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Tax Evasion on a Social Network

Abstract

We relate tax evasion behavior to a substantial literature on self and social comparison in judgements. Tax payers engage in tax evasion as a means to boost their expected consumption relative to others in their "local" social network, and relative to past consumption. The unique Nash equilibrium of the model relates optimal evasion to a (Bonacich) measure of network centrality: more central taxpayers evade more. The indirect revenue effects from auditing are shown to be ordinally equivalent to a related Bonacich centrality. We generate networks corresponding closely to the observed structure of social networks observed empirically. In particular, our networks contain celebrity taxpayers, whose consumption is widely observed, and who are systematically of higher wealth. In this context we show that, if the tax authority can observe the social network, it is able to raise its audit revenue by around six percent.

JEL-Codes: H260, D850, K420.

Keywords: tax evasion, social networks, network centrality, optimal auditing, social comparison, self comparison, habit, indirect effects, relative consumption.

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1 Introduction

Tax evasion is a significant economic phenomenon. Estimates provided by the UK tax authority put the value of the tax gap – the difference between the theoretical tax liability and the amount of tax paid – at 6.5 percent (H.M. Revenue and Customs, 2016). Academic studies for the US and Europe put the gap substantially higher, at around 18-20 percent (Cebula and Feige, 2012; Buehn and Schneider, 2016).

In this paper we link evasion behavior to a mass of evidence that people engage continually in comparisons – with others (social comparison) and with themselves in the recent past (self comparison – or "habit"). Utility, evidence for developed economies suggests, is in large part derived from consumption relative to these comparators, rather than from its absolute level (e.g., Ferrer-i-Carbonell, 2005; Luttmer, 2005; Clark and Senik, 2010; Mujcic and Frijters, 2013). The evolutionary processes that might explain this phenomenon are explored in Postlewaite (1998), Rayo and Becker (2007) and Samuelson (2004), among others. Researchers have proposed that self and social comparison can explain economic phenomena including the Easterlin paradox (Clark *et al.*, 2008; Rablen, 2008), the equity-premium puzzle (Constantinides, 1990; Galí, 1994); stable labor supply in the face of rising incomes (Neumark and Postlewaite, 1998); upward rather than downward sloping wage profiles (Loewenstein and Sicherman, 1991; Frank and Hutchens, 1993); the feeling of poverty (Sen, 1983); the demand for risky activities (Becker *et al.*, 2005); and migration choices (Stark and Taylor, 1991). There are important consequences for consumption and saving behavior (Dybvig, 1995; Chapman, 1998; Carroll *et al.*, 2000), for the desirability of economic growth (Layard, 1980, 2005), for monetary policy (Fuhrer, 2000), and for tax policy (Boskin and Sheshinki, 1978; Ljungqvist and Uhlig, 2000; Koehne and Kuhn, 2015).

Despite the overwhelming evidence of a concern for self and social comparison, these features have yet to be explored simultaneously in the context of the tax evasion decision. In this paper we provide a network model in which taxpayers are assumed to have an intrinsic concern for income relative to a benchmark that reflects both self and social comparison.[1] Taxpayers in our model observe the consumption of a subset of other taxpayers (the "reference group") with whom they are linked on a social network. In this context, taxpayers may seek to evade tax so as to improve their standing relative to those they compare against. Taxpayers also

[1]The economics of networks is a growing field. For recent overviews, see Ioannides (2012), Jackson and Zenou (2015), and Jackson *et al.* (2017). Our analysis connects to a broader literature that applies network theory to the analysis of crime (e.g., Glaeser *et al.*, 1996; Ballester *et al.*, 2006).

benchmark their current consumption against its lagged values. The model exhibits strategic complementaries in evasion choices, so that more evasion by one taxpayer reinforces other taxpayers' decisions to evade also. Following the lead of Ballester *et al.* (2006), we utilize linear-quadratic utility functions to provide a characterization of Nash equilibrium. We show that there is a unique Nash equilibrium in which evasion is a weighted network centrality measure of the form proposed by Bonacich (1987). Network centrality is a concept developed in sociology to quantify the influence or power of actors in a network. It counts the number of all paths (not just shortest paths) that emanate from a given node, weighted by a decay factor that decreases with the length of these paths. In this sense, our contribution combines sociological and economic insights in seeking to understand tax evasion behavior.

Although the model is simple enough to admit an analytic solution, it is also sufficiently rich that it may be used to address a range of questions of interest to academics and practitioners in tax authorities. Here we focus on three such questions: first, we investigate – for an arbitrary network structure – how changes in the model's exogenous parameters affect optimal evasion; second, we explore how the marginal indirect effects arising from performing one extra audit vary across taxpayers in the network. Last, we investigate the value to a tax authority – in terms of additional revenue raised through audits – of knowing the structure of the social network. The analysis is performed on a class of generative networks that possess many of the empirically observed features of social networks – in particular allowing for highly visible celebrity taxpayers. Our results suggest that, if a tax authority moves from not observing the social network to observing fully the social network, it may increase audit revenues by around six percent. A stronger concern for social comparison by taxpayers increases the value of information relating to the social network, while a greater concentration of links within a social network decreases the value of such network information.

An important feature of our model is that it addresses explicitly the role of *local* comparisons on a social network. By contrast, the existing analytical literature on tax evasion allows only *global* (aggregate) social information to enter preferences: the global statistic that taxpayers are assumed to both have a concern for, and to be able to observe, is either (i) the proportion of taxpayers who report honestly (Gordon, 1989; Myles and Naylor, 1996; Davis *et al.*, 2003; Kim, 2003; Traxler, 2010; Ratto *et al.*, 2013); (ii) the average post-tax consumption level (Goerke, 2013); (iii) the level of evasion as a share of GDP (Dell'Anno, 2009); or (iv) the average tax payment (Mittone and Patelli, 2000; Panadés, 2004).

While reducing social information to a single statistic known to all taxpayers promotes analytical tractability, it is problematic in other respects. First, from the perspective of modelling with explicit social networks, assuming that taxpayer's observe aggregate-level information is implicitly the assumption that every taxpayer observes the behavior of every other taxpayer. As we adopt the convention that a link from i to j in the social network signifies that i can observe j's consumption, full observability is equivalent to the assumption that the social network is the complete network (in which every taxpayer is directly linked to all other taxpayers). Yet there are reasons to think that relative consumption externalities are, in fact, heterogeneous across individuals. In particular, we know that people's reference group is typically composed of "local" comparators such as neighbors, colleagues, and friends (Luttmer, 2005; Clark and Senik, 2010).[2] Moreover, implicitly assuming a complete network implies that all taxpayers are equally connected socially, thereby ruling out, in particular, the existence of "stars" or "celebrities" whose consumption is very widely observed in the network. Yet, this feature of social networks may matter for the targeting of tax audits (Andrei *et al.*, 2014).

The only literature that has enriched the analysis of social information to allow for local social information is that which uses agent-based simulation techniques as an alternative to analytical methods. Models in this tradition nonetheless employ representations of social networks that appear to differ markedly from real world examples. A common property of the network structures employed (e.g., Korobow *et al.*, 2007; Hokamp and Pickhardt, 2010; Bloomquist, 2011; Hokamp, 2014) is that the number of taxpayers who observe the behavior of each taxpayer is fixed, thereby ruling out the existence of highly-observed celebrity taxpayers. Other authors (e.g., Davis *et al.* 2003; Hashimzade *et al.*, 2014, 2016) utilize an *undirected* network, meaning that, if i is linked to j, then necessarily j is linked to i. Yet social networks display marked asymmetry in the direction of links (Foster *et al.*, 2010; Szell and Thurner, 2010).[3] We offer a model that is both analytically tractable and that allows for local comparisons on an arbitrary social network. In this sense, our approach lies in the cleavage between existing analytical and agent-based approaches, and is complementary to each.[4] We perform simulation analysis on a class of generative networks that are not subject

[2] More generally, relative consumption externalities may be viewed as a form of *peer effect*. In other contexts, generative models of peer effects predict heterogeneous exposure. For instance, when job information flows through friendship links, employment outcomes vary across otherwise identical agents with their location in the network of such links (Calvó-Armengol and Jackson, 2004).

[3] Zaklan *et al.* (2008) and Andrei *et al.* (2014) are among exceptions that do explore more general network structures.

[4] By extending analytical understanding of network effects upon tax evasion – in particular being able to

to the restrictions discussed above, and which are widely utilized to model network structures in the natural sciences. Our methodology in this regard, therefore, has applicability beyond the current context of tax evasion.

To our knowledge, no previous contribution allows simultaneously for both self and social comparison in the tax evasion decision. Goerke (2013), however, assumes an intrinsic concern for relative consumption by taxpayers. The primary focus of his contribution is, however, the derived impact on tax evasion from endogenous changes in labor supply, whereas we treat income as an exogenous parameter. In the remaining literature that considers a social dimension to the tax evasion decision, taxpayers are assumed to derive utility solely from absolute consumption, but react nonetheless to social information because they experience social stigma – the extent of which depends on the evasion of other taxpayers – if caught evading. The focus of much of this literature is on the potential for multiple equilibria, whereas our model yields a unique equilibrium. While a concern for relative consumption is compatible with the simultaneous existence of social stigma towards evaders, the two approaches differ in emphasis. Underlying the idea of social stigma is the concept of *social conformity*, in which agents seek to belong to the crowd, whereas the presumption of relative consumption theories is that individuals seek to stand out from the crowd. A literature relating to this point in the context of tax evasion supports the notion that social information impacts compliance behavior (Webley *et al.*, 1988; De Juan *et al.*, 1994; Alm and Yunus, 2009; Alm *et al.*, 2017), but rejects social conformity as the underlying mechanism (Fortin *et al.*, 2007).

A recent contribution that allows explicitly for self comparison in the tax evasion decision is Bernasconi *et al.* (2016). There are, however, important differences in approach and results. In our model, a higher level of habit consumption is associated with higher evasion, for it generates a negative internality on myopic taxpayers: higher past consumption outcomes reduce present utility. To overcome this internality, taxpayers must gamble (evade) more. Conversely, in Bernasconi *et al.*, higher habit consumption reduces tax evasion. In their model taxpayers are far-sighted, so consumption internalities do not arise. Instead, higher habit consumption levels stimulate increased risk aversion, for taxpayers are assumed infinitely loss averse over consumption levels below the habit level. By contrast, in our model, consumption may fall below its habit level in periods in which a taxpayer is audited and

prove formal comparative statics properties of the model – we assist the interpretation of simulation output from related agent-based models.

fined.

The paper proceeds as follows: section 2 develops a formal model of tax evasion on a social network. Section 3 analyzes the comparative statics predictions of the model, and section 4 characterizes the indirect effects of an audit, both on the future behavior of the audited taxpayer, and to the behavior of other, unaudited, taxpayers through the channel of social comparison. Section 5 considers the value of network information to a tax authority, and section 6 concludes. Proofs are collected in the Appendix.

2 Model

Let $\mathcal{N}$ be a set of taxpayers of size N. A taxpayer $i \in \mathcal{N}$ has an (exogenously earned) income $W_i > 0$. By law taxpayers should declare W_i to the tax authority and pay tax $\theta(W_i)$, where $\theta : \mathbb{R}_{\geq 0} \mapsto (0, W_i)$ is a non-decreasing function. If a taxpayer declares their true gross income, W_i, they receive a (legal) net disposable income $X_i \equiv X_i(W_i) = W_i - \theta(W_i)$. Taxpayers can, however, choose to declare less than their true income, thereby evading an amount of tax $E_{it} \in [0, W_i - X_i]$. Taxpayer i is audited with probability $p_i \in (0, 1)$ in each period. Heterogeneity in the p_i can arise, for example, if the tax authority conditions audit selection upon observable features of taxpayers. Audited taxpayers face a fine at rate $f > 1$ on all undeclared tax, à la Yitzhaki (1974).

