, then she would have already figured

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out all her future choices. More precisely, the perfectly rational tax payer chooses on the basis of a general probabilistic inter-temporal plan, built on a complete preference mapping of all the possible, alternative, probabilistic, weighted outcomes. In contrast to this picture, in our setting, we assume that the probability of evading depends on the current subjective state of the tax payer which is determined by the local status quo.

Another similar view of a locally determined decision maker, which is closer to our theoretical design, is suggested by Selten (1998). In his Aspiration Adaptation Theory the Seltenian agent chooses her actions by considering a limited set of decisional dimensions (the aspiration level) described by discrete scales of measure which are determined by the specific local state of nature. The same agent can choose opposite actions, depending on the local bond of a dynamically adaptive network of aspirations described in a discrete finite set of alternatives. Moving from one bond to another, means changing from one aspiration level to another, without having a complete picture of the whole set of aspirations. In this sense, we can imagine a possible (extreme) adaptation of the Aspiration Adaptation Theory to our approach. In our setting, the relevant dimensions of choice in the tax payer's problem is represented by the two states "has been audited", "has not been audited" and the tax payer decides only according to the characteristic of her current state.

It is worth noting that the Aspiration Adaptation Theory applies very well as a general descriptive tool for modeling the tax payer's behavior, and can also be applied to the experimental design used here. An aspiration level in Selten's definition can be described as a vector $a = (a_1, a_m)$ where a_j is the partial aspiration level for a generic G_j goal. A goal for a tax payer could be the amount of income "saved" from taxes or the psychological cost implied by the decision to evade due to social blame. In the theoretical setting of the Adaptation Aspiration Theory, the tax payer should move from one aspiration level to another according to the starting point and using a sort of backward-looking logic that pushes her from one local aspiration level to another. The choice of the new aspiration level depends on the local informational bundle which, in our example, could be represented by the amount of disposable income, the value attributed to the moral constraints, etc. An exhaustive description of an aspiration level applied to tax evasion goes beyond our aims, so what we shall take from the Adaptation Aspiration Theory is a methodological hint rather than a complete theoretical frame.

The idea that finite automata theory may be useful for modeling human decision-making is not new. Rubinstein, quoted above, originally developed a research agenda where automaton was used for modeling bounded rationality and Romera (2000) uses finite automata to represent mental models. Having better computational representation of tax payers can help to improve the application of artificial intelligence to tax services (Rayman, Meservy, & Hansen, 1992).

Our model does not explain the agent's full process of rationalizing before making her decision. Instead of this, we characterize the states where the subjects are more willing to evade or not. The willingness to evade will be represented as a probability.

We use a type of finite automaton named Moore machine (see Sipser (1997) and Moore (1956)). This machine consists of a finite set of states, one of which includes an initial state, an output function and a transition function. We partially modify the output function; instead of depending only on the current state, the decision to evade or not, depends on the current state and on its related probability of evasion. As the number of states of the machine increases, we obtain a better explanation of the subjects behavior. However, in this case, we obtain automata with a high number of states. These types of automata do not produce a useful theory for explaining subjects' decisions. Therefore, we want to model the behavior of the agents with the lowest level of complexity. Having a simple automaton allows us to have a good explanation of subjects' decisions. Although several measures of complexity for the automata have been suggested in the literature (see Rubinstein (1986)), we will use a fairly naive definition of complexity: what counts is the number of states in the machine.

Our main conclusion is that taking into account the extensive decision on evasion made by the subjects, we distinguish two patterns of behavior: on the one hand, there is a group of individuals who behave honestly, paying all their taxes all the time; on the other hand, we confirm the relevance of the so-called "bomb crater effect" Mittone (2006) which predicts that individuals are more willing to evade right after being audited (see Section 3).

In the Section 2, we will formalize the Moore Automata with Binary Stochastic Output Function for capturing the subjects' behavior. After the formalization, we will illustrate two methods for estimating the probabilities in every state: firstly, we use different probabilities for discriminating the subjects' behavior during the experiments run in Chile and Italy and, secondly, we optimize the probabilities for explaining only with one automaton the behavior of all the subjects in a given experiment. After this, we will conclude, describing the results and future work to be done.

2. The Moore Automata with Binary Stochastic Output Function

The Moore machine is a finite state automaton where the outputs are determined only by the current state and does not depend directly on the input. The standard state diagram for a Moore machine includes a deterministic output signal for each state. We introduce a variation in the output function of the Moore Automata: instead of producing a deterministic output signal, the output function can produce either of two values 0 or 1. Every state s has a probability p_s of producing 1 and a probability $(1 - p_s)$ of producing 0. Thus, the Moore machine with a Binary Stochastic Output Function can be defined as a 7-tuple $\Gamma = \{S, S_0, P, \Sigma, \Lambda, T, G\}$ consisting of the following objects:

- A finite set of states (S).
- A start state (also called initial state) S_0 which is an element of (S).
- A set of probability values (P). Every state $s \in S$ has a probability $p_s \in P$. The initial state has a probability $p_{S_0} \in P$. The numerosity of the set P is equal to the numerosity of S plus 1, i.e. the initial state.
- A finite set called the input alphabet (Σ).
- A finite set called the output alphabet ($\Lambda = \{0, 1\}$).
- A transition function ($T : S \times \Sigma \to S$) mapping a state and an input to the next state.
- An output function ($G : S \to \Lambda$) mapping each state and its probability in (P) to the output alphabet as follows.

$$G(p_s) = \begin{cases} 1, & \text{if } \epsilon < p_s; \\ 0, & \text{otherwise}. \end{cases} \tag{1}$$

where ϵ is a uniform random number between 0 and 1.

If we feed this machine with an string of symbols from Σ, where every symbol represents whether the agent is audited or not, this automaton produces a binary string of 0's and 1's according to the visited state and the probability of that state. Each 1 and 0 is the prediction made by the automaton about the subject's decision for the next period. If the probabilities of all the states is 0.5, the automaton will produce a random string of 1's and 0's.

The design chosen for our automata is quite close to Selten's idea of dynamically-adaptive aspiration plans. Our automata agent can be described as a decision maker who chooses her actions in accordance with a given aspiration level. In our model, the local