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The slippery slope framework on tax compliance: An attempt to formalization

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ABSTRACT

Kirchler, Hoelzl, and Wahl (2008) presented with the so-called 'slippery slope' framework a new approach to understand tax compliance. The slippery slope approach supposes two routes to tax compliance: deterrence of tax evasion by audits and fines on the one hand, and building a trusting relationship with taxpayers by services and support on the other hand. In this paper, the slippery slope framework is formalized by assuming two groups of taxpayers: compliance-minded and evasion-minded persons. Defining reaction functions for persons of both groups with respect to coercive and persuasive power instruments of tax authorities, the typical slippery slope picture emerges that characterises the authorities' work. As a consequence, both groups of policy tools are considered necessary to generate tax compliance. In addition to that, it is shown that coercive and persuasive power may be substitutes or complements to each other, depending of the parameters of the taxpayers' reaction functions. As a further crucial determinant of tax compliance, the behaviour of the fellow citizens with respect to taxpaying is identified.

1. Introduction

Tax compliance, as it seems, is a precarious behaviour from the taxpayer's viewpoint: On the one hand, paying taxes correctly is a civic duty and well accepted as a social norm among a large majority of citizens; on the other hand, tax laws, the conduct of tax authorities as well as the taxpaying behaviour of the fellow citizens make it more difficult to behave conform to the law: Tax laws are not transparent, difficult to understand, unjust and much too complicated. Tax authorities are considered too lenient with others and too stern with oneself. Moreover, other people are believed to behave unethical with respect to taxes. In this mental framework, to comply fully with the tax law is not an easy endeavour.

The first wave of economic literature on the behaviour of taxpayers was concerned with tax evasion rather than tax compliance. Applying the Becker (1968) model on crime and punishment, tax evasion was theoretically explained as rational choice (Allingham & Sandmo, 1972; Yitzhaki, 1974). However, the predicted behaviour of taxpayers differed widely from their actual behaviour: the high level of tax compliance rather than the level tax evasion was to be explained (see Andreoni,

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Erard, & Feinstein, 1998, for a survey).[1] In this respect, tax psychology plays a major role (Kirchler, 2007). Although there were early attempts to combine insights as well as methods from psychology and social psychology with the economics of taxation (see for an overview Hansmeyer & Mackscheidt, 1977), it took a long time until these insights and methods were recognized in mainstream public economics.

A recent result of the economic psychology of taxation is the so-called slippery slope framework (Kirchler et al., 2008). In this framework, *trust* in authorities and *power* of authorities as well as their *interaction* are decisive for tax compliance. In contrast to former approaches to tax compliance, it is taken into account that not all taxpayers share the same mentality to taxpaying and that not all of them react in the same way to measures of tax enforcement. Two forms of compliances are distinguished: *enforced* compliance and *voluntary* compliance. Whereas the former is assumed to depend mainly on power of authorities to enforce taxpaying, e.g., through audits and fines, the latter form of compliance depends mainly on trust in authorities and a good relationship with taxpayers, e. g., by providing certain kinds of services and support to make taxpaying easier and more convenient. Both strategies may be useful and necessary to guarantee a high level of tax compliance. As it seems, the combination of power and trust is crucial. A reduction of power and/or trust may lead to a slippery slope: At first, overall tax compliance decreases somewhat; beneath a certain level of power and/or trust, tax compliance might begin to sink quite drastically.

In the following, it is attempted to formalize the slippery slope framework of tax compliance by Kirchler et al. (2008). In the context of a macroeconomic model of the labour market, a first formalization was presented by Lisi (2012a). In Eq. (5) of Lisi (2012a), a function for the generation of trust is defined in which the level of trust increases with the power of the tax authorities up to a certain point. Beyond that point, however, a further increase of power decreases trust; as a consequence, there is a unique level of power that maximizes trust in the tax authorities (Lisi, 2012a, Fig. 1, p. 5). Since trust increases tax compliance, declared income increases with the trust level. In contrast to Lisi (2012a), in this paper two different group of taxpayers are distinguished that react differently on power and trust, respectively. The static as well as the dynamic interaction of these type-groups are essential in our opinion to understand the difficulties tax authorities may face when deciding on a strategy to enhance tax compliance.

The main contributions of the following formalization of the concept consist of the following points:

1. It concretizes ideas from the slippery slope approach by identifying the key parameters of the framework. In this way, it may serve as a starting point for empirical analyses.
2. It makes it easier to design experimental studies of the slippery slope phenomenon.
3. It provides insights for tax policy and tax authorities to set parameters for the deterrence-oriented as well as cooperation-oriented policies.

2. The model

The general idea for the following model is that tax compliance consists (in accordance with Kirchler et al., 2008) of two parts: enforced compliance and voluntary compliance. However, by contrast to the original slippery slope framework, the present model describes taxpayers from the viewpoint of the state.[2] Therefore, two *groups of taxpayers* are differentiated: a number V of tax complying people in a population of N persons and a number of E tax evaders (with $V + E = N$). This means that although the allocation of taxpayers to types is an endogenous adaptation process – which might be understood along the lines of the Gordon (1989) model in which psychic reputation costs divide evaders from compliers –, the division of people in evaders and compliers seems exogenously determined although it is actually endogenously established, but not modelled here.

In the following, c_v (c_e) denotes the probability of full tax compliance of a single compliance-minded (evasion-minded) taxpayer. Hence, the average probability of full tax compliance in a society is given by:

$$c = c_v \cdot \frac{V}{N} + c_e \cdot \frac{E}{N} = (c_v \cdot V + c_e \cdot E) \cdot \frac{1}{N} \tag{1}$$

Tax authorities are assumed to have two groups of instruments available: instruments of *coercive power* and instruments of *persuasive power*. This differentiation is inspired by Turner (2005) who distinguishes coercive power and *legitimate power*. However, with respect to taxation it might be more adequate to go a step further than Turner: The willingness of compliance-minded taxpayers to cooperate with the tax authorities might be enhanced by the service quality of tax authorities. Being served as a customer might increase cooperation of compliance-minded taxpayers, especially in cases where the tax law is not very clear and the problem of tax 'avoision' (a combination of tax avoidance and tax evasion; Seldon, 1979; Tullock, 2002, pp. 63–70) demands some degree of voluntary cooperation. Therefore the notion of 'persuasive power' instead of legitimate power will be used in the following.

[1] It is worth mentioning that also in general the crime and punishment model of Becker (1968) was put into question; for recent developments see, e.g., Tyler (2008), Licht (2008), Tabbach (2009) and Girvan (2009).

[2] In Kirchler et al. (2008) an individual perspective is adopted. Therein also a mixture of both motivations for compliance is possible, whereas in the model presented here we assume that it is one of both that primarily drives taxpayers' compliance. Furthermore, in the original framework it was assumed that taxpayers' motivation is influenced by *perceived* power of and trust in authorities rather than the actual measures applied by the state.

The aim of this paper is to present a formal model of the psychological approach of Kirchler et al. (2008; Wahl, Kastlunger, & Kirchler, 2010) on the effects of different tax policy instruments to deter tax evasion. They found experimentally a slippery slope effect of both above mentioned power instruments on tax evasion. For this reason, both instruments are considered in the formal model.[3] As shown by Lisi (2012b), both power and trust are required to bring about a high level of tax compliance (with trust seemingly more important than power). In the following the level of the employment of the power instruments is denoted by p_c for coercive and p_p for persuasive power. Furthermore, the additional employment of persuasive power is suggested to produce trust with respect to compliance-minded taxpayers. Note, however, that also the employment of coercive power is in general an instrument to create and maintain trust for compliance-minded taxpayers. In this way, those taxpayers can be assured that evasion-minded taxpayers may not end up in a better position than honest taxpayers (to the question of the role of control in creating trust see, e.g., Nooteboom, 2009). In addition to that, as pointed out by Kirchler et al. (2008), the perception of the respective instrument by the taxpayer population may be crucial. Hence, the communication and justification of the employment of instruments by the tax authorities seems to be also decisive for the creation of trust. Moreover, as argued by Cooter, Feldman, and Feldman (2008), providing accurate information about the extent of unethical behaviour with respect to, e.g., tax evasion might motivate more people to behave as required by the law. The reason for the latter is the "others are bad" bias found in psychological studies (Cooter et al., 2008). Learning that many other people behave ethically may correct the misperception of others, at least to a certain extent.