Taxpayers are assumed to derive utility from their level of consumption relative to a reference level of consumption R_{it} (the determination of which we shall discuss later). As is standard in agent-based modelling, although taxpayers live for multiple periods, each makes a succession of single-period decisions and so is "myopic". In this context, myopic behavior could be the result of cognitive limitations of the part of taxpayers. Consistent with this notion, and our emphasis on social networks, Manski (1991) and McFadden (2006) argue that individuals faced with dynamic stochastic decision problems that pose immense computational challenges may instead look to other individuals to infer satisfactory policies.[5]

In each period, taxpayers behave as if they maximize expected utility, where utility is denoted by $U(.)$. The expected utility of taxpayer i at time t is therefore given by

$$\mathbb{E}(U_{it}) \equiv [1 - p_i] U(C^n_{it} - R_{it}) + p_i U(C^a_{it} - R_{it}), \tag{1}$$

[5] For a small theoretical literature that assumes far-sighted taxpayers see Levaggi and Menoncin (2012, 2013).

where consumption in the audited state (C_{it}^{a}) and not-audited states (C_{it}^{n}) is given by:

$$C_{it}^{n} \equiv X_i + E_{it}; \qquad C_{it}^{a} \equiv C_{it}^{n} - fE_{it}. \tag{2}$$

An obvious objection to this formulation is that it neglects entirely the possibility of absolute utility. Although an absolute component to utility surely exists, we note that measures of subjective wellbeing typically become uncorrelated with absolute income above a threshold of average national income estimated at $5,000 (in 1995, PPP) by Frey and Stutzer (2002). As most citizens of developed countries lie above this threshold, our model may be a reasonable approximation in such cases. Optimal evasion in period t is the solution to the problem $\max_{E_{it}} \mathbb{E}\left(U_{it}\right)$ subject to the Cournot constraint that reference consumption, R_{it}, is taken as given. The first order condition for optimal evasion is therefore given by

$$\left[1 - p_i\right] U'(C_{it}^{n}) - p_i f U'(C_{it}^{a}) = 0. \tag{3}$$

2.1 Reference Consumption

Reference consumption, R_{it}, is a function of self and social comparison. To formalize the notion of social comparison, we assume that each taxpayer observes the consumption of a non-empty set of taxpayers $\mathcal{R}_i \subset \mathcal{N}$, a set we term the *reference group.* A taxpayer, i, is said to be *observed* if their consumption is visible to at least one other taxpayer in the network, i.e., $i \in \cup_{j \in \mathcal{N} \setminus i} \mathcal{R}_j$.

We represent the observability of consumption in the form of a directed network (graph), where a link (edge) from taxpayer (node) i to taxpayer j indicates that i observes j's consumption. Links are permitted to be subjectively weighted, for some members of the reference group may be more focal comparators than are others. The network is represented as an $N \times N$ (adjacency) matrix, $\mathbf{G}$, of subjective comparison intensity weights $g_{ij} \in [0, 1]$, where $g_{ii} = 0$. We normalize the g_{ij} for each taxpayer to sum to unity: $\sum_{j \in \mathcal{R}_i} g_{ij} = 1$. Taxpayers i and j with $g_{ij} > 0$ are said to be *linked.* Accordingly, the reference group of taxpayer i is the set of all taxpayers to whom i is linked: $\mathcal{R}_i = \{j \in \mathcal{N} : g_{ij} > 0\}$. For later reference, a network, $\mathbf{G}$, in which there is a path (though not necessarily a direct link) between every pair of taxpayers is said to be *connected.* The set of connected networks we denote by $\mathcal{C}$. A necessary condition for $\mathbf{G} \in \mathcal{C}$ is that all taxpayers belonging to $\mathcal{N}$ are observed.

To define reference consumption we first introduce a latent variable, Z_{it}, which reflects self and social comparison. Specifically, Z_{it} is the sum of a level of habit consumption h_{it}

reflecting self comparison (weighted by $\iota_h > 0$), and a level of consumption s_{it} reflecting social comparison (weighted by $\iota_s > 0$):

$$Z_{it} \equiv Z(h_{it}, s_{it}) = \iota_h h_{it} + \iota_s s_{it}.$$

Habit consumption we specify as $h_{it} \equiv h_{it}(C_{t-1})$.[6] To specify s_{it} we first write expected consumption as $q_{it} = X_i + [1 - p_i f]E_{it}$. We then set s_{it} as the (weighted) mean of q_{jt} over i's reference group ($j \in \mathcal{R}_i$). This weighted average is conveniently written as $s_{it} \equiv s_{it}(\mathbf{q}_t) = \mathbf{g}_i \mathbf{q}_t$, where $\mathbf{g}_i$ is the i^{th} row of $\mathbf{G}$, and $\mathbf{q}_t$ is a $N \times 1$ column vector of the expected consumptions.

To form reference consumption, we embed Z_{it} in a simple linear difference equation, given by

$$R_{it}(h_{it}, \mathbf{q}_t) = R_{i,t-1} + \varsigma_R [Z_{it} - R_{i,t-1}]; \qquad \varsigma_R \in [0,1]. \tag{4}$$

Under the specification in (4) reference consumption adjusts towards Z_{it} in each period, with the strength of this adjustment regulated by the parameter ς_R. In this sense ς_R may be interpreted as determining the persistence of shocks to reference consumption. In the special case $\varsigma_R = 1$ there is full adjustment in every period, so $R_{it} = Z_{it}$, whereas, when $\varsigma_R = 0$, R_{it} is fixed at its initial value R_{i0} for all t.

2.2 Nash Equilibrium

Using (4) in the first order condition (3), we now solve for the unique Nash equilibrium of the model. To do this, we first define a notion of network centrality due to Bonacich (1987), which computes the (weighted) discounted sum of paths originating from a taxpayer in the network:

Definition 1 *Consider a network with (weighted) adjacency matrix* $\mathbf{G}$*. For a diagonal matrix* $\boldsymbol{\beta}$ *and weight vector* $\boldsymbol{\alpha}$*, the weighted Bonacich centrality vector is given by* $\mathbf{b}(\mathbf{G}, \boldsymbol{\beta}, \boldsymbol{\alpha}) = [\mathbf{I} - \mathbf{G}\boldsymbol{\beta}]^{-1} \boldsymbol{\alpha}$ *provided that* $[\mathbf{I} - \mathbf{G}\boldsymbol{\beta}]^{-1}$ *is well-defined and non-negative.*

[6] In writing $h_{it} = h(C_{i,t-1})$ we adopt the convention, observed widely in the empirical literature, that habit depends only on consumption in the previous period. For examples of this approach see, e.g., Muellbauer (1988), Carroll and Weil (1994) and Guariglia and Rossi (2002). As, however, we shall embed habit consumption within a long-memory reference consumption level, past consumption levels nonetheless have persistent effects.

In Definition 1, the matrix $\boldsymbol{\beta}$ specifies discount factors that scale down (geometrically) the relative weight of longer paths, while the vector $\boldsymbol{\alpha}$ is a set of weights. In the present context the matrix $[\mathbf{I} - \mathbf{G}\boldsymbol{\beta}]^{-1}$ is a form of social comparison multiplier. It measures the way in which actions by one taxpayer feed through into other taxpayers' actions. Ballester *et al.* (2006) show that $[\mathbf{I} - \mathbf{G}\boldsymbol{\beta}]^{-1}$ will be well-defined, as required in Definition 1, when $\mathbf{I} > \rho(\mathbf{G})\boldsymbol{\beta}$, where $\rho(\mathbf{G})$ is the largest absolute value of the eigenvalues of $\mathbf{G}$. Intuitively, this condition is that the local externality that a taxpayer's evasion imparts upon other taxpayers cannot be too strong. If local externality effects are too strong then the set of equations that define an interior Nash equilibrium of the model have no solution. In this case, multiple corner equilibria can instead arise (see, e.g., Bramoullé and Kranton, 2007). Focusing on the case when local externality effects are not too strong, we have the following Proposition:

Proposition 1 *If*

(i) *utility is linear-quadratic,* $U(z) = \left[b - \frac{az}{2}\right] z$, *with* $a \in \left(0, \frac{b}{\max_{i \in \mathcal{N}} W_i}\right)$ *and* $b > 0$*;*

(ii) $\mathbf{I} > \rho(\mathbf{M})\boldsymbol{\beta}$*;*

then there is a unique interior Nash equilibrium, at which the optimal amount of tax evaded is given by

$$\mathbf{E}_t = \mathbf{b}(\mathbf{M}, \boldsymbol{\beta}, \boldsymbol{\alpha}_t),$$

where

$$\begin{aligned} m_{ij} &= \frac{[1 - p_i f][1 - p_j f]}{\zeta_i} g_{ij}; \\ \beta_{ii} &= \varsigma_R \iota_s; \\ \alpha_{i1,t} &= \frac{1 - p_i f}{a\zeta_i} \{b - a[X_i - R(h_{it}, \mathbf{X})]\}; \\ \zeta_i &= [1 - p_i f]^2 + p_i [1 - p_i] f^2 > 0. \end{aligned}$$

According to Proposition 1, in the case of linear-quadratic utility a taxpayer's optimal evasion corresponds to a Bonacich centrality on the social network $\mathbf{M}$, weighted to reflect a taxpayer's marginal utility of consumption.[7] By this measure, *taxpayers that are more central in the social network evade more.* The uniqueness of equilibrium evasion follows intuitively from

[7] Marginal utility in the linear-quadratic specification is given by $U'(z) = b - az$. Accordingly, the term in braces in the expression for α_{i1t} is the marginal utility from ones own legal consumption, X_i, relative to a reference level of consumption reflecting the weighted average over the reference group of legal consumption.

the observation that, under linear-quadratic utility, each taxpayer's best response function is linear in the evasion of every other taxpayer. The social network $\mathbf{M}$ transforms the underlying comparison intensity weights, g_{ijt}, by a factor $[1 - p_i f][1 - p_j f]\zeta_i^{-1} > 0$ that reflects potential heterogeneity in audit probabilities across taxpayers. It follows that, in the special case that all taxpayers face a common audit probability, as might occur if a tax authority has committed to a policy of random auditing, no adjustment to the underlying comparison intensity weights is warranted. In this case, therefore, optimal evasion is a weighted Bonacich centrality measure on the untransformed network $\mathbf{G}$:

Corollary 1 *Under the conditions of Proposition 1 and setting $p_i = p$ for all $i \in \mathcal{N}$, the unique interior Nash equilibrium for evasion is given by $\mathbf{E}_t = \mathbf{b}(\mathbf{G}, \boldsymbol{\omega}, \boldsymbol{\alpha}_t)$, where*

$$\omega_{ii} = \frac{\iota_s \varsigma_R [1 - pf]^2}{\zeta}.$$

What if utility is not linear-quadratic? For an arbitrary twice-differentiable utility function we may generalize the model by considering the first order linear approximation around a Nash equilibrium to a set of (potentially non-linear) first order conditions of the form in (3). The resulting set of equations are given by

$$\mathbf{E}_t = \mathbf{J}\mathbf{E}_t + \hat{\boldsymbol{\alpha}}_t = [\mathbf{I} - \mathbf{J}]^{-1} \hat{\boldsymbol{\alpha}}_t = \left[\sum_{k=0}^{\infty} \mathbf{J}^k \right] \hat{\boldsymbol{\alpha}}_t, \tag{5}$$

where $\hat{\boldsymbol{\alpha}}_t$ is again a vector of weights for the different taxpayers, and $\mathbf{J}$ is a matrix of coefficients measuring how actions interact. By appropriate decomposition of $\mathbf{J}$, therefore, a solution to the equation system in (5) is a Bonacich centrality measure of the form contained in Definition 1.