Individual tax compliance of both, compliance-minded as well as evasion-minded taxpayers will depend on the relative size of these groups. The larger (smaller) the group of evasion-minded taxpayers relative to all taxpayers, the lower (higher) will be the probability of full tax compliance in both groups. This aspect of taxpayer behaviour may be based theoretically on Axelrod's norm game (Axelrod, 1986). One of the mechanisms identified by Axelrod to support norms in a society is that one group is dominated by another. If one of the groups gains dominance, the norm itself (and the behaviour as well) may change rapidly, drastically and discontinuously (Kulakowski, 2009).

Individual tax compliance is assumed to depend on the *levels of coercive and/or persuasive power* and on the relative proportion of compliance-minded and evasion-minded taxpayers. The metric to measure both levels of power is defined as follows:

Level of $p_c(p_p)$ = {zero, very low, low, medium, high, very high, extremely high} $\rightarrow p_c\,(p_p) = \{b \cdot 0, \ldots, b \cdot 7\}$.

I.e., the (perceived) levels of coercive and persuasive power that are measured, for instance, by questionnaires according to levels from 'zero' to 'extremely high', are represented uniquely up to a cardinal transformation, e.g. by a constant number $b > 0$.[4]

Individual tax compliance probability from the viewpoint of an *evasion-minded taxpayer* is supposed to depend on the *level of coercive power* and on the share of evasion-minded to compliance-minded taxpayers in the population, but not on the level of persuasive power. The reason is that evasion-minded persons are presumably not susceptible to persuasion. The tax compliance probability may then be written as (to simplify the notation, $E/N =: e$, $V/N =: v = (1 - e)$ and $E/V = e/(1 - e) =: s$ will be used in the following)[5]:

$$c_e = \max\left[1 - p_c^{-\alpha} \cdot \left(\frac{E}{V}\right)^{\beta}, 0\right] = \max\left(1 - \frac{\left(\frac{e}{1-e}\right)^{\beta}}{p_c^{\alpha}}, 0\right) = \max\left(1 - \frac{s^{\beta}}{p_c^{\alpha}}, 0\right) \tag{2}$$

According to Eq. (2), the probability of full tax compliance of an evasion-minded taxpayer is by definition 1 if nobody (including the respective taxpayer itself) actually evades the tax, i.e. $E = e = s = 0$. Otherwise, tax compliance decreases with an increasing number of tax evaders when $\beta \geqslant 1$. The parameter β measures the degree of dependence of an evasion-minded taxpayer on the proportion of similar-minded taxpayers in the population. More technically, it may be dubbed the 'share of evasion-mindedness'-elasticity of individual compliance probability of an evasion-minded taxpayer. Note that it is not required that taxpayers actually know this share; however, taxpayers may expect a certain share of similar-minded persons within the population.[6] As a consequence, the probability to comply fully with the tax law decreases at a decreasing rate for higher shares of tax evaders. This norm-eroding influence of the number of tax evaders can be counteracted by the employment of coercive power, p_c, $p_c \geqslant 1$, by the fiscal authorities. The effectiveness of this power is represented in (2) by α, $0 < \alpha < 1$. Hence the probability of full tax compliance of an evasion-minded taxpayer is equal to or larger than zero if:

$$c_e \geqslant 0 \Longleftrightarrow e \leqslant p_c^{\frac{\alpha}{\beta}} \Big/ \left(1 + p_c^{\frac{\alpha}{\beta}}\right) \tag{3}$$

Therefore there exists a proportion of tax evaders at which the probability of full tax compliance is zero for an evasion-minded taxpayer.

[3] From a mathematical point of view, even one instrument could exhibit the slippery slope effect, as will be shown below.

[4] We like to thank an anonymous referee for this hint. – For solutions to the problem of arbitrary metrics in psychology see Blanton and Jaccard (2006).

[5] Note that Eq. (2) can be interpreted as the *individual reaction function* in a game theoretical sense of an evasion-minded taxpayer with respect to the tax authorities' employment of coercive power and to the (actual or perceived) proportion of tax evaders to tax compliers.

[6] Known as the false-consensus effect, individuals tend to overestimate generally the proportion of other persons showing the same behavior as they do (for a review see Marks & Miller, 1987).

For a *compliance-minded taxpayer*, individual tax compliance probability is defined as follows[7]:

$$c_v = \max\left[1 - p_c^{-\gamma} \cdot p_p^{-\delta} \cdot \left(\frac{E}{V}\right)^{\varepsilon}, 0\right] = \max\left(1 - \frac{s^{\varepsilon}}{p_c^{\gamma} \cdot p_p^{\delta}}, 0\right) \tag{4}$$

As for an evasion-minded taxpayer, the probability of full tax compliance of a compliance-minded taxpayer is 1 if nobody actually evades the tax, i.e. $E = 0$, and neither coercive nor persuasive power are to be employed (i.e. $p_c = p_p = 0$). Otherwise, tax compliance decreases with an increasing number of tax evaders when $\varepsilon > 0$. Hence, the probability to comply fully with the tax law decreases for higher numbers of tax evaders. The norm-eroding influence of the number of tax evaders can be counteracted via the employment of coercive power, p_c, and persuasive power, p_p, by the fiscal authorities. The effectiveness of these measures is represented in (4) by γ, $0 < \gamma < 1$, and by δ, $0 < \delta < 1$.[8]

From (4) it follows that the probability of full tax compliance of a compliance-minded taxpayer is equal to or larger than zero if:

$$c_v \geqslant 0 \Longleftrightarrow e \leqslant \left(p_c^{\gamma} \cdot p_p^{\delta}\right)^{\frac{1}{\varepsilon}} \Big/ \left[1 + \left(p_c^{\gamma} \cdot p_p^{\delta}\right)^{\frac{1}{\varepsilon}}\right] \tag{5}$$

As in the case of an evasion-minded taxpayer, also for a compliance-minded taxpayer there exists a share of tax evaders at which the probability of full tax compliance becomes zero.

3. Tax compliance and the share of tax evaders[9]: Slippery slopes

The tax compliance functions defined in (2) and (4) are dependent on the share of tax evaders. Differentiating (2) and (4), respectively, with respect to e yields:

$$\frac{\partial c_e}{\partial e} = \frac{-\beta \cdot p_c^{-\alpha} \cdot s^{\beta-1}}{(1-e)^2} < 0 \tag{6}$$

$$\frac{\partial c_v}{\partial e} = \frac{-\varepsilon \cdot p_c^{-\gamma} \cdot p_p^{-\delta} \cdot s^{-\varepsilon-1}}{(1-e)^2} < 0 \tag{7}$$

As is easy to see, in both cases the probability of full tax compliance decreases as the number of evasion-minded taxpayers increases relative to compliance-minded taxpayers.

$$\frac{\partial^2 c_e}{\partial e^2} = \frac{-\beta \cdot p_c^{-\alpha} \cdot s^{\beta-1} \cdot \left(\frac{\beta-1}{e} + 2\right)}{(1-e)^3} \tag{8}$$

$$\frac{\partial^2 c_v}{\partial e^2} = \frac{-\varepsilon \cdot p_c^{-\gamma} \cdot p_p^{-\delta} \cdot s^{\varepsilon-1} \cdot \left(\frac{\varepsilon-1}{e} + 2\right)}{(1-e)^3} \tag{9}$$

(8) indicates that for $\beta > (<) 1 - 2e$ the average rate of tax compliance of an evasion-minded taxpayer is a concave (convex) function of the share of evasion-minded taxpayers; according to (9) tax compliance of a compliance-minded taxpayer is a for $\varepsilon > (<) 1 - 2e$ a concave (convex) function of e.[10]

Figs. 1 and 2 show the surface of the individual tax compliance functions as defined in Eqs. (2) and (4). The depicted functions are specified as follows[11]:

Fig. 1:

$$c_e = 1 - p_c^{-0.8} \cdot s^{1.5} \tag{10}$$

[7] Note that Eq. (4) can be interpreted as the *individual reaction function* in a game theoretical sense of a compliance-minded taxpayer with respect to the tax authorities' employment of coercive and persuasive power as well as to the (actual or perceived) proportion of tax evaders to tax compliers.

[8] However, the restriction for the effectiveness parameter of coercive power with compliance-minded taxpayer, γ, may be too narrow. It can be argued that up to a certain degree of coercive power it increases the probability of full tax compliance, but for levels of coercive power beyond that point the probability to comply with the tax laws decreases with increases of coercive power, *ceteris paribus*. The reason is that too little as well as too much control by the authorities may give rise to distrust of compliance-minded taxpayers towards the tax authorities. As a consequence, γ could be restricted as follows: $0 < \gamma < 1$ for $0 < p_c \leqslant p_c^*$ and $\gamma < 0$ for $p_c > p_c^*$ with p_c^* as the tipping point for coercive power. Throughout the following analysis we assume $p_c < p_c^*$.

[9] Note that the mathematical characteristics of the tax compliance functions, c_e and c_v, are discussed in Appendix A.

[10] It is worth noting that the compliance level described here can be reconciled with utility theory (I thank one of the anonymous referees for the following approach to reconciliation) as presented in the Gordon (1989) model: In this model, the level of psychic cost that divides tax compliers and tax evaders is given by the difference between the expected level of utility with evasion minus the (sure) utility of paying the tax honestly. Consequently, if this cost level increases, people with higher psychic costs evade (because of increasing benefits of evasion) the tax which reduces tax compliance. Evasion increases if policy changes lead to higher utility levels of tax evasion in comparison to the (sure and therefore constant) utility level with paying the tax honestly.

[11] Note that the parameter values for α, β, δ and γ are chosen arbitrarily from the respective domains of these parameters defined in the main text. However, see the Appendix for the effects of these parameters on the qualitative features of the respective compliance function.

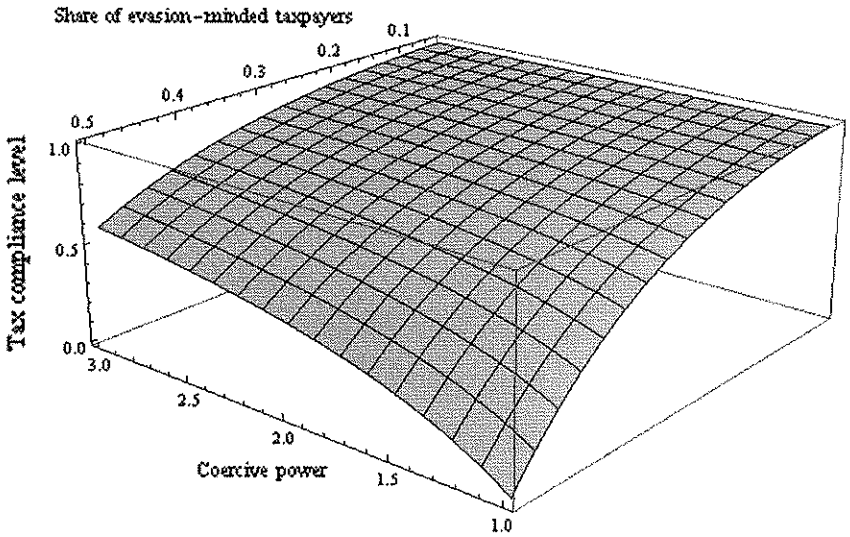

Fig. 1. Compliance probability of an evasion-minded taxpayer. Source: Own depiction.

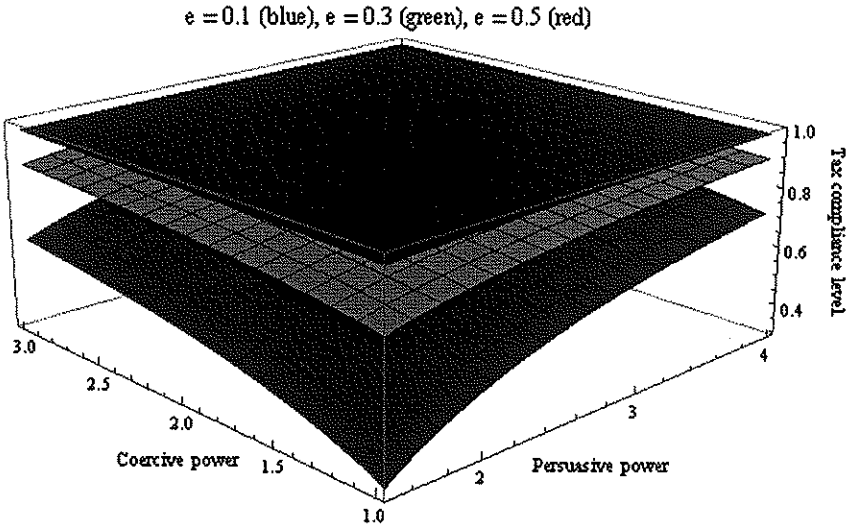

Fig. 2a. Compliance probability of a compliance-minded taxpayer (version 1). Source: Own depiction.

Fig. 2a:

$$c_v = 1 - p_c^{-0.5} \cdot p_p^{-0.9} \cdot s^{1.2} \tag{11}$$

Fig. 2b:

$$c_v = 1 - p_c^{-0.5} \cdot p_p^{0.9} \cdot s^{0.3} \tag{12}$$

In Fig. 1, the full compliance probability of an evasion-minded taxpayer is depicted as a function of the level coercive power and of the share of tax evaders in a society. The surface of the function defined by (10) exhibits the slippery slope characteristic of Kirchler et al. (2008).[12] Tax compliance of an evasion-minded taxpayer increases with a decreasing rate as the level of coercive power employed by the tax authorities increases. Moreover, tax compliance decreases at an increasing rate with an increasing share of evasion-minded taxpayers, e, within the population.

[12] Note, however, that the slippery slope characteristic in the Kirchler et al. (2008) framework arises from the interaction of *perceived* coercive and persuasive power. In the formal model presented here, it emerges from the interaction of coercive (and later on – in Figs. 2 and 3 – persuasive) power and the ratio of evasion-minded and compliance-minded taxpayers, which captures the social norm.

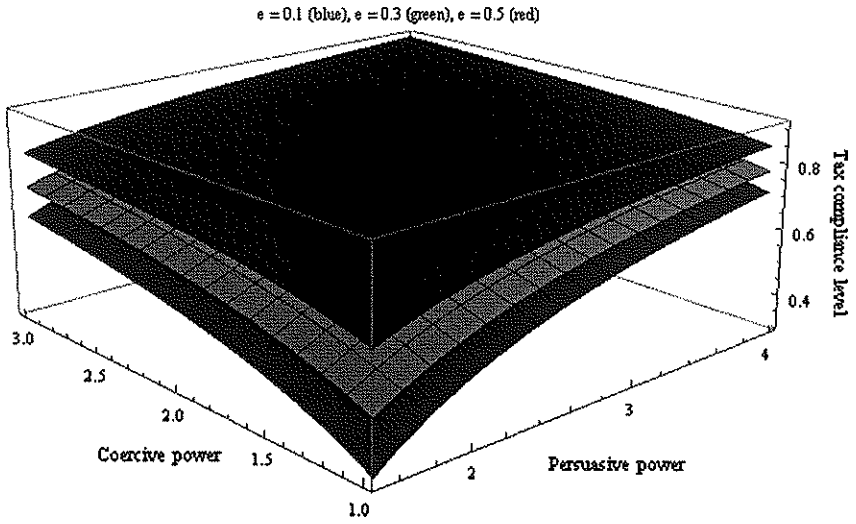

Fig. 2b. Compliance probability of a compliance-minded taxpayer (version 2). Source: Own depiction.