The model we have outlined is sufficiently rich that it may be used to address a range of questions of interest to academics and practitioners in tax authorities. Subsequent sections will consider how changes in the exogenous parameters affect evasion; how the marginal revenue effects that arise from performing one extra audit vary across taxpayers in the social network; and the value of knowing of network information to a tax authority. To study these questions, however, requires a controlled environment that, in particular, abstracts from the stochastic perturbations generated by tax authority audits. Accordingly, in a second corollary of Proposition 1, we finish this section by defining the notion of steady state, in which $C_{it} = C_{i,t-1} = C_{it}^n$ for all $i \in \mathcal{N}$.[8] This corresponds to the state the model converges toward if the auditing process is temporarily "switched off":

Corollary 2 *In a steady state of the model consumption satisfies* $\mathbf{C}^{SS} = \mathbf{C}^{n,SS} = \mathbf{X} + \mathbf{E}^{SS}$, *where steady-state evasion,* $\mathbf{E}^{SS}$, *is given by the vector of Bonacich centralities,* $\mathbf{b}(\mathbf{M}, \boldsymbol{\beta}, \boldsymbol{\alpha}^{SS})$, *with*

$$\alpha_{i1}^{SS} = \frac{1 - p_i f}{a\zeta_i} \left\{ b - a \left[X_i - R\left(h_i^{SS}, \mathbf{X}\right)\right]\right\}.$$

3 Comparative Statics

Under linear-quadratic utility the model exhibits strategic complementaries in evasion choices: expected utility is supermodular in cross evasion choices. An advantage of this feature of the model is that we may employ the theory of monotone comparative statics (Edlin and Shannon, 1998; Quah, 2007) to analyze, in a straightforward way, the qualitative (sign) implications of changes in the underlying exogenous parameters for an otherwise arbitrary social network satisfying condition (ii) in Proposition 1.[9]

We consider a steady state of the model and analyze a permanent marginal increase in a parameter z. The model is then allowed to adjust to a new steady state. This marginal response of the steady-state level of evasion to a change in z we denote by dE_i^{SS}/dz. Because the effects of habit are not contemporaneous, the full adjustment to a new steady state (dE_i^{SS}/dz) comprises a contemporaneous adjustment ($\partial E_i^{SS}/\partial z$) and a delayed adjustment. To analyze the sign of the full adjustment, we first prove a Lemma that links the signs of the contemporaneous and full adjustments.

Lemma 1 *For an arbitrary exogenous variable,* z, *if* $\frac{\partial X_i}{\partial z}\frac{\partial E_i^{SS}}{\partial z} \geq 0$ *then*

$$\text{sign}\left(\frac{dE_i^{SS}}{dz}\right) = \text{sign}\left(\frac{\partial E_i^{SS}}{\partial z}\right).$$

According to Lemma 1, the sign of the full and contemporaneous adjustments of steady-state evasion are related. The condition in the Lemma encompasses a number of cases; in

[8] In this sense, analysis at a steady-state of the model removes unhelpful time-dependencies from the analysis. It also permits the underlying behavioral trends predicted by the model to be observed visually and calculated algebraically. These trends are otherwise obscured, both algebraically and in visual output, by uninformative noise.

[9] For an excellent introduction to monotone comparative statics methods see Tremblay and Tremblay (2010).

particular, it holds if (i) X_i is independent of z ($\partial X_i/\partial z = 0$); and (ii) if $\partial X_i/\partial z$ and $\partial E_i^{SS}/\partial z$ both take the same sign. The intuition for the condition in the Lemma is that it is sufficient to ensure that the contemporaneous adjustment of evasion, $\partial E_i^{SS}/\partial z$, and of steady-state consumption, $\partial C_i^{SS}/\partial z$, are of the same sign. In the event, however, that z induces opposing contemporaneous responses from X_i and E_i^{SS} the overall effect on steady-state consumption may take either sign, so Lemma 1 does not apply.

With Lemma 1 in hand we prove the following Proposition:

Proposition 2 *Under the conditions of Proposition 1 it holds at an interior Nash equilibrium that:*

$$\begin{aligned}
\frac{dE_i^{SS}}{da} &< 0; \qquad \frac{dE_i^{SS}}{\partial b} > 0; \\
\frac{dE_i^{SS}}{dp_i} &< 0; \qquad \frac{dE_i^{SS}}{dp_j} \leq 0; \\
\frac{dE_i^{SS}}{df} &< 0; \qquad \frac{dE_i^{SS}}{dh_{it}} > 0; \\
\frac{dE_i^{SS}}{d\iota_h} &> 0; \qquad \frac{dE_i^{SS}}{d\iota_s} > 0; \\
\frac{dE_i^{SS}}{dX_i} &\gtrless 0; \qquad \frac{dE_i^{SS}}{dX_j} \geq 0.
\end{aligned}$$

We begin with the results for the pair of parameters $\{a, b\}$ belonging to the linear-quadratic utility function. Noting that the coefficient of absolute risk aversion is given by $\mathcal{A}(z) = a[b - az]^{-1} > 0$, increases in a associate with decreased risk aversion, while increases in b associate with increased risk aversion. Consistent with this observation, increases in a cause optimal evasion to increase, while increases in b decrease optimal evasion.

An increase in one's own audit probability lowers optimal evasion, as does an increase in the audit probability of another taxpayer in the social network. The latter result is a weak inequality, but can be strengthened to a strict inequality if $\mathbf{G} \in \mathcal{C}$. When a taxpayer's audit probability increases they decrease their evasion, thereby decreasing the evasion required of other taxpayers to maintain a given level of expected relative consumption. Albeit with differences in economic interpretation, these results are in line with those of models of tax evasion that introduce social concerns through a social norm for compliance. As is standard, an increase in the fine on undeclared tax reduces optimal evasion.

The parameter, ι_s, which measures the extent to which taxpayers care about social comparison, is positively associated with evasion. Taxpayers impose a negative externality upon other taxpayers when their expected consumption increases, and the size of this externality is directly regulated by ι_s. The greater the externality, the more evasion is pushed upwards in the struggle among taxpayers to maintain relative consumption. The parameters h_{it} and ι_h, which both reflect the role of self comparison, are also positively associated with evasion, but the economic intuition (relative to social comparison) differs. Whereas social comparison generates negative *externalities*, self comparison generates negative *internalities*: past consumption outcomes affect negatively the evaluation of current consumption. To overcome this internality, taxpayers must seek a present consumption level that exceeds h_{it}, which entails attempting greater evasion.[10] The effects of self and social comparison therefore *interact positively*: the desire to out-consume one's reference group induces evasion, which then pushes up past consumption (in expectation), causing a further increase in evasion on account of the concern for self comparison.

The finding for X_j in Proposition 2 governs how a taxpayer's evasion responds to changes in the income of other taxpayers. This cross effect is always non-negative (and strictly positive if $\mathbf{G} \in \mathcal{C}$), for W_j enters optimal evasion only through $X_j(W_j)$ and $\partial X_j(W_j)/\partial W_j > 0$, so $\text{sign}(\partial E_{it}/\partial W_j) = \text{sign}(\partial E_{it}/\partial X_j)$. This effect arises as one taxpayer becoming richer implies that, to preserve their level of expected relative consumption, other taxpayers must evade more. The role of own-income is the only case where Lemma 1 does not apply, for $\partial X_i/\partial z$ and $\partial E_i^{SS}/\partial z$ are of opposite signs. Empirically, evasion and income are positively related (Clotfelter, 1983; Baldry, 1987). Accordingly, in the simulation analysis, we calibrate the model to be consistent with this evidence.

4 Indirect Effects

Consider a single audit to a taxpayer i that perturbs the steady state of the model. The revenue effects this generates are commonly broken down three ways: the *direct effect*, D_i, is the tax recovered contemporaneously with the audit that would otherwise have been evaded; the *own indirect effect* (I_{ii}) refers to the additional revenue that arises from future changes

[10] As noted in the Introduction, our finding that the level of habit consumption increases optimal evasion is the opposite of the finding of Bernasconi *et al.* (2016), who consider the intertemporal problem facing a far-sighted taxpayer. In their framework the intuition above need not hold, for taxpayers do not generate unforeseen internalities on their future selves when they consume more in the present.

in evasion behavior by the audited taxpayer i, while the *cross indirect effect* (I_{ij}) refers to the additional future revenue that arises from spillover (or "ripple") to the evasion behavior of the (unaudited) taxpayer j ($j \neq i$). Cross indirect effects occur in our model through the channel of social comparison: perturbations in the consumption of other taxpayers as a result of audit activity affect the reference consumption of other "local" taxpayers. The *aggregate indirect effect*, Σ_i, is the sum of the indirect effects across $\mathcal{N}$ from an audit of i, $\Sigma_i = \sum_{k \in \mathcal{N}} I_{ik}$. As own and cross effects are hard to distinguish empirically, studies in this tradition focus solely on the aggregate effect. Our model, however, allows us to characterize indirect effects at the individual level, and to relate heterogeneity in these effects to differences in individual characteristics.

The pattern of indirect effects across taxpayers may differ markedly from the pattern of direct effects. To see this, suppose there is a taxpayer who has high evasion but is not observed by any other taxpayer, and another who has lower evasion, but is widely observed. Choosing to audit the former taxpayer will yield a higher direct effect, but the cross indirect effects will all be zero, potentially making the latter taxpayer a more gainful choice. Understanding the pattern of indirect effects is important as empirical evidence points to their dominance over direct effects: Dubin *et al.* (1990), for instance, estimate the aggregate indirect effect of an audit to be, on average, six times larger than the direct effect in the US.[11]

Let $\mathbf{I}_i$ denote the vector of indirect effects, whose j^{th} entry corresponds to the indirect effect I_{ij}; and $\mathbf{\Sigma}$ denote the vector of aggregate cross indirect effects, whose j^{th} entry corresponds to Σ_j. In many contexts what is important to tax authorities is measures that rank audit revenue effects across taxpayers, for then audit resources may be targeted towards the highest ranked taxpayers (see, e.g., Hashimzade *et al.*, 2016). We therefore formally introduce the notion of *ordinal equivalence*: two column vectors $\mathbf{A}$ and $\mathbf{B}$ are ordinally equivalent (written $\mathbf{A} \sim \mathbf{B}$) if and only if $A_{i1} \gtreqless A_{j1} \Leftrightarrow B_{i1} \gtreqless B_{j1}$ for all distinct i, j.

Proposition 3 *The indirect revenue effects of conducting a single audit of i that perturbs the steady state of the model satisfy $\mathbf{I}_i \sim \mathbf{E}_i^{SS}\mathbf{b}(\mathbf{M}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS})$, where $\{\mathbf{M}, \boldsymbol{\beta}\}$ are defined as in Proposition 1, $\mathbf{E}_i^{SS}$ is an $N \times N$ diagonal matrix of the constant E_i^{SS}, and $\boldsymbol{\rho}_i^{SS}$ is an $N \times 1$ vector of weights given by*

$$\boldsymbol{\rho}_i^{SS} = \frac{\partial \boldsymbol{\alpha}^{SS}}{\partial C_i^{SS}}.$$

[11] Other estimates of this ratio are 2:1 (Tauchen *et al.*, 1993), 4:1 (Alm *et al.*, 2009), 11:1 (Plumley, 1996), and 15:1 (Dubin, 2007). Despite the marked variability, all estimates are consistent with the dominance of indirect effects over direct effects.