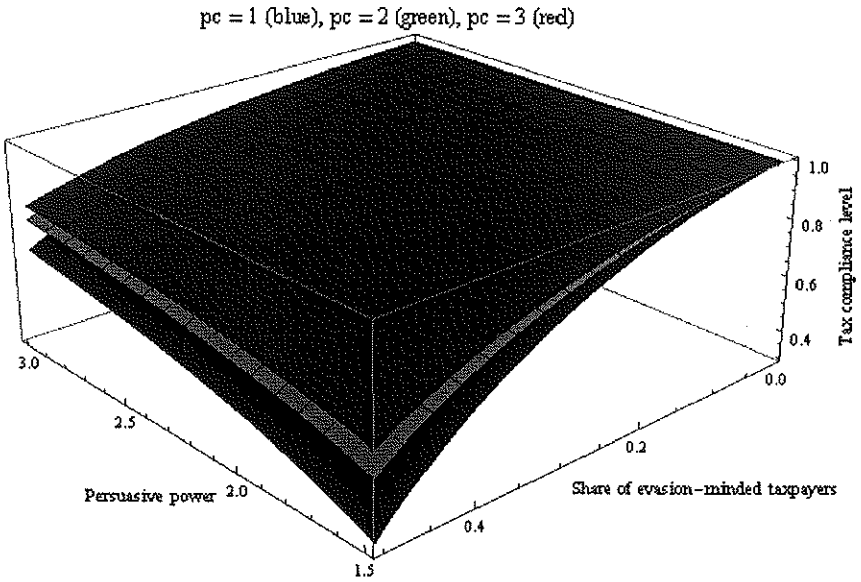

Fig. 3. Compliance probability of a compliance-minded taxpayer for different levels of coercive power. Source: Own depiction.

In Figs. 2a and 2b, the full compliance probability of a compliance-minded taxpayer is shown as a function of the level of persuasive power of the tax authorities as well as of the level of persuasive power for different values of the share of evasion-minded taxpayers in a society. In Fig. 2a it is assumed that a compliance-minded taxpayer reacts in a similar way as evasion-minded taxpayers to an increasing share of tax evaders in the society; i.e., the effect of an increasing proportion of evaders is increasing with this proportion.

Fig. 2b depicts the results for tax compliance when even a relative small proportion of tax evaders deteriorates the tax morale of compliance-minded taxpayers. For constant levels of persuasive as well as of coercive power, the compliance probability is lower and decreases rather quickly in comparison to Fig. 2a. However, also for a compliance-minded taxpayer the slippery slope characteristic emerges. Due to different coefficients of the model, tax compliance increases with both the level of persuasive power and the declining number of tax evaders in society.

In Fig. 3, in addition to the features assumed for Fig. 2a, the level of coercive power employed by the authorities is varied successively from 1 to 3. The effect is that the entire surface is lifted by this increase of coercive power. This means that the probability of full tax compliance increases as the level of coercive power is increased.

4. Taxpayer group dynamics

In the preceding sections the reactions of compliance-minded and evasion-minded taxpayers are analyzed separately. We took into account that there is a close association between both kinds of taxpayers as defined in (2) and (4) by the individual tax compliances probabilities, c_e and c_v, via the share of tax evaders, e. However, the type of taxpayer was given exogenously at the start of our analysis. As a consequence, the model was static. In the following section, the model is dynamically extended. In this extension, the initial composition of the population with tax compliers and tax evaders is given. However, the type of taxpayer may be changed if the utility level, depending (among others) on the initial relative group size of the respective taxpayer types, can be increased by a type-group change. This may be interpreted as a kind of evolutionary development; the utility levels are then considered as 'economic fitness'. Since the type change is modelled in relation to the relative utility levels of the type-groups, the ways, in which the relation of type shares develop, are described in terms of evolutionary game theory, as replicator dynamics (Sandholm, 2010). Since the shares of compliance-minded and evasion-minded taxpayers are determined via relative utility levels which depend on the level of persuasive and coercive power employed by the tax authorities, a taxpayer may switch, for instance, from the group of evasion-minded taxpayers to compliance-minded taxpayers as a consequence of changing the usage of coercive power p_c and persuasive power p_p. In this sense the static model of the previous section is dynamically extended.

To start with, the tax compliance probabilities may be translated into utility levels between 0 and 1. As said above, the tax compliance probabilities may be interpreted as reaction functions in the sense of game theory. Then the *optimal utility levels* (i.e., the indirect utility functions) for both kinds of taxpayers can be determined as follows, depending on the shares of evasion-minded to compliance-minded taxpayers (which are to be determined, given the values of coercive and persuasive power):

$$u_e = 1 - c_e \Rightarrow u_e = \max\left[1, p_c^{-\alpha}\left(\frac{e}{1-e}\right)^{\beta}\right] = \max[1, p_c^{-\alpha} s^{\beta}] \tag{13}$$

$$u_v = 1 - c_v \Rightarrow u_v = \max\left[1, p_c^{-\gamma} p_p^{-\delta}\left(\frac{e}{1-e}\right)^{\varepsilon}\right] = \max[1, p_c^{-\gamma} p_p^{-\delta} s^{\varepsilon}] \tag{14a}$$

or alternatively

$$u_v = 1 - c_v \Rightarrow u_v = \max\left[1, p_c^{-\gamma} p_p^{\delta}\left(\frac{e}{1-e}\right)^{\varepsilon}\right] = \max[1, p_c^{-\gamma} p_p^{\delta} s^{\varepsilon}] \tag{14b}$$

The level of utility of both kinds of taxpayers is assumed to be unity minus the probability of full tax compliance. This might be rationalized as follows: Tax payments are a burden and reduce utility in general; as a consequence, in Eqs. (13) and (14a) tax payments are utility reducing for both types of taxpayers.[13] However, as Allingham and Sandmo (1972) have already emphasized, besides income loss there are certainly other factors affecting utility, such as the reputation as a citizen of the community (Allingham & Sandmo, 1972), the "warm glow" of giving (Andreoni, 1990), the intrinsic value inherent in civic virtue (Frey & Jegen, 2001). Therefore in Eq. (14b) the employment of persuasive power has a positive effect on utility with respect to taxpaying.

To compare levels of utility among taxpayers, the levels of utility are defined on the interval between 0 and 1. At full tax compliance, utility is set to zero in (13) and (14a) since the tax burden is on its highest level; at a tax compliance of zero, utility reaches its highest level because the tax burden is zero. In contrast, according to (14b) full tax compliance is compatible with a utility level larger than zero (but smaller than unity) if at least some persuasive power is employed by the tax authorities. Since the compliance probabilities (as best response functions with respect to the share of evasion-minded to compliance-minded taxpayers) are employed to define utility, the resulting (normalized) utility functions are indirect (i.e. maximized with respect to e) utility functions for parameterized values of coercive and persuasive power.

Employing a formalization from econophysics for the dynamics of social groups, let be the evolution of the share of evasion-minded taxpayers as follows (Abrams, Yaple, & Wiener, 2011):

$$\frac{de}{dt} = v \cdot P_{ve}(e, u_e) - e \cdot P_{ev}(e, u_e) \tag{15}$$

In the differential equation defined by (15), t means time. P_{ve} is the probability for a compliance-minded taxpayer to become an evasion-minded taxpayer; this probability is dependent on the share of evasion-minded taxpayers and on the utility level of these taxpayers. The move of compliance-mindedness to evasion-mindedness occurs relative to the share of compliance-minded taxpayers, v. In a similar way the second term in (15) can be interpreted. There might also be a move of evasion-minded taxpayers to compliance-mindedness with a probability P_{ev} which depends on the share as well as the utility level

[13] It could be argued that the employment of persuasive power to induce more tax compliance should unambiguously lead to a higher level of utility in those taxpayers who are susceptible to persuasion. Although this might be obviously the case – see Eq. 14(b) – it is not the only possibility. The reason is that "persuasion" may convince a taxpayer to accept a tax burden without the threat of punishment, but this might be nonetheless accompanied with a lower level of utility. Theoretically speaking, persuasion would be successful without a "warm glow" on the part of the taxpayer. One can even argue that this kind of persuaded taxpaying is of moral value if and only if it is connected with a voluntarily accepted utility loss.

of evasion-minded taxpayers. The difference between these movements of taxpayers gives the change of the share of evasion-minded taxpayers over time.

To get quantitative results, let be the probability functions as follows (Abrams et al., 2011):

$$P_{ve}(e,u_e) = c \cdot e \cdot \frac{u_e}{u_v} \tag{16}$$

and

$$P_{ev}(e,u_e) = 1 - c \cdot e \cdot \frac{u_e}{u_v} \tag{17}$$

with c as the time scale coefficient (Breslavsky, 2011). Note that the probabilities defined by (16) and (17) require a restriction on c in such a way that they can obtain values between 0 and 1 only: $0 < c \leqslant u_v/(e \cdot u_e)$ for u_v, $u_e \neq 0$.

In contrast to Abrams et al. (2011) as well as Breslavsky (2011) it is assumed here that the probability to change from one group of taxpayers to the other depends on the relative size of the utility between the groups and not from absolute utilities. A practical reason for this is that relative levels of utility are easier to compare than absolute levels. Moreover, the behavioural economics literature suggests that relative utility (and consumption) levels are more important for behaviour than absolute ones (Duesenberry, 1949; Holländer, 2001; Mason, 2000).

For the model considered here, the differential equation for the dynamics of the share of evasion-minded taxpayers reads by employing Eqs. (13) and (14a):

$$\frac{de}{dt} = (1-e)\cdot c \cdot e \cdot \frac{u_e}{u_v} - e \cdot \left(1 - c \cdot e \cdot \frac{u_e}{u_v}\right) = e\left(c \cdot \frac{u_e}{u_v} - 1\right) = e\left(c \cdot \left[p_c^{\gamma-\alpha} p_p^{\delta} \left(\frac{e}{1-e}\right)^{\beta-\varepsilon}\right] - 1\right) \tag{18a}$$

or alternatively when Eq. (14b) is used instead of Eq. (14a):

$$\frac{de}{dt} = e\left(c \cdot \left[p_c^{\gamma-\alpha} p_p^{-\delta} \left(\frac{e}{1-e}\right)^{\beta-\varepsilon}\right] - 1\right) \tag{18b}$$

The steady-state of the evolutionary dynamics described by (18a) is attained when the share of evasion-minded taxpayers (and hence compliance-minded taxpayers) does no longer change (i.e., if a steady-state is reached):

$$\begin{aligned} &\tfrac{de}{dt} = e\left(c \cdot \left[p_c^{\gamma-\alpha} p_p^{\delta} \left(\tfrac{e}{1-e}\right)^{\beta-\varepsilon}\right] - 1\right) = 0 \\ &\Longleftrightarrow 1.\ e = 0, \\ &\quad 2.\ e \neq 0 : e = \frac{1}{1 + (c \cdot p_c^{\gamma-\alpha} p_p^{\delta})^{\frac{1}{\beta-\varepsilon}}}, \end{aligned} \tag{19a}$$

or alternatively when Eq. (18b) is used:

$$\begin{aligned} &\tfrac{de}{dt} = e\left(c \cdot \left[p_c^{\gamma-\alpha} p_p^{-\delta} \left(\tfrac{e}{1-e}\right)^{\beta-\varepsilon}\right] - 1\right) = 0 \\ &\Longleftrightarrow 1.\ e = 0, \\ &\quad 2.\ e \neq 0 : e = \frac{1}{1 + (c \cdot p_c^{\gamma-\alpha} p_p^{-\delta})^{\frac{1}{\beta-\varepsilon}}}, \end{aligned} \tag{19b}$$

with $0 \leqslant e < 1$.[14]

The share of compliance-minded taxpayers is given for Eq. (19a) by:

$$\begin{aligned} &v = 1 - e \\ &\Rightarrow 1.\ v = 1, \\ &\quad 2.\ v = \frac{1}{1 + (c^{-1} p_c^{\alpha-\gamma} p_p^{-\delta})^{\frac{1}{\beta-\varepsilon}}}, \end{aligned} \tag{20a}$$

and for Eq. (19b) by:

$$\begin{aligned} &v = 1 - e \\ &\Rightarrow 1.v = 1, \\ &\quad 2.v = \frac{1}{1 + (c^{-1} p_c^{\alpha-\gamma} p_p^{\delta})^{\frac{1}{\beta-\varepsilon}}}, \end{aligned} \tag{20b}$$

with $0 < v \leqslant 1$.

As a consequence, in either version of the model there are two steady-states: In the first, all taxpayers are compliance-minded. In the second, the share of evasion-minded taxpayers is smaller than 100%, but larger than 0%, depending on the policy parameters (coercive and persuasive power) and the sensitivity of the taxpayers on these measures.

[14] Note that the second solution for e can also be derived by interpreting the compliance probabilities as reaction functions on e, $c_e(e)$ and $c_v(e)$, and solving them by setting $c_e(e^*) = c_v(e^*)$ with e^* as the Nash equilibrium of the game between the taxpayers. The only difference is that in the Nash equilibrium e^* the time scale parameter c is equal to unity.

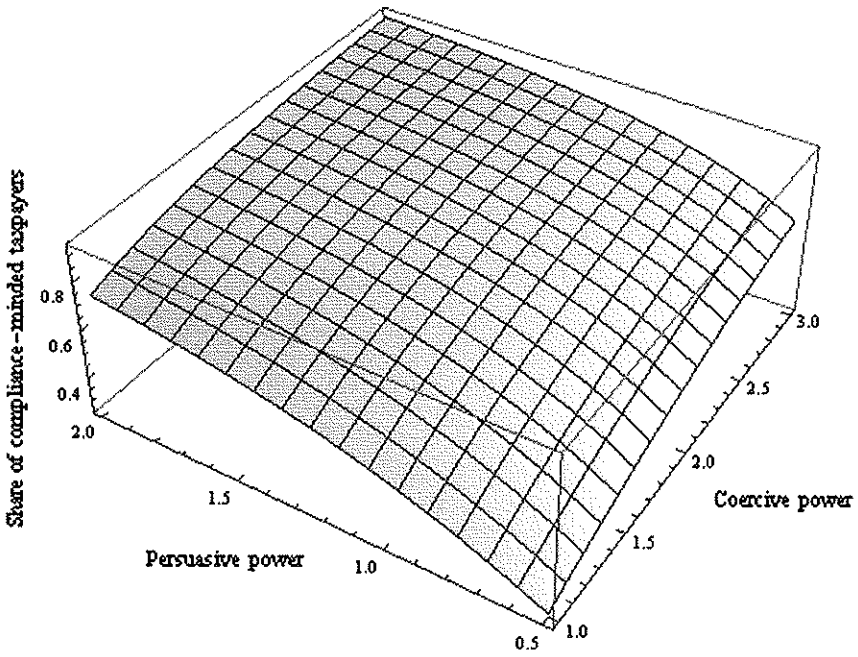

Fig. 4a. Share of compliance-minded taxpayers, v, between steady-states for different combinations of coercive and persuasive power according to Eq. (20a) for $(\beta - \varepsilon) = 0.4$. Source: Own depiction.