According to Proposition 3, the sizes of the own and cross indirect effects from auditing a taxpayer i are, in each case, ordinally equivalent to the product of a Bonacich centrality and i's steady-state level of evasion. Thus, more central taxpayers, in the sense of $\mathbf{b}(\mathbf{M}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS})$, generate greater indirect effects when audited. The intuition for Proposition 3 is as follows: an audit of a taxpayer i may have effects on the evasion behavior of both i and a set of other taxpayers, and these effects are long-lasting (when $\varsigma_R > 0$). Nonetheless, as the convergence of evasion back to its steady-state value is at a uniform rate for all affected taxpayers, the size of the indirect effect I_{ij} is ordinally equivalent to the size of the initial deviation from steady state of j's evasion in the period after the audit of i. This initial effect can, in turn, be decomposed exactly (by virtue of the linearity of evasion in habit consumption), into the product of the marginal effect of a change in i's consumption on j's evasion ($\partial E_j^{SS} / \partial C_i^{SS}$) and the change in i's consumption ($C_i^{n,SS} - C_i^{a,SS}$). The former writes as $\partial E_j^{SS} / \partial C_i^{SS} = b_{j1}(\mathbf{M}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS})$, and the latter writes as $C_i^{n,SS} - C_i^{a,SS} = [1 + f]\, E_i^{SS}$, which is proportional to simply E_i^{SS}. Hence, the I_{ij} rank in the same way across j as do the $b_{j1}(\mathbf{M}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS}) E_i^{SS}$.[12]

5 Audit Targeting and Network Structure

Can tax authorities observe links in social networks? Although surely the full gamut of links cannot be observed, importantly, there exist some individuals – celebrities – for whom it is common knowledge that many people observe them. Also, even for non-celebrities, the idea that tax authorities know at least something about people's associations is becoming more credible with the advent of "big data". The UK tax authority, for instance, uses a system known as "Connect", operational details of which are in the public domain (see, e.g., Baldwin and McKenna, 2014; Rigney, 2016; Suter, 2017). Connect cross-checks public sector and third-party information, seeking to detect relationships among actors. According to Baldwin and McKenna (2014), the system produces "spider diagrams" linking individuals to other individuals and to other legal entities such as "property addresses, companies, partnerships and trusts." The IRS is known to have also invested in big data heavily, but has so far been much more reticent in revealing its capabilities.

Given the discussion above, in this final section we consider the business case for investing in the means to acquire information about social networks. Can such knowledge be used to raise

[12] As an immediate corollary of Proposition 3 the vector of aggregate indirect effects satisfies $\boldsymbol{\Sigma} \sim \boldsymbol{\chi}$, where the i^{th} entry of $\boldsymbol{\chi}$ is given by $\chi_{i1} = \sum_{k \in \mathcal{N}} b_{k1}(\mathbf{M}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS}) E_i^{SS}$.

additional revenue, and, if so, how much extra might realistically be raised? We also address the related questions of how the value of network information varies with the topological properties of the network, and with the assumed level of concern for social comparison. We begin by developing a theoretical framework for analyzing rigorously these questions, and then perform simulations of this framework to obtain numerical estimates.

5.1 Theoretical Framework

To understand the value of network information to a tax authority we seek to understand the additional revenue that a tax authority could raise when moving from a position of not observing the social network to a position of fully observing the social network. To focus attention solely on the role of network information, we shall assume the tax authority observes all other information. In particular, the tax authority observes (i) the functional forms $h(.)$ and $X(.)$, which govern the formation of, respectively, habit consumption and legal disposable income; (ii) the set of audit probabilities $\{p_i\}_{i\in\mathcal{N}}$; and (iii) the parameters $\{a, b, \iota_h, \iota_s\}$.[13]

Let $\mathfrak{R}_i$ be a measure of the additional revenues accruing from an audit of taxpayer i, potentially allowing for both direct and indirect effects. In analogous fashion, let $\hat{\mathfrak{R}}_i$ be the best prediction of $\mathfrak{R}_i$ of a tax authority that cannot observe the social network. We consider a tax authority that, in each period, utilizes the vector of taxpayer income declarations, $\mathbf{d}_i$, to choose a set $\mathcal{N}_A \subset \mathcal{N}$ of taxpayers to be audited. The set $\mathcal{N}_A$ is taken to be chosen to maximize additional predicted revenue, $\hat{\mathfrak{R}}_A \equiv \sum_{j\in\mathcal{N}_A} \hat{\mathfrak{R}}_j$, subject to a binding budget constraint. The IRS, for instance, ranks tax returns for the purpose of audit selection by assigning each return a "DIF score" that reflects the potential revenue gain from auditing it (see, e.g., Alm and McKee, 2004; Plumley and Steuerle, 2004; Hashimzade *et al.*, 2016).

How does the tax authority compute $\hat{\mathfrak{R}}_i$, conditional on observing an income declaration d_i? To address this question, let the taxpayer's income declaration by denoted as d_{it}. Using this notation, we may write evasion as $E_{it} = \theta(W_i) - \theta(d_i)$, thereby giving the income declaration as

$$d_{it} = \hat{d}_{it}(W_i) = \theta^{-1}(\theta(W_i) - E_{it}(W_i)). \tag{6}$$

[13] In practice, tax authorities do not perfectly observe these quantities. Hence, to the extent that uncertainty over these quantities interacts positively with uncertainty over the structure of the network, our estimates of the value of knowledge of the latter will represent a lower bound.

The function $\hat{d}_{it}(W_i)$ in equation (6) gives the optimal disclosure d_{it} for a taxpayer with income W_i. Of relevance to our purpose, however, is the inverse function $W_i = \hat{W}(d_{it}) = \hat{d}_{it}^{-1}(d_{it})$, which gives the true income W_i of a taxpayer who optimally declares an income d_{it}. Accordingly, if the tax authority observes fully the network, then on receipt of the taxpayer's declaration d_{it} it can infer true income, W_i, *exactly*. If, however, the tax authority does not observe the social network, then $\hat{d}_{it}^{-1}(d_{it})$ must be computed with respect to the tax authority's prior beliefs about the network, rather than with respect to the true network, causing taxpayer income to be inferred imprecisely. To capture this point formally, let $\mathcal{G}$ denote the set of all feasible networks $\mathbf{G}$, for a given N. We then write $\hat{\mathfrak{R}}_i(\mathbf{G})$ as the expectation of $\mathfrak{R}_i$ over the set of all feasible networks:

$$\hat{\mathfrak{R}}_i(\mathbf{G}) = \mathbb{E}_{\mathbf{H}\in\mathcal{G}}\left(\mathfrak{R}_i\left(\hat{W}(d_i(\mathbf{G});\mathbf{H})\right)\right). \tag{7}$$

As the set $\mathcal{G}$ is unmanageably large, we approximate equation (7) by

$$\hat{\mathfrak{R}}_i(\mathbf{G}) \approx \mathfrak{R}_i\left(\hat{W}(d_i(\mathbf{G}), \mathbb{E}_{\mathbf{H}\in\mathcal{G}}(\mathbf{H}))\right),$$

where $\mathbb{E}_{\mathbf{H}\in\mathcal{G}}(\mathbf{H})$ is a network whose adjacency matrix has the (common) value $[N-1]^{-1}$ for all off-diagonal elements. Thus, the tax authority's uncertainty is represented by setting all comparison intensity weights (both within and across taxpayers) to a uniform value. Computing estimates for $\hat{\mathfrak{R}}_i(\mathbf{G})$ in this way, our analysis centers on the the statistic

$$\Delta\mathfrak{R}(\mathbf{G}) \equiv \frac{\mathfrak{R}_A(\mathbf{G}) - \hat{\mathfrak{R}}_A(\mathbf{G})}{\hat{\mathfrak{R}}_A(\mathbf{G})} \times 100 \tag{8}$$

which measures, for a given social network $\mathbf{G}$, the percentage increase in audit revenue that is achieved when a tax authority moves from not observing the social network to full observing it. To obtain numerical estimates of $\Delta\mathfrak{R}(\mathbf{G})$ we now simulate the model.

5.2 Simulation

5.2.1 The Social Network

To generate the social network, we follow the approach of network scientists, who utilize a class of network models, known as *generative models*, to investigate complex network formation (see, e.g., Pham *et al.*, 2016). In this modelling paradigm, complex networks are generated by means of the incremental addition of nodes and edges to a seed network over a long sequence of time-steps. Two processes governing the node/edge dynamics in generative models have been shown to generate features consistent with a multitude of social, biological, and technological networks (see, e.g., Redner, 1998; Adamic and Huberman, 2000; Jeong *et al.*, 2000; Ormerod and Roach, 2004; Capocci *et al.*, 2006). The first – the *node-degree* (or *preferential attachment*) process – makes the probability that a new addition to the network observes an existing taxpayer, i, a positive function of i's degree (the number of taxpayers who already observe i). The second – the *node-fitness* process – makes the probability that a new addition to the network observes an existing taxpayer, i, a positive function of i's *fitness* (an exogenous and time-invariant characteristic of node i).

At step s of the generative process consider a taxpayer i with degree $\mathfrak{d}_{is}$, and fitness $\eta_i > 0$. The separate node-degree and node-fitness processes are entwined in a single process by allowing the probability that said taxpayer i is observed by the taxpayer added at step s to be proportional to the product $\eta_i A(\mathfrak{d}_{is})$, where $A(.)$ is an increasing function. Important special cases of this approach include that of Barabási and Albert (1999), who assume η_i to be equal across taxpayers; and that of Bianconi and Barabási (2001), who assume $A(\mathfrak{d}) = \mathfrak{d}$. Recent research, however, suggests that social networks may be consistent with non-linear forms for $A(.)$. In particular, the *sublinear* specification, $A(\mathfrak{d}) = \mathfrak{d}^{\phi}$, $\phi < 1$, finds empirical support (Backstrom *et al.*, 2006; Kunegis *et al.*, 2013; Pham *et al.*, 2016). Pham *et al.* (2016: 7) estimate $\phi = 0.43$ for the social network constituted by a sample of 46,000 Facebook wall-posts, and we adopt this estimate (we also investigate the systematic effects of varying this estimate of ϕ).

In allowing for a role for node-fitness in social network formation, we are able to account for the observation that, empirically, celebrity taxpayers are surely not drawn at random from the distribution of income, but rather belong systematically to the upper tail. TV and sports stars, whose consumption habits are widely reported, are also some of the richest members of society. To replicate this feature, we equate node-fitness with income: $\eta_i = W_i$. We specify the distribution function of W_i across taxpayers to satisfy a power law, consistent with a large body of empirical evidence (e.g., Coelho *et al.*, 2008).