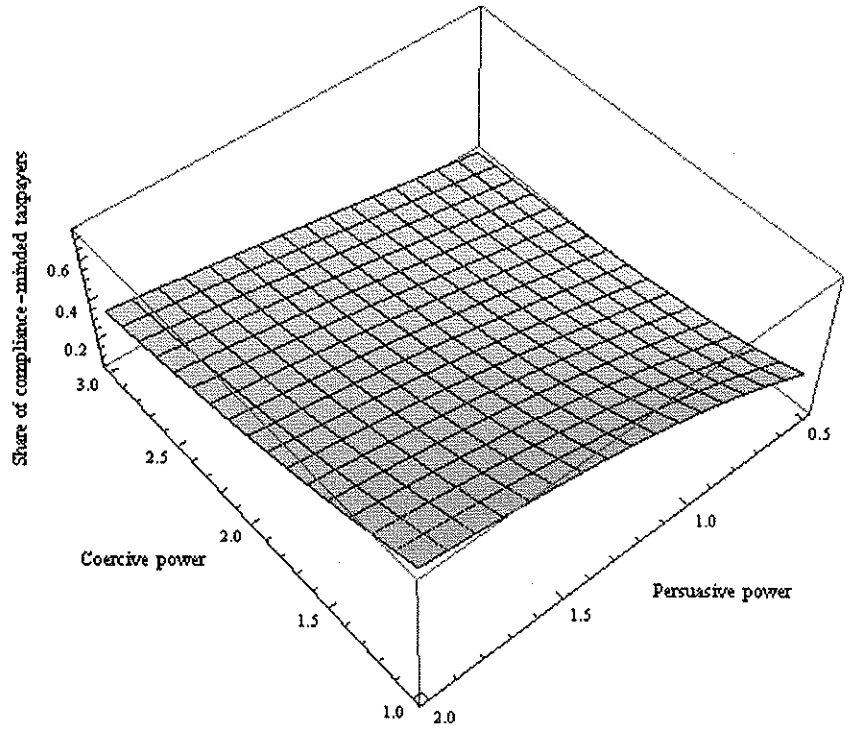

Fig. 4b. Share of compliance-minded taxpayers, v, between steady-states for different combinations of coercive and persuasive power according to Eq. (20b) for $(\beta - \varepsilon) = -0.4$. Source: Own depiction.

The slippery slope structure will emerge again if the function in (20a) that defines the steady-states of the share of compliance-minded taxpayers, $0 < v(p_c, p_p) < 1$, is concave with respect to p_c and p_p and the function in (19a), defining the share of evasion-minded taxpayers, $0 < e(p_c, p_p) < 1$, is convex with respect to these variables. Since the function in (20a) is 1 minus

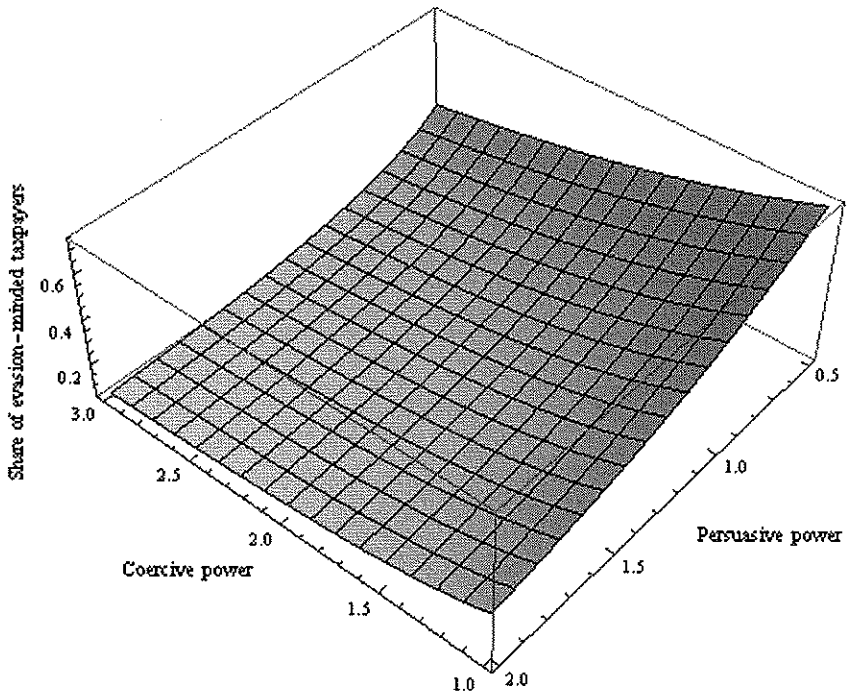

Fig. 5a. Share of evasion-minded taxpayers, e, between steady-states for different combinations of coercive and persuasive power according to Eq. (19a) for $(\beta - \varepsilon) = 0.4$. Source: Own depiction.

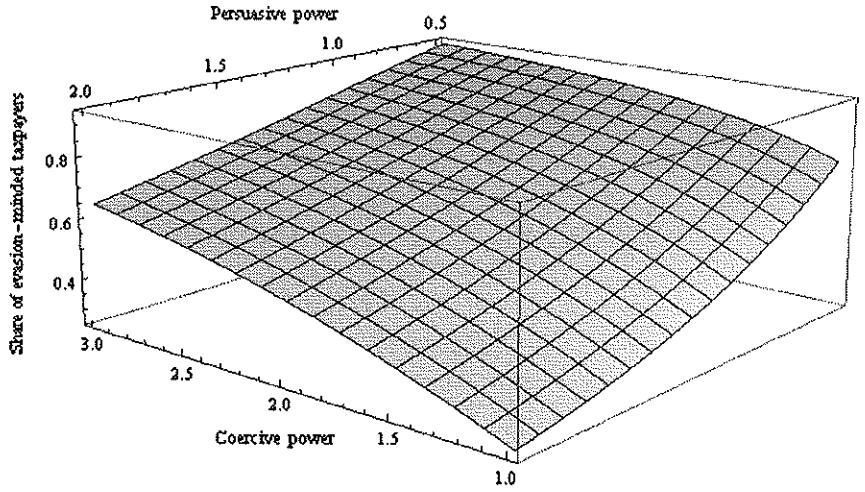

Fig. 5b. Share of evasion-minded taxpayers, e, between steady-states for different combinations of coercive and persuasive power according to Eq. (19b) for $(\beta - \varepsilon) = -0.4$. Source: Own depiction.

the share of evasion-minded taxpayers, the convexity of (19a) implies immediately the concavity of (20a). See Appendix B for the derivation of the range of values that implies concavity of $v(p_c, p_p)$ in (20a). It is worth noting that this is different for (19b) and (20b), as can be seen by Figs. 4b and 5b, respectively.

Fig. 4a shows the steady-states of the shares of compliance-minded taxpayers, v, as defined by (20a) for different combinations of levels of coercive and persuasive power. The following parameters for the determination of (20a) are employed[15]: $c = 1$, $\alpha - \gamma = -0.6$, $\delta = 0.6$, $\beta - \varepsilon = 0.4$. Obviously, the slippery slope structure emerges again.

In contrast, using $(\beta - \varepsilon) < 0$ and the otherwise same absolute parameter values as in Fig. 4a, Fig. 4b shows that the slippery slope structure changes if the employment of persuasive power creates positive utility effects among compliance-

[15] These parameters are arbitrarily chosen from their ranges identified in Appendix B.

minded taxpayers, but does not disappear. According to Fig. 4b, the share of compliance-minded taxpayers increases at a decreasing rate when persuasive power is increased whereas it decreases when coercive power is used more heavily.

For the same values as in Fig. 4a the (complementary) shares of evasion-minded taxpayers, e, as defined by (19a) are shown in Fig. 5a.

Given the parameters mentioned above, the share of evasion-minded taxpayers increases with *increasing rates* as the levels of coercive and persuasive power decrease.

In Fig. 5b, the use of persuasive power creates some positive utility effects in compliance-minded taxpayers. This also changes the surface of the change-function for evasion-minded taxpayers. Again, the slippery slope changes, but does not vanish.

To check the stability of the steady-states, the differential equation in (19a) (and (19b), respectively) is differentiated with respect to e:

$$\frac{d\left(\frac{de}{dt}\right)}{de} = c \cdot p_c^{\gamma-\alpha} p_p^{\delta} \left(\frac{e}{1-e}\right)^{\beta-\varepsilon} \cdot \left(1 + \frac{\beta-\varepsilon}{1-e}\right) - 1 \tag{21a}$$

$$\frac{d\left(\frac{de}{dt}\right)}{de} = c \cdot p_c^{\gamma-\alpha} p_p^{-\delta} \left(\frac{e}{1-e}\right)^{\beta-\varepsilon} \cdot \left(1 + \frac{\beta-\varepsilon}{1-e}\right) - 1 \tag{21b}$$

Note that a steady-state is stable if

$$d\left(\frac{de}{dt}\right) \Big/ de_{e=e^*} < 0 \tag{22}$$

Hence the first steady-state at $e_1 = 0$ in (21a) and (21b) is stable since:

$$d\left(\frac{de}{dt}\right) \Big/ de\Big|_{e=e_1} = -1 \tag{23}$$

The second steady-state at e_2 in (19a) is stable if (since $1 - e_2 > 0$):

$$d\left(\frac{de}{dt}\right) \Big/ de\Big|_{e=e_2} = \frac{\beta-\varepsilon}{1-e_2} < 0 \Longleftrightarrow \beta - \varepsilon < 0 \tag{24a}$$

and at e_2 in (19b) if (since again $1 - e_2 > 0$):

$$d\left(\frac{de}{dt}\right) \Big/ de\Big|_{e=e_2} = \frac{\beta-\varepsilon}{1-e_2} \Longleftrightarrow \beta - \varepsilon < 0 \tag{24b}$$

Consequently, e_2 is in both cases stable (unstable) if $(\beta - \varepsilon) < (>)0$. As shown in Appendix B, convexity of $e(p_c, p_p)$ requires that $(\beta - \varepsilon) > 0$. Hence the second steady-state is unstable in the first variant of the model in (18a). In this case, small deviations from e_2 will trigger an increasing or decreasing share of evasion-minded taxpayers, depending on the direction of the deviation from e_2: an increase (decrease) of the number of evasion-minded taxpayers will increase (decrease) the share of evasion-minded taxpayers. From a policy point of view this means that a positive share of evasion-minded taxpayers might be counteracted by a policy that decreases this share initially. This is different in the second variant of the model in (18b) where $(\beta - \varepsilon) < 0$ is assumed. Therefore, the second steady-state is stable in this second variant of the model.

5. Conclusion

To conclude the paper, we first determine its practical implications. In a second section we suggest approaches to test the model presented here empirically. In the final section, the paper is summarized.

5.1. Practical Implications

Empirical tax literature offers a variety of answers to the question, how coercive and persuasive power could be implemented by tax authorities (for an overview see for example Alm, 2007). Coercive power is achieved by the "classical" tools of deterrence, namely audit rates and fine rates (for a recent review of such effects see Kirchler, Muehlbacher, Kastlunger, & Wahl, 2010), but also by the effectiveness of audits, for instance through implementing different audit schemes such as the "cutoff rule" (Collins & Plumlee, 1991). Establishing persuasive power, however, might be more a complex endeavour. Several authors pointed out the importance of the interaction between tax authorities and taxpayers (e.g., Adams & Webley, 2001; Braithwaite, 2009; Cullis & Lewis, 1997; Schmölders, 1970) and claim a shift from the cops-and-robbers paradigm in tax authorities' work to a service-client approach (Alm & Torgler, 2011; Braithwaite, 2003b; Kirchler et al., 2008). It is likely to assume that a fair interaction results in higher levels of trust towards authorities and increases their persuasive power. Another issue is the (perceived) quality of authorities work. Institutional quality was shown to affect the size of the shadow economy (Torgler & Schneider, 2009), and confidence in national government institutions was shown to affect taxpayers'

morale (Fischer, 2008). Procedural fairness, i.e. transparency, consistency and fairness of the authorities' decision process, also seems to affect trust and, in turn, tax compliance (Wahl, Muehlbacher, & Kirchler, 2010). High procedural fairness is achieved by allowing citizens to give their voice and vote for their preferences in policy. Hence shifting towards a more direct democracy would increase trust in authorities and consequently persuasive power. Indeed, the rich opportunities for participation in some of the Swiss Cantons often serve as explanation for the high degree of tax morale in Switzerland (e.g., Pommerehne & Weck-Hannemann, 1996).

5.2. Suggestions for testing the model empirically

An empirical test of the model and the effects of coercive and persuasive power can be probably done most easily in the lab. For instance, both forms of power could be manipulated in an experiment using the scenario-technique. Hereby participants are required to put themselves in a situation that is presented in a vignette, which describes an artificial state exerting one or both forms of power to enforce tax compliance (c.f., Wahl, Kastlunger et al., 2010). Surveys are another possibility to test the model's assumptions. They have the advantage to allow for measuring taxpayers' perceptions of the power exerted by tax authorities. The transition from what governmental action is still perceived as persuasion or legitimate to what is clearly seen as coercion might be continuous. Measuring perceptions overcomes this problem and in addition would allow testing for the validity of distinguishing two forms of power. When using aggregate data from secondary sources such as the World Values Survey or others, levels of coercive and persuasive power can only be approximated. Proxies for both forms of power could be formed by some of the governance indicators from the World Bank (c.f., Kaufmann, Kraay, & Mastruzzi, 2010), which have previously been used to assess the quality of government (as in Torgler & Schneider, 2009), as well as power of authorities in general (as in Ruiu & Lisi, 2011). Regarding persuasive power the World Value Survey (as in Fischer & Schneider, 2009) and the Taxpayer Opinion Survey (as in Torgler, 2003) offer several items on confidence and trust in the national government, the parliament, the legal system, etc. Alternatively, coercion could be measured by the fine rates, the number of tax auditors, the budget for tax fraud investigation, etc., although admittedly these numbers are not officially published and would have to be collected first. Similarly, persuasive power could be measured for instance by the budget spent for tax services such as info-lines, websites, brochures, etc.

5.3. Summary

The model presented here is an attempt to formalize the ideas of the slippery slope framework by Kirchler et al. (2008). The basic assumption is that taxpayers follow two different motivations for compliance. First, we assume that a group of taxpayers exists, whose compliance is mainly driven by the "classical" measures of deterrence as suggested in the standard economic model of tax evasion (Allingham & Sandmo, 1972; Srinivasan, 1973). Second, we think that another group of taxpayers complies voluntary – simply because they feel morally obliged (c.f., Braithwaite, 2003a). The latter group's compliance might mainly depend on the degree of persuasive power of tax authorities, which builds a base of trust that one's tax money is in good hands. Based on these assumptions the model shows that authorities are well advised to apply *both* groups of instruments: measures that express their coercive power as well as measures of persuasive power are needed to establish tax compliance. The model captures the decreasing marginal return of these measures and demonstrates the slippery slope in tax authorities' work: Since we assume that compliance-minded and evasion-minded taxpayers are not solely influenced by the instruments applied by tax authorities, but also by prevailing norms and the (actual or perceived) tax compliance levels of their fellow citizens, an unfavorable ratio of compliers and non-compliers might erode the authorities' endeavour. Moreover, the dynamical analysis shows that the actual share of compliance-minded (evasion-minded) taxpayer can be understood as the equilibrium point of a strategic interaction of taxpayers. However, a share of evasion-minded taxpayers larger than zero and smaller than one seems to be an unstable fixed point of the dynamic if paying taxes does not provide utility for taxpayers. Hence, public policy should be careful to really decrease the share of evasion-minded taxpayers rather than to increase them. In this respect, the combination of instruments of coercive and persuasive power is crucial. If taxpayers draw utility from taxation which is based on persuasion rather than coercion, a stable equilibrium of a mix of tax evaders and tax compliers may result, which cannot be changed by small variations of both policy instruments.

Appendix A.

A.1. Mathematical characteristics of the compliance functions, c_e and c_v

To analyze the implications of the assumed tax compliance functions, the first and second derivatives are calculated with respect to coercive and persuasive power. The first derivatives indicate how the level of compliance reacts to changes in the tax authorities' instruments.

We start with *evasion-minded taxpayers* because they represent the simpler case, where only coercive power is assumed to be the driving force for compliance. The first derivative of the compliance function of *evasion-minded taxpayers* reads:

$$\frac{\partial c_e}{\partial p_c} = \alpha \cdot p_c^{-\alpha-1} \cdot s^{\beta} > 0 \tag{A1}$$

This implies that the probability of full tax compliance of evasion-minded taxpayers increases with increasing coercive power.

The second derivative of the compliance function of evasion-minded taxpayers with respect to coercive power is given by:

$$\frac{\partial^2 c_e}{\partial p_c^2} = -(\alpha+1)\cdot\alpha\cdot p_c^{-\alpha-2}\cdot s^{\beta} < 0 \tag{A2}$$

Hence, the compliance function of evasion-minded taxpayers is concave with respect to coercive power.