In our implementation we generate networks of $N = 200$ taxpayers, starting from a seed network composed of two interlinked taxpayers. Each taxpayer incrementally added to the network is linked to members of the existing network according to the outcome of five random draws under the probability distribution $\eta\mathfrak{d}_{is}^{\phi}$ discussed above. Note, however, that these draws are with replacement, so a taxpayer may be linked multiple times to another. As the model of section 2 allows for only a single, albeit weighted, link between taxpayers, we use the frequency of links realized by the generative process to construct the comparison intensity weights. Specifically, let $\#_{ij} \in \mathbb{N}$ denote the number of times taxpayer i is linked with j by the generative process. If $\#_{ij} = 0$ then taxpayers i and j are not linked. If $\#_{ij} \geq 1$ then taxpayers i and j are linked, and the intensity of the link is given by

$$g_{ij} = \frac{\#_{ij}}{\sum_{k \in \mathcal{R}_i} \#_{ik}}.$$

5.2.2 Model Functions and Parameters

Having now described the social network, we specify the remaining model functions and parameters. Habit consumption is specified as $h_{it} = C_{i,t-1}$, and, to make concrete the vector of predicted income, $\hat{\mathbf{W}}$, we specify the tax system as a linear income tax, $\theta\left(W_i\right) = \theta W_i$, where $\theta \in (0,1)$. We may then write evasion as $E_{it} = \theta\left[W_i - d_{it}\right]$ and the legal disposable income level as $X\left(W_i\right) = \left[1-\theta\right] W$. Next, we show that the vector $\hat{\mathbf{W}}$ takes the form of a weighted Bonacich centrality:

Lemma 2 *Under the conditions of Proposition 1, and with a linear income tax, the income of a taxpayer who declares income optimally according to (6) is given by*

$$\hat{\mathbf{W}}\left(\mathbf{G}\right) = \mathbf{b}(\mathbf{V}\left(\mathbf{G}\right), \boldsymbol{\kappa}, \boldsymbol{\gamma}_t\left(\mathbf{G}\right)),$$

where

$$\begin{aligned}
v_{ij} &= \frac{\left[1-p_i f\right]\left[1-p_j f\right] g_{ij}}{\xi_i}; \\
\kappa_{ii} &= \theta \varsigma_R \iota_s; \\
\gamma_{ij,t} &= \frac{\{1+\left[f-2\right] p_i f\}\theta a d_{it} + b\left[1-p_i f\right]}{a \xi_i} + \frac{\left[1-p_i f\right] R(h_{it}, \mathbf{X} - \boldsymbol{\psi}\mathbf{d}_t)}{\xi_i}; \\
\psi_{ii} &= \theta\left[1-p_i f\right]; \qquad \psi_{ij} = 0 \ (j \neq i); \\
\xi_i &= \left[1-\theta\right]\left[1-p_i f\right] + \theta\left\{1+\left[f-2\right] p_i f\right\} > 0.
\end{aligned}$$

We now choose the audit probabilities. Although $\hat{\mathbf{W}}\left(\mathbf{G}\right)$ in Lemma 2 controls for the systematic effects of the p_i, nonetheless the quantitative findings are not wholly immune to the values chosen. The restriction to interior equilibria, however, pins down the implied pattern of the p_i across taxpayers. To see this, suppose a taxpayer will belong to $\mathcal{N}_A$ (i.e., $p_i = 1$) then they will optimally choose the corner solution $E_i = 0$. Similarly, if a taxpayer will not belong to $\mathcal{N}_A$ (i.e., $p_i = 0$) they will optimally choose the other corner solution, $E_i = \theta W_i$. To avoid a corner solution, therefore, no taxpayer must belong to $\mathcal{N}_A$ for sure. The only instance in which random selection of the set $\mathcal{N}_A$ is optimal is when the $\hat{\mathfrak{R}}_i$ are equal across all taxpayers, such that every taxpayer is predicted to be an equally attractive audit target. We therefore choose the p_i to equalize the $\hat{\mathfrak{R}}_i$, where we take $\mathfrak{R}_i$ to be the total additional revenue accruing from an audit of taxpayer i, allowing for both direct and indirect effects ($\mathfrak{R}_i = D_i + \Sigma_i$).[14] As we find multiple such solutions for the p_i, we choose the one corresponding as closely as possible to an observed level of steady-state evasion of 20 percent, as is broadly consistent with the empirical evidence for developed countries cited in the Introduction.[15]

As the memory parameter, ς_R, governs – independently of the other parameters – the rate of convergence of evasion back to its steady-state level, it may be calibrated using a growing body of empirical evidence (Gemmell and Ratto, 2012; DeBacker *et al.*, 2015, 2017; Advani *et al.*, 2017; Mazzolini *et al.*, 2017) that own indirect effects persist for approximately four years after an audit. Figure 1 shows the temporal profile of the deviation in evasion from its steady-state level following an audit. It may be seen that, when interpreting periods as years, for $\varsigma_R = 0.9$ the model predicts a speed of convergence that matches closely the empirical evidence. A level of fine $f \in [1.5, 2]$ is broadly consistent with practice in the UK and US, and we set $f = 1.75$. As an approximation to income tax schedules in many developed countries, we set $\theta = 0.3$.

Values for the parameters $\{a, b, \iota_s\}$ cannot be chosen with reference to an existing empirical evidence base. As such, the values we use in the reported results – $\{a, b, \iota_s\} = \{2, 80, 1.5\}$ – are intended only to be interpreted as illustrative. We have, however, examined the model over a range of parameter values consistent with the conditions in Proposition 1. Although, for brevity, we do not report the results of these additional simulations, they suggest that our qualitative findings are not affected by the precise settings of these parameters.

[14] This is an objective setting of $\mathfrak{R}_i$ in the sense that \$1 of direct revenue is valued equivalently to \$1 of indirect revenue. We note as an aside, however, that tax authorities often place greater weight on direct revenue than on indirect revenue, for the former is tangible, whereas the latter is much less tangible: it must be inferred against a counterfactual that is never actually observed.

[15] Solutions for the p vector are obtained numerically to an arbitrary degree of precision using the augmented Lagrange multiplier method with a sequential quadratic programming (SQP) interior algorithm (see, e.g., Bertsekas, 1982).

Using the parameter values specified above, the empirical observation that tax evasion is increasing in income permits us to place a lower bound on ι_h, which measures the concern for habit. As may be verified by differentiation in Proposition 1, optimal evasion is linear in X_i – and thereby in W_i – and the gradient of this linear relationship is itself linearly increasing in ι_h. Figure 2 depicts the gradient $\partial E_i^{SS}/\partial W_i$ for different values of ι_h; $\partial E_i^{SS}/\partial W_i > 0$ for $\iota_h > 0.9995$. Satisfying this lower bound, we choose to align ι_h with ι_s by setting $\iota_h = 1.5$ in the main results.[16]

5.2.3 Results

To compute an estimate of $\Delta\mathfrak{R}(\mathbf{G})$, as defined in (8), we simulate the model in the manner described above. As, however, $\Delta\mathfrak{R}(\mathbf{G})$ is defined for a single $\mathbf{G}$ it has the potential to be misleading when the realized $\mathbf{G}$ is unrepresentative of the generative process. Moreover, computation of $\Delta\mathfrak{R}(\mathbf{G})$ is sufficiently burdensome to make its calculation for many different $\mathbf{G}$ infeasible. To mitigate this source of variability, therefore, we instead form $\mathbf{G}$ as the average of multiple independent iterations of the generative process.[17] We then obtain

$$\Delta\mathfrak{R}(\mathbf{G}) = 6.01. \tag{9}$$

Our result in (9) is that knowledge of the network increases audit revenues by six percent. Thus, in a way we have made precise, knowledge of the structure of social networks is of value to tax authorities.

How does the estimate in (9) respond as a function of ι_s, the weight attached to social comparison? Figure 3 depicts estimates for $\Delta\mathfrak{R}(\mathbf{G})$ as ι_s is varied on the interval $[0, 3]$. For $\iota_s = 0$ the evasion decision is based entirely on private information, and the network plays no role. In this case the tax authority can predict evasion perfectly even when not observing the network (implying $\Delta\mathfrak{R}(\mathbf{G}) = 0$). As ι_s is increased above zero taxpayers exhibit increasing concern for social comparison, with the implication that network information increases in value, for it becomes more critical to predicting patterns of evasion across taxpayers.

It is also of interest to understand the systematic effects of network structure. Figure 4 depicts the estimates for $\Delta\mathfrak{R}(\mathbf{G})$ as ϕ is varied on the interval $[0, 1]$. Note that ϕ regulates the

[16] Summarizing, the fixed parameter values used in all figures in this paper are $a = 2$, $b = 80$, $\iota_h = \iota_s = 1.5$, $f = 1.75$, $\theta = 0.3$, $\phi = 0.43$. Our codes are available upon request.

[17] That is, each element g_{ij} of $\mathbf{G}$ is the mean of the realized comparison intensity weights across the independently generated networks. We do not average over a prescribed number of iterations, but rather implement a stopping rule that monitors the rate of convergence of the sample mean towards the true mean.

importance of node-degree (preferential attachment) in the network formation process: high values of ϕ produce networks with a highly concentrated distribution of links, implying the existence of a small number of extremely visible taxpayers. It is seen that as the concentration of links is increased the value of network information decreases monotonically. This finding might appear counterintuitive at first glance, for the level of heterogeneity between the most and least visible taxpayers in the network grows with ϕ, seemingly making network effects more pronounced. The widening gap at the extremes of the distribution of links masks, however, the reality that the variability across taxpayers in reference consumption actually diminishes with ϕ. As ϕ increases a growing proportion of taxpayers have the same few celebrity taxpayers in their reference group. As everyone is, by degrees, comparing to the same set of taxpayers, the amount of variability in the social information obtained by each taxpayer decreases. This reduction in variance permits a tax authority to target audits effectively, even when not observing the network, thereby reducing the value of obtaining network information.

6 Conclusion

Tax evasion is estimated to cost governments of developed countries up to 20 percent of income tax revenues. We link the tax evasion decision with a large literature on the role in individual decision-making of self and social comparison. Previous studies have focused on only one of these forms of comparison, and social comparison has been restricted to comparisons at the aggregate, rather than local, level. Moreover, the network structures that have been employed in these models possess few of the topological properties of observed social networks.

In this paper we have sought to provide an analysis that addresses these issues. Taxpayers compare their consumption with others in their social network, and also to their own consumption in the recent past. In making social comparisons, each taxpayer makes "local" comparisons on their part of the social network. Engaging in tax evasion is a tool by which taxpayers can seek to increase their consumption relative to others, and relative to their own prior consumption. In this setting, we show that a linear-quadratic specification of utility yields a unique solution for optimal evasion corresponding to a weighted Bonacich centrality measure on a social network: by this measure, taxpayers that are more central in the social network evade more.

Our model provides a rich framework for understanding how a variety of variables, some under the control of tax authorities, will influence evasion behavior. Although optimal evasion depends in quite a complex way on the underlying parameters, we are able to sign unambiguously its comparative statics for all but one of the exogenous parameters. Allowing for self comparison makes ours a dynamic model in which audits have long-lasting impacts. This permits a rich decomposition of the direct and indirect effects of an audit. Although the precise value of indirect effects is algebraically complex in our model, we show that a relatively simple Bonacich centrality measure is ordinally equivalent to the vector of individual indirect effects. We believe the techniques developed in this regard may be used to understand more generally the predictions of a range of related social network models.

We show that network information allows a tax authority to better predict the likely revenue benefits from conducting an audit of a particular taxpayer. We obtain numerical estimates of this effect using a social network that permits, in particular, the existence highly-observed "celebrity" taxpayers belonging systematically to the upper tail of the income distribution. Although our precise numerical estimates must be treated with care due to uncertainty over some of the parameter values of the model, our results point to an important role for network effects: audit revenues are increased by around six percent when network information is known, relative to when it is not.

We finish with some possible avenues for future research. First, the comparative statics exercises we have performed are by no means exhaustive: it would, for instance, also be of interest to investigate systematically the effects of adding or removing links within the social network. Second, while we have focused on tax evasion, it seems possible to extend the model to consider tax avoidance behavior, or indeed criminal activity more generally. While these extensions must await a dedicated treatment, we hope our contribution at least clarifies the role of self and social comparison in driving tax evasion behavior on a social network.

References

Adamic, L.A. and Huberman, B.A. (2000). "Power-law distribution of the World Wide Web", *Science* 287(5461), 2115.

Advani, A., Elming, W., and Shaw, J. (2017). "The dynamic effects of tax audits". Working Paper W17/24, Institute for Fiscal Studies.

Alm, J., Bloomquist, K.M., and McKee, M. (2017). "When you know your neighbour pays taxes: Information, peer effects and tax compliance", *Fiscal Studies* 38(4), pp. 587–613.

Alm, J. and McKee, M. (2004). "Tax compliance as a coordination game", *Journal of Economic Behavior & Organization* 54(3), pp. 297–312.

Alm, J., Jackson, B.R., and McKee, M. (2009). "Getting the word out: Enforcement information dissemination and compliance behavior", *Journal of Public Economics* 93(3-4), pp. 392–402.

Alm, J. and Yunus, M. (2009). "Spatiality and persistence in U.S. individual income tax compliance", *National Tax Journal* 62(1), pp. 101–124.

Andrei, A.L., Comer, K., and Koelher, M. (2014). "An agent-based model of network effects on tax compliance and evasion", *Journal of Economic Psychology* 40(1), pp. 119–133.

Backstrom, L., Huttenlocher, D., Kleinberg, K., and Lan, X. (2006). "Group formation in large social networks: membership, growth, and evolution". In *Proceedings of the 12th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, pp. 44-54, New York: Association for Computing Machinery.

Baldry, J.C. (1987). "Income tax evasion and the tax schedule: Some experimental results", *Public Finance / Finances Publiques* 42(3), pp. 357–383.

Baldwin, R. and McKenna, A. (2014) "Well connected", *Taxation* 174 (4467).

Ballester, C., Calvó-Armengol, A., and Zenou, Y. (2006). "Who's who in networks. Wanted: the key player", *Econometrica* 74(5), pp. 1403–1417.

Barabási, A.-L. and Albert, R. (1999). "Emergence of scaling in random networks", *Science* 286 (5439), pp. 509–512.

Becker, G., Murphy, K., and Werning, I. (2005). "The equilibrium distribution of income and the market for status", *Journal of Political Economy* 113(2), pp. 282–310.

Bernasconi, M., Levaggi, R., and Menoncin, F. (2016). "Dynamic tax evasion with habit formation", Working Paper No. 31, Department of Economics, Ca' Foscari University of Venice.

Bertsekas, D.P. (1982). *Constrained Optimization and Lagrange Multiplier Methods*, New York: Academic Press.

Bianconi, G. and Barabási, A.-L. (2001). "Competition and multiscaling in evolving networks", *Europhysics Letters* 54(4), pp. 436–442.

Bloomquist, M.K. (2011). "Tax compliance as an evolutionary coordination game: An agent-based approach", *Public Finance Review* 39(1), pp. 25–49.

Bonacich, P. (1987). "Power and centrality: A family of measures", *American Journal of Sociology* 92(5), pp. 1170–1182.

Boskin, M. and Sheshinski, E. (1978). "Optimal redistributive taxation when individual welfare depends upon relative income", *Quarterly Journal of Economics* 92(4), pp. 589–601.

Bramoullé, Y. and Kranton, R. (2007). "Public goods and networks", *Journal of Economic Theory* 135(1), pp. 478–494.

Buehn, A. and Schneider, F. (2016). "Size and development of tax evasion in 38 OECD countries: What do we (not) know?", *Journal of Economics and Political Economy* 3(1), DOI: 10.1453/jepe.v3i1.634

Calvó-Armengol, A. and Jackson, M.O. (2004). "The effects of social networks on employment and inequality", *American Economic Review* 94(3), pp. 426–454.

Capocci, A., Servedio, V.D.P., Colaiori, F., Buriol, L.S., Donato, D., Leonardi, S., and Caldarelli, G. (2006). "Preferential attachment in the growth of social networks: The internet encyclopedia Wikipedia", *Physical Review E* 74(3). DOI: 10.1103/PhysRevE.74.036116

Carroll, C.D., Overland, J., and Weil, D.N. (2000). "Saving and growth with habit formation", *American Economic Review* 90(3), pp. 341–355.

Carroll, C.D. and Weil, D.N. (1994), "Saving and growth: a reinterpretation", *Carnegie-Rochester Conference Series on Public Policy* 40(1), pp. 133–192.

Cebula, R.J. and Feige, E.L. (2012). "America's unreported economy: measuring the size, growth and determinants of income tax evasion in the U.S.", *Crime, Law and Social Change* 57(3), pp. 265–285.

Chapman, D.A. (1998). "Habit formation and aggregate consumption", *Econometrica* 66(5), pp. 1223–1230.

Clark, A.E., Frijters, P., and Shields, M.A. (2008). "Relative income, happiness, and utility: An explanation for the Easterlin paradox and other puzzles", *Journal of Economic Literature* 46(1), pp. 95–144.

Clark, A.E. and Senik, C. (2010). "Who compares to whom? The anatomy of income comparisons in Europe", *Economic Journal* 120(544), pp. 573–594.

Clotfelter, C.T. (1983). "Tax evasion and tax rates: An analysis of individual returns", *Review of Economics and Statistics* 65(3), pp. 363–373.

Coelho, R., Richmond, P., Barry, J., and Hutzler, S. (2008). "Double power laws in income and wealth distributions", *Physica A* 387(15), pp. 3847–3851.

Constantinides, G.M. (1990). "Habit formation: a resolution of the equity premium puzzle", *Journal of Political Economy* 98(3), pp. 519–543.

Davis, J.S., Hecht, G., and Perkins, J.D. (2003). "Social behaviors, enforcement, and tax compliance dynamics", *Accounting Review* 78(1), pp. 39–69.

DeBacker, J., Heim, B.T., Tran, A., and Yuskavage, A. (2015). "Once bitten, twice shy? The lasting impact of IRS audits on individual tax reporting". Paper presented at the NBER Public Economics Program Meeting, Cambridge, MA.

DeBacker, J., Heim, B.T., Tran, A., and Yuskavage, A. (2017). "The effects of IRS audits on EITC claimants", Mimeo.

De Juan, A., Lasheras, M.A., and Mayo, R. (1994). "Voluntary tax compliant behavior of Spanish income tax payers", *Public Finance / Finances Publiques* 49(S), pp. 90–105.

Dell'Anno, R. (2009). "Tax evasion, tax morale and policy maker's effectiveness", *Journal of Socio-Economics* 38(6), pp. 988–997.

Dubin, J. (2007). "Criminal investigation enforcement activities and taxpayers noncompliance" *Public Finance Review* 35(4), pp. 500–529.

Dubin, J., Graetz, M., and Wilde, L.L. (1990). "The effect of audit rates on the Federal Individual Income Tax 1977-1986", *National Tax Journal* 43(4), pp. 395–409.

Dybvig, P.H. (1995). "Duesenberry's ratcheting of consumption: Optimal dynamic consumption and investment given intolerance for any decline in standard of living", *Review of Economic Studies* 62(2), pp. 287–313.

Edlin, A.S. and Shannon, C. (1998). "Strict monotonicity in comparative statics", *Journal of Economic Theory* 81(1), pp. 201–219.

Ferrer-i-Carbonell, A. (2005). "Income and well-being: an empirical analysis of the comparison income effect", *Journal of Public Economics* 89(5-6), pp. 997–1019.

Fortin, B., Lacroix, G., and Villeval, M.-C. (2007). "Tax evasion and social interactions", *Journal of Public Economics* 91(11-12), pp. 2089–2112.

Foster, J.G., Foster, D.V., Grassberger, P., and Paczuski, M. (2010). "Edge direction and the structure of networks", *PNAS* 107(24), pp. 10815–10820.

Frank, R.H. and Hutchens, R.M. (1993). "Wages, seniority, and the demand for rising consumption profiles", *Journal of Economic Behavior & Organization* 21(3), pp. 251–276.

Frey, B.S. and Stutzer, A. (2002). *Happiness and Economics*, Princeton: Princeton University Press.

Fuhrer, J.C. (2000). "Habit formation in consumption and its implications for monetary-policy models", *American Economic Review* 90(3), pp. 367–390.

Galí, J. (1994). "Keeping up with the Joneses: consumption externalities, portfolio choice, and asset prices", *Journal of Money, Credit, and Banking* 26(1), pp. 1–8.

Gemmell, N. and Ratto, M. (2012). "Behavioral responses to taxpayer audits: Evidence from random taxpayer inquiries", *National Tax Journal* 65(1), pp. 33–58.

Glaeser, E., Sacerdote, B., and Scheinkman, J. (1996). "Crime and social interactions", *Quarterly Journal of Economics* 111(2), pp. 507–548.

Goerke, L. (2013). "Relative consumption and tax evasion", *Journal of Economic Behavior & Organization* 87(1), pp. 52–65.

Gordon, J.P.P. (1989). "Individual morality and reputation costs as deterrents to tax evasion", *European Economic Review* 33(4), pp. 797–805.

Guariglia, A. and Rossi, M. (2002). "Consumption, habit formation, and precautionary saving: evidence from the British Household Panel Survey", *Oxford Economic Papers* 54(1), pp. 1–19.

Hashimzade, N., Myles, G.D., Page, F., and Rablen, M.D. (2014). "Social networks and occupational choice: The endogenous formation of attitudes and beliefs about tax compliance", *Journal of Economic Psychology* 40(1), pp. 134–146.

Hashimzade, N., Myles, G.D., and Rablen, M.D. (2016). "Predictive analytics and the targeting of audits", *Journal of Economic Behavior & Organization* 124(1), pp. 130–145.

H.M. Revenue and Customs (2016). *Measuring Tax Gaps 2016 Edition: Tax Gap Estimates for 2014-15*. London: H.M. Revenue and Customs.

Hokamp, S. (2014). "Dynamics of tax evasion with back auditing, social norm updating, and public goods provision – an agent-based simulation", *Journal of Economic Psychology* 40(1), pp. 187–199.

Hokamp, S. and Pickhardt, M. (2010). "Income tax evasion in a society of heterogeneous agents – evidence from an agent-based model", *International Economic Journal* 24(4), pp. 541–553.

Ioannides, Y. (2012). *From Neighborhoods to Nations: The Economics of Social Interactions*, Princeton: Princeton University Press.

Jackson, M.O., Rogers, B.W., and Zenou, Y. (2017). "The economic consequences of social-network structure", *Journal of Economic Literature* 55(1), pp. 49–95.

Jackson, M.O. and Zenou, Y. (2015). Games on networks. In P. Young and S. Zamir (Eds.), *Handbook of Game Theory*, Vol. 4, pp. 34–61, Amsterdam: Elsevier.

Jeong, H., Tombor, B., Albert, R., Oltvai, Z., and Barabási, A. (2000). "The large-scale organization of metabolic networks", *Nature* 407, pp. 651–654.

Kim, Y. (2003). "Income distribution and equilibrium multiplicity in a stigma-based model of tax evasion", *Journal of Public Economics* 87(7-8), pp. 1591–1616.

Koehne, S. and Kuhn, M. (2015). "Optimal taxation in a habit formation economy", *Journal of Public Economics* 122(1), pp. 31–39.

Korobow, A., Johnson, C., and Axtell, R. (2007). "An agent-based model of tax compliance with social networks", *National Tax Journal* 60(3), pp. 589–610.

Kunegis, J., Blattner, M., and Moser, C. (2013). "Preferential attachment in online networks: measurement and explanations". In *Proceedings of the 5th Annual ACM Web Science Conference*, pp. 205-214, New York: Association for Computing Machinery.

Layard, R. (1980). "Human satisfactions and public policy", *Economic Journal* 90(360), pp. 737–750.

Layard, R. (2005). *Happiness. Lessons from a New Science*, London: Allen Lane.

Levaggi, R. and Menoncin, F. (2012). "Tax audits, fines and optimal taxation in a dynamic context", *Economics Letters* 117(1), pp. 318–321.

Levaggi, R. and Menoncin, F. (2013). "Optimal dynamic tax evasion", *Journal of Economic Dynamics and Control* 37(11), pp. 2157–2167.

Ljungqvist, L. and Uhlig, H. (2000). "Tax policy and aggregate demand management under catching up with the Joneses", *American Economic Review* 90(3), pp. 356–366.

Loewenstein, G. and Sicherman, N. (1991). "Do workers prefer increasing wage profiles?", *Journal of Labor Economics* 9(1), pp. 67–84.

Luttmer, E.F.P. (2005). "Neighbors as negatives: Relative earnings and well-being", *Quarterly Journal of Economics* 120(3), pp. 963–1002.