For a *compliance-minded taxpayer*, the marginal changes of the instruments (coercive and persuasive power) of the tax authorities are given by the following equations[16]:

$$\frac{\partial c_v}{\partial p_p} = \delta\cdot p_c^{-\gamma}\cdot p_p^{-\delta-1}\cdot s^{\varepsilon} > 0 \tag{A3}$$

$$\frac{\partial c_v}{\partial p_c} = \gamma\cdot p_c^{-\gamma-1}\cdot p_p^{-\delta}\cdot s^{\varepsilon} > 0 \tag{A4}$$

These results indicate that the probability of full tax compliance of a compliance-minded taxpayer increases with both increasing persuasive as well as coercive power.

The second derivatives of the compliance functions with respect to the power instruments are:

$$\frac{\partial^2 c_v}{\partial p_p^2} = -(\delta+1)\cdot\delta\cdot p_c^{-\gamma}\cdot p_p^{-\delta-2}\cdot s^{\varepsilon} < 0 \tag{A5}$$

$$\frac{\partial^2 c_v}{\partial p_c^2} = -(\gamma+1)\cdot\gamma\cdot p_c^{-\gamma-2}\cdot p_p^{-\delta}\cdot s^{\varepsilon} < 0 \tag{A6}$$

The cross-derivative of the compliance function of compliance-minded taxpayers is given by:

$$\frac{\partial^2 c_v}{\partial p_p \partial p_c} = -\gamma\cdot\delta\cdot p_c^{-\gamma-1}\cdot p_p^{-\delta-1}\cdot s^{\varepsilon} < 0 \tag{A7}$$

I.e., increasing the level of coercive power will decrease the *marginal* effect of persuasive power on tax compliance of compliance-minded taxpayers.

The condition for concavity of the $c_v(p_c, p_p)$ function is given by:

$$\frac{\partial^2 c_v}{\partial p_p^2}\cdot\frac{\partial^2 c_v}{\partial p_c^2} - \left(\frac{\partial^2 c_v}{\partial p_p \partial p_c}\right)^2 > 0 \tag{A8}$$

which requires:

$$1+\delta+\gamma > 0 \tag{A9}$$

Since $\delta > 0$ is assumed already, $-1-\delta < \gamma < 1$ is imposed throughout the paper.

Because of the concavity of the compliance functions for both types of taxpayers their weighted sum – i.e. the total tax compliance function – is also concave in the instruments of the fiscal authorities.

Appendix B.

B.1. Concavity of the steady-state function $v(p_c, p_p)$ (and convexity of $e(p_c, p_p)$) in (19a) and (20a)

To make the following calculations a bit easier, define:

$$A := (c^{-1}p_c^{\alpha-\gamma}p_p^{-\delta})^{\frac{1}{\beta-\varepsilon}} \tag{A10}$$

The steady-state function in (20) can be written as:

$$v(p_c,p_p) = \frac{1}{1+(c^{-1}p_c^{\alpha-\gamma}p_p^{-\delta})^{\frac{1}{\beta-\varepsilon}}} := \frac{1}{1+A} \tag{A11}$$

[16] Note that the employment of coercive power is restricted to $0 < p_c \leqslant p_c^*$.

First derivatives:

$$\frac{\partial v(p_c,p_p)}{\partial p_c}=\frac{-\frac{\alpha-\gamma}{\beta-\varepsilon}(c^{-1}p_c^{\alpha-\gamma}p_p^{-\delta})^{\frac{1}{\beta-\varepsilon}}p_c^{-1}}{[1+(c^{-1}p_c^{\alpha-\gamma}p_p^{-\delta})^{\frac{1}{\beta-\varepsilon}}]^2}=\frac{-\frac{\alpha-\gamma}{\beta-\varepsilon}Ap_c^{-1}}{(1+A)^2} \tag{A12}$$

The share of compliance-minded taxpayers increases with increasing coercive power, p_c, if:

$$\frac{\partial v(p_c,p_p)}{\partial p_c}>0\Longleftrightarrow\alpha-\gamma>0\wedge\beta-\varepsilon<0\vee\alpha-\gamma<0\wedge\beta-\varepsilon>0 \tag{A13}$$

$$\frac{\partial v(p_c,p_p)}{\partial p_p}=\frac{\frac{\delta}{\beta-\varepsilon}(c^{-1}p_c^{\alpha-\gamma}p_p^{-\delta})^{\frac{1}{\beta-\varepsilon}}p_p^{-1}}{[1+(c^{-1}p_c^{\alpha-\gamma}p_p^{-\delta})^{\frac{1}{\beta-\varepsilon}}]^2}=\frac{\frac{\delta}{p_p(\beta-\varepsilon)}A}{(1+A)^2} \tag{A14}$$

The share of compliance-minded taxpayers increases with increasing persuasive power, p_p, if:

$$\frac{\partial v(p_c,p_p)}{\partial p_p}>0\Longleftrightarrow\delta>0\wedge\beta-\varepsilon>0 \tag{A15}$$

Hence, to *increase* the share of compliance-minded taxpayers with both kinds of power, $\alpha-\gamma<0\wedge\beta-\varepsilon>0$ is to be assumed.

Second derivatives:

$$\frac{\partial^2 v(p_c,p_p)}{\partial p_c^2}=\frac{\frac{\alpha-\gamma}{\beta-\varepsilon}Ap_c^{-2}[A(1+\frac{\alpha-\gamma}{\beta-\varepsilon})+(1-\frac{\alpha-\gamma}{\beta-\varepsilon})]}{(1+A)^3} \tag{A16}$$

$$\frac{\partial^2 v(p_c,p_p)}{\partial p_p^2}=\frac{-\frac{\delta}{\beta-\varepsilon}Ap_p^{-2}[(1+A)+\frac{\delta}{\beta-\varepsilon}(1+3A)]}{(1+A)^3} \tag{A17}$$

$$\frac{\partial^2 v(p_c,p_p)}{\partial p_c\partial p_p}=\frac{\partial^2 v(p_c,p_p)}{\partial p_p\partial p_c}=\frac{\frac{\delta(\alpha-\gamma)}{(\beta-\varepsilon)^2}p_c^{-1}p_p^{-1}A(A-1)}{(1+A)^3} \tag{A18}$$

Concavity of $v(p_c, p_p)$ and convexity of $e(p_c, p_c)$, hence, requires (remember that $\alpha-\gamma<0$ and $\beta-\varepsilon>0$):

$$\frac{\partial^2 v(p_c,p_p)}{\partial p_c^2}<0\Longleftrightarrow 1+\frac{\alpha-\gamma}{\beta-\varepsilon}>0\Longleftrightarrow\beta-\varepsilon>-(\alpha-\gamma) \tag{A19}$$

$$\frac{\partial^2 v(p_c,p_p)}{\partial p_p^2}<0\Longleftrightarrow\delta>0\wedge\beta-\varepsilon>0 \tag{A20}$$

and

$$\frac{\partial^2 v(p_c,p_p)}{\partial p_c^2}\cdot\frac{\partial^2 v(p_c,p_p)}{\partial p_p^2}-\left(\frac{\partial^2 v(p_c,p_p)}{\partial p_p\partial p_c}\right)^2>0\Longleftrightarrow A^2(3\delta+\beta-\varepsilon)[(\alpha-\gamma)+(\beta+\varepsilon)]+(\delta+\beta-\varepsilon)[(\beta+\varepsilon)-(\alpha-\gamma)]>-\frac{\delta(\alpha-\gamma)}{\beta-\varepsilon}(1-A)^2 \tag{A21}$$

Note that both the left-hand side and the right-hand side of (A21) are larger than zero.

As a consequence, the assumptions for the parameters $(\alpha-\gamma)<0$, $(\beta-\varepsilon)>0$, $0<\delta<1$ and the condition in (A21) are sufficient for the concavity of $v(p_c, p_p)$ and the convexity of $e(p_c, p_c)$.

Note that A20 does not hold for the alternative model described by Eqs. (19b) and (20b). As a consequence, the alternative model exhibits no longer concavity of $v(p_c, p_p)$ and convexity of $e(p_c, p_c)$. Therefore $(\beta-\varepsilon)<0$ is assumed in Figs. 4b and 5b to get plausible results.

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