Manski, C.F. (1991). "Nonparametric estimation of expectations in the analysis of discrete choice under uncertainty". In *Nonparametric and Semiparametric Methods in Econometrics and Statistics: Proceedings of the Fifth International Symposium in Economic Theory and Econometrics*, pp. 259–275, Melbourne: Cambridge University Press.

Mazzolini, G., Pagani, L., and Santoro, A. (2017). "The deterrence effect of real-world operational tax audits", DEMS Working Paper no. 359, University of Milan-Bicocca.

McFadden, D. (2006). "Free markets and fettered consumers", *American Economic Review* 96(1), pp. 5–29.

Mittone, L. and Patelli, P. (2000). "Imitative behaviour in tax evasion". In F. Luna and B. Stefansson (Eds.), *Economic Modelling with Swarm*, Ch. 5, Amsterdam: Kluwer.

Muellbauer, J. (1988), "Habits, rationality, and myopia in the life cycle consumption function", *Annals of Economics and Statistics* 9(1), pp. 47–70.

Mujcic, R. and Frijters, P. (2013). "Economic choices and status: measuring preferences for income rank", *Oxford Economic Papers* 65(1), pp. 47–73.

Myles, G.D. and Naylor, R.A. (1996). "A model of tax evasion with group conformity and social customs", *European Journal of Political Economy* 12(1), pp. 49–66.

Neumark, D. and Postlewaite, A. (1998). "Relative income concerns and the rise in married women's employment", *Journal of Public Economics* 70(1), pp. 157–183.

Ormerod, P. and Roach, A.P. (2004). "The medieval inquisition: scale-free networks and the suppression of heresy", *Physica A: Statistical Mechanics and its Applications* 339(3), pp. 645–652.

Panadés, J. (2004). "Tax evasion and relative tax contribution", *Public Finance Review* 32(2), pp. 183–195.

Pham, T., Sheridan, P., and Shimodaira, H. (2016). "Joint estimation of preferential attachment and node fitness in growing complex networks" *Scientific Reports* 6: 32558. DOI: 10.1038/srep32558

Plumley, A. (1996). "The determinants of individual income tax compliance" Internal Revenue Service Publication 1916 (Rev. 11-96), IRS: Washington, DC.

Plumley, A.H. and Steuerle, C.E. (2004). "Ultimate objectives for the IRS: Balancing revenue and service". In H.J. Aaron and J. Slemrod (eds.) *The Crisis in Tax Administration*, pp. 311–346, Washington, DC: Brookings Institution Press.

Postlewaite, A. (1998). "The social basis of interdependent preferences", *European Economic Review* 42(3-5), pp. 779–800.

Quah, J.K.-H. (2007). "The comparative statics of constrained optimization problems", *Econometrica* 75(2), pp. 401–443.

Rablen, M.D. (2008). "Relativity, rank and the utility of income", *Economic Journal* 118(528), pp. 801–821.

Ratto, M., Thomas, R., and Ulph, D. (2013). "The indirect effects of auditing taxpayers", *Public Finance Review* 41(3), pp. 317–333.

Rayo, L. and Becker, G.S. (2007). "Evolutionary efficiency and happiness", *Journal of Political Economy* 115(2), pp. 302–337.

Redner, S. (1998)." How popular is your paper? An empirical study of the citation distribution", *European Physical Journal B – Condensed Matter and Complex Systems* 4, pp. 131–134.

Rigney, P. (2016). *The All Seeing Eye – An HMRC Success Story?* London: Institute of Financial Accountants.

Samuelson, L. (2004). "Information-based relative consumption effects", *Econometrica* 72(1), pp. 93–118.

Sen, A. (1983). "Poor, relatively speaking", *Oxford Economic Papers* 35(2), pp. 153–169.

Stark, O. and Taylor, J. (1991). "Migration incentives, migration types: the role of relative deprivation", *Economic Journal* 101(408), pp. 1163–1178.

Suter, L. (2017). *Taxman Unleashes Snooper Computer: What Information Does it Have on You?*, 7th January, London: Telegraph Media Group.

Szell, M. and Thurner, S. (2010). "Measuring social dynamics in a massive multiplayer online game", *Social Networks* 32(4), pp. 313–329.

Tauchen, H.V., Witte, A.D., and Beron, K.J. (1993). "Tax compliance: An investigation using individual taxpayer compliance measurement program (TCMP) data", *Journal of Quantitative Criminology* 9(2), pp. 177–202.

Traxler, C. (2010). "Social norms and conditional cooperative taxpayers", *European Journal of Political Economy* 26(1), pp. 89–103.

Tremblay, C.H. and Tremblay, V.J. (2010). "The neglect of monotone comparative statics methods", *Journal of Economic Education* 41(2), pp. 177–193.

Webley, P., Robben, H., and Morris, I. (1988). "Social comparison, attitudes and tax evasion in a shop simulation", *Social Behaviour* 3(3), pp. 219–228.

Yitzhaki, S. (1974). "A note on 'Income tax evasion: A theoretical analysis'", *Journal of Public Economics* 3(2), pp. 201–202.

Zaklan, G., Lima, F.W.S., and Westerhoff, F. (2008). "Controlling tax evasion fluctuations", *Physica A: Statistical Mechanics and its Applications* 387(23), pp. 5857–5861.

Appendix

Proof of Proposition 1. Under linear-quadratic utility equation (3) can be solved to give optimal evasion at an interior solution as

$$E_{it} = \frac{1 - p_i f}{a\zeta_i} \{b - a[X_i - R_{it}]\}, \tag{A.1}$$

where $\zeta_i > 0$ is defined in the Proposition. Marginal utility, $b - a[X_i - R_{it}]$, is positive by the assumed restrictions on a. Using (4), optimal evasion in (A.1) is written in full as

$$E_{it} = \frac{1 - p_i f}{a\zeta_i} \{b - a[R(h_{it}, \mathbf{X}) + \iota_s[1 - p_i f]\mathbf{g}_i\mathbf{E}_t]\}, \tag{A.2}$$

where necessarily $1 - p_i f > 0$ at an interior optimum. Then the set of N equations defined by (A.2) for taxpayers $i \in \mathcal{N}$ can be written in matrix form as $\mathbf{E}_t = \boldsymbol{\alpha}_t + \mathbf{M}\boldsymbol{\beta}\mathbf{E}_t$ where the elements of $\{\boldsymbol{\alpha}_t, \boldsymbol{\beta}, \mathbf{M}\}$ are as in Proposition 1. It follows that $[\mathbf{I} - \mathbf{M}\boldsymbol{\beta}]\,\mathbf{E}_t = \boldsymbol{\alpha}_t$, so $\mathbf{E}_t = [\mathbf{I} - \mathbf{M}\boldsymbol{\beta}]^{-1}\boldsymbol{\alpha}_t \equiv \mathbf{b}(\mathbf{M}, \boldsymbol{\beta}, \boldsymbol{\alpha}_t)$. ■

Proof of Lemma 1. Without loss of generality, we may set $\varsigma_R = 1$ so that full convergence to the new steady state occurs at time $t+1$ following a change in z at time t. The full adjustment, dE_i^{SS}/dz, is then given by

$$\frac{dE_i^{SS}}{dz} = \frac{\partial E_i^{SS}}{\partial z} + \frac{\partial E_i^{SS}}{\partial R_i^{SS}} \frac{\partial R_i^{SS}}{\partial h_i^{SS}} \frac{\partial h_i^{SS}}{\partial C_i^{SS}} \left[\frac{\partial C_i^{SS}}{\partial X_i} \frac{\partial X_i}{\partial z} + \frac{\partial C_i^{SS}}{\partial E_i^{SS}} \frac{\partial E_i^{SS}}{\partial z} \right], \tag{A.3}$$

where the first term is the contemporaneous adjustment, and the second term is the delayed adjustment. Noting that $\partial C_i^{SS}/\partial X_i = \partial C_i^{n,SS}/\partial X_i = \partial C_i^{SS}/\partial E_i^{SS} = \partial C_i^{n,SS}/\partial E_i^{SS} = 1$, and, from (4), that $\partial R_i^{SS}/\partial h_i^{SS} = \iota_h$, (A.3) reduces to

$$\frac{dE_i^{SS}}{dz} = \frac{\partial E_i^{SS}}{\partial z} + \iota_h \frac{\partial E_i^{SS}}{\partial R_i^{SS}} \frac{\partial h_i^{SS}}{\partial C_i^{SS}} \left[\frac{\partial X_i}{\partial z} + \frac{\partial E_i^{SS}}{\partial z} \right]. \tag{A.4}$$

From (A.1) we see that $\partial E_i^{SS}/\partial R_i^{SS} > 0$, and, by construction, $\partial h_i^{SS}/\partial C_i^{SS} \geq 0$. Hence, the term in square brackets in (A.4) is positive. It follows that if $\left[\partial X_i/\partial z + \partial E_i^{SS}/\partial z\right]$ is of weakly the same sign as $\partial E_i^{SS}/\partial z$ then dE_i^{SS}/dz takes the sign of $\partial E_{it}/\partial z$. For this condition to hold requires $\partial X_i/\partial z \gtreqless \partial E_i^{SS}/\partial z \Leftrightarrow \partial E_i^{SS}/\partial z \gtrless 0$, which is equivalent to the condition

$$\frac{\partial E_i^{SS}}{\partial z} \frac{\partial X_i}{\partial z} \geq -\left[\frac{\partial E_i^{SS}}{\partial z} \right]^2. \tag{A.5}$$

As the right side of (A.5) is negative, a sufficient condition for (A.5) to hold is that

$$\frac{\partial E_i^{SS}}{\partial z} \frac{\partial X_i}{\partial z} \geq 0,$$

which is the condition given in the Lemma. ■

Proof of Proposition 2. We begin by first computing the sign of $\partial E_{it}/\partial z$, where z is a placeholder for each variable given in Proposition 2. Observe that E_{it} and E_{jt} $(j \neq i)$ are complementary actions. We have

$$\frac{\partial^2 \mathbb{E}(U_{it})}{\partial E_{it} \partial E_{jt}} = a g_{ij} \iota_s [1 - p_i f][1 - p_j f] \geq 0.$$

With this result we are able to utilize the theory of monotone comparative statics. In particular, we establish globally the sign of the derivative $\partial^2 \mathbb{E}(U_{it}) / [\partial E_{it} \partial z]$ for each exogenous variable z. It then follows that if $\partial^2 \mathbb{E}(U_{it}) / [\partial E_{it} \partial z] \geq 0$ for all i, then $\partial E_{it}/\partial z \geq 0$, and if $\partial^2 \mathbb{E}(U_{it}) / [\partial E_{it} \partial z] \leq 0$ for all i, then $\partial E_{it}/\partial z \leq 0$. Differentiating in (1) we obtain

$$\begin{aligned}
\frac{\partial^2 \mathbb{E}(U_{it})}{\partial E_{it} \partial b} &= 1 - p_i f > 0; \\
\frac{\partial^2 \mathbb{E}(U_{it})}{\partial E_{it} \partial f} &= -p_i \left[b - a \left\{ X_i - R_{it} - 2\left[f - 1 \right] E_{it} \right\} \right] < 0; \\
\frac{\partial^2 \mathbb{E}(U_{it})}{\partial E_{it} \partial p_i} &= -f \left[b - a \left\{ X_i - R_{it} - \left[f - 2 \right] E_{it} \right\} \right] < 0; \\
\frac{\partial^2 \mathbb{E}(U_{it})}{\partial E_{it} \partial p_j} &= -a E_{it} g_{ij} \iota_s \varsigma_R [1 - p_i f] \leq 0; \\
\frac{\partial^2 \mathbb{E}(U_{it})}{\partial E_{it} \partial X_i} &= -a[1 - p_i f] < 0; \\
\frac{\partial^2 \mathbb{E}(U_{it})}{\partial E_{it} \partial X_j} &= a g_{ij} \iota_s \varsigma_R [1 - p_i f] \geq 0; \\
\frac{\partial^2 \mathbb{E}(U_{it})}{\partial E_{it} \partial \iota_s} &= a[1 - p_i f] \mathbf{g}_i \mathbf{q}_t > 0; \\
\frac{\partial^2 \mathbb{E}(U_{it})}{\partial E_{it} \partial \iota_h} &= a[1 - p_i f] h_{it} > 0; \\
\frac{\partial^2 \mathbb{E}(U_{it})}{\partial E_{it} \partial h_{it}} &= a \iota_h \varsigma_R [1 - p_i f] > 0.
\end{aligned}$$

The exception is the exogenous variable a, for which we show that $\partial^2 \mathbf{E}(U_{it}) / [\partial E_{it} \partial a]$ is signed locally to an interior equilibrium. Under a set of regularity conditions – that utility is C^2 and concave, $U(.) > 0$ for positive values of the argument, and that the problem has a unique solution that obeys the first order conditions and varies smoothly with the variable of interest (a here) – Quah (2007, p. 420) shows that signing $\partial^2 \mathbb{E}(U_{it}) / [\partial E_{it} \partial a]$ local to the (unique) interior maximum is sufficient to determine the equilibrium sign of $\partial E_{it}/\partial a$. As these regularity conditions hold in the current context, we utilize this approach to establish the equilibrium sign of $\partial E_{it}/\partial a$. We obtain

$$\left. \frac{\partial^2 \mathbb{E}(U_{it})}{\partial E_{it} \partial a} \right|_{\partial EU_{it}/\partial E_{it} = 0} = -\frac{[1 - p_i f] b}{a} < 0.$$

We now utilize Lemma 1. The variables $z \in \{a, b, f, p_i, p_j, X_j, \iota_h, \iota_s, h_{it}\}$ satisfy $\partial X_i/\partial z = 0$, giving the sign of dE_i^{SS}/dz as the sign of $\partial^2 \mathbb{E}(U_{it}) / [\partial E_{it} \partial z]$ above. For X_i we have $\partial X_i/\partial z > 0$ and $\partial E_i^{SS}/\partial z < 0$, hence Lemma 1 does not apply. ■

Proof of Proposition 3. Suppose, in a steady state of the model, that taxpayer i is audited at time $t = t_a$, and otherwise no audits take place. In period $t_a + 1$ his/her evasion deviates below the steady-state level, reflecting the consumption shock in period t_a. Beyond period $t_a + 1$ the taxpayer's evasion converges back to its steady-state level at a rate determined by ς_R. These deviations in the evasion behavior of taxpayer i generate a matching pattern of deviation from steady state, followed by uniform convergence, in the evasion of (some or all) other taxpayers in the network. The indirect effect I_{ij} is, therefore, given by $I_{ij} = \sum_{t=t_a+1}^{\infty} [E_j^{SS} - E_{jt|i}]$, where $E_{jt|i}$ is j's evasion at time t following an audit to taxpayer i. But, given that the speed of convergence of $E_{jt|i}$ back to steady state is independent of i and j (it is determined only by ς_R), we have that $E_j^{SS} - E_{j,t_a+1|i} \gtreqless E_k^{SS} - E_{k,t_a+1|i} \Rightarrow E_j^{SS} - E_{j,t_a+v|i} \gtreqless E_k^{SS} - E_{k,t_a+v|i}$ for all $v > 1$. It follows that, for each taxpayer j, the sum over time of the deviations from j's steady-state evasion level (induced by an audit of i) is ordinally equivalent to the initial deviation of j's evasion from its steady-state level, i.e., $[E_j^{SS} - E_{j,t_a+1|i}]$:

$$\sum_{t=t_a+1}^{\infty} \left[\mathbf{E}^{SS} - \mathbf{E}_{t|i}\right] \sim \left[\mathbf{E}^{SS} - \mathbf{E}_{t_a+1|i}\right].$$

$[\mathbf{E}^{SS} - \mathbf{E}_{t_a+1|i}]$ can, in turn, be decomposed exactly (by the linearity of evasion in habit consumption), as

$$\mathbf{E}^{SS} - \mathbf{E}_{t_a+1|i} = [\Delta\mathbf{C}_i]\,[\partial\mathbf{E}^{SS}/\partial C_i^{SS}] = [\Delta\mathbf{C}_i]\,\mathbf{b}(\mathbf{M}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS}),$$

where $\Delta\mathbf{C}_i$ is an $N \times N$ diagonal matrix of the constant $C_i^{n,SS} - C_i^{a,SS} = [1+f]\,E_i^{SS}$. As $C_i^{n,SS} - C_i^{a,SS}$ is proportional to E_i^{SS} it follows that $[\Delta\mathbf{C}_i]\,\mathbf{b}(\mathbf{M}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS}) \sim \mathbf{E}_i^{SS}\mathbf{b}(\mathbf{M}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS})$, which proves the Proposition. ∎

Proof of Lemma 2. Substituting $X(W_i) = [1-\theta]\,W_i$ and $E_{it} = \theta\,[W_i - d_{it}]$ into (A.1) and rearranging for W_i gives

$$\begin{aligned} W_i &= \frac{\{1 + [f-2]\,p_i f\}\,\theta a d_{it} + b\,[1 - p_i f] + a\,[1 - p_i f]\,R_{it}}{a\xi_i}; \\ \xi_i &= [1-\theta]\,[1 - p_i f] + \theta\,\{1 + [f-2]\,p_i f\}. \end{aligned} \tag{A.6}$$

Noting that the second order condition for (A.1) to define a maximum is $-\theta^2 a\,\{1 + [f-2]\,p_i f\} < 0$, it follows that $\xi_i > 0$. Using (4), (A.6) is written in full as

$$W_i = \frac{\{1 + [f-2]\,p_i f\}\,\theta a d_{it} + b\,[1 - p_i f]}{a\xi_i} + \frac{a\,[1 - p_i f]\,\{R\,(h_{it}, \mathbf{X} - \boldsymbol{\psi}\mathbf{d}_t) + [1 - p_i f]\,[1 - p_i f]\,\mathbf{g}_i\mathbf{W}\}}{a\xi_i}. \tag{A.7}$$

Then the set of N equations defined by (A.7) for taxpayers $i \in \mathcal{N}$ can be written in matrix form as $\mathbf{W} = \boldsymbol{\gamma}_t + \mathbf{V}\boldsymbol{\kappa}\mathbf{W}$ where the elements of $\{\boldsymbol{\gamma}_t, \boldsymbol{\kappa}, \mathbf{V}\}$ are as in Proposition 2. Hence $\mathbf{W} = [\mathbf{I} - \mathbf{V}\boldsymbol{\kappa}]^{-1}\,\boldsymbol{\gamma}_t = \mathbf{b}(\mathbf{V}, \boldsymbol{\kappa}, \boldsymbol{\gamma}_t)$. ∎

Figures

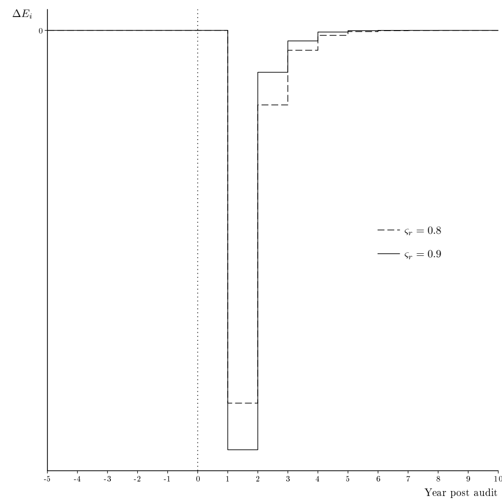

Figure 1: Temporal profile of the deviation in evasion from steady state following an audit.

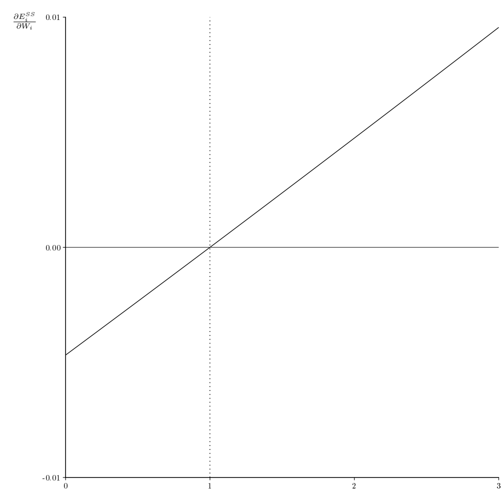

Figure 2: Full effect of a change in income on steady-state evasion.

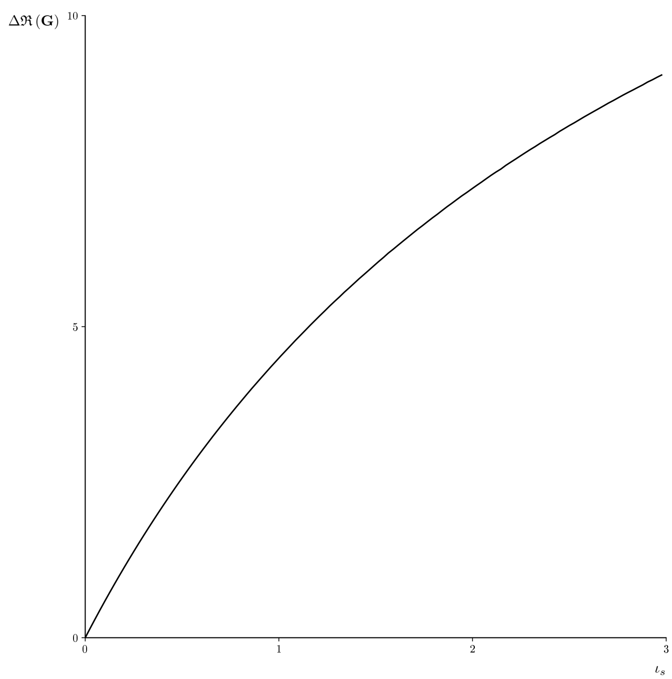

Figure 3: Percentage increase in audit revenues when observing the network, plotted against ι_s, the importance of social comparison.

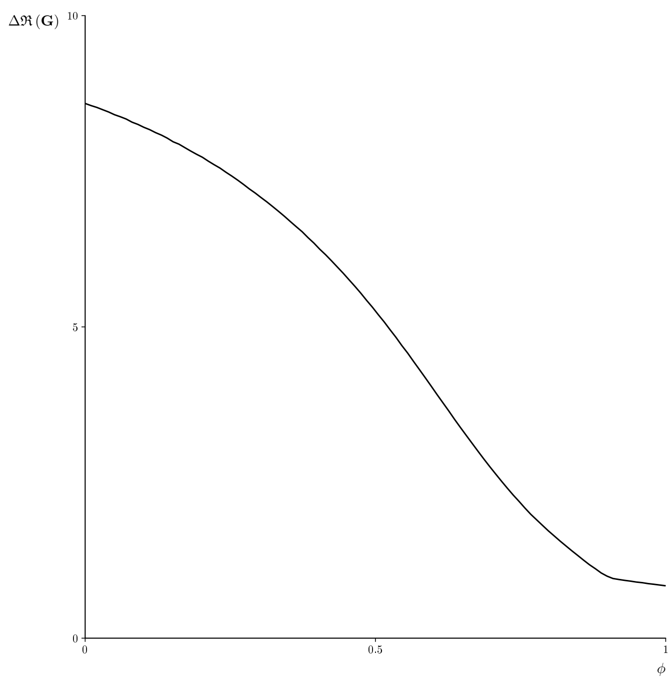

Figure 4: Percentage increase in audit revenues when observing the network, plotted against ϕ, the importance of preferential attachment.