Tax Evasion on a Social Network[*]

Duccio Gamannossi degl'Innocenti[†]
d.gamannossi@exeter.ac.uk

Matthew D. Rablen[‡]
m.rablen@sheffield.ac.uk

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Abstract

We relate tax evasion behaviour to a substantial literature on self and social comparison in judgements. Taxpayers engage in tax evasion as way to potentially boost their 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 direct and indirect revenue effects from auditing are shown to be ranked by 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. If the tax authority can (partially) observe the social network, we show that of the plethora of measures of centrality a tax authority might compute, the measure most correlated with evasion and direct/indirect effects is a taxpayer's in-degree centrality.

PRELIMINARY: DO NOT CITE

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1   Introduction

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% (H.M. Revenue and Customs, 2016). Academic studies for the US and Europe put the gap substantially higher, at around 18-20% (Cebula and Feige, 2012; Buehn and Schneider, 2016).

In this paper we link evasion behavior to a mass of evidence that people continually engage 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 simultaneously explored in the context of the tax evasion decision. In this paper we provide a network model of the tax evasion decision in which taxpayers are assumed to have an intrinsic concern for income relative to a benchmark that can reflect 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 benchmark their current consumption in part against

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[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).

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 how changes in the exogenous parameters affect evasion; second, we explore how the marginal revenue effects that arise from performing one extra audit vary across taxpayers with different levels of network centrality; and last we consider the dynamic profile of behavioral responses to an audit.

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 modelled as either (i) the proportion of taxpayers who report honestly (Gordon, 1989; Myles and Naylor, 1996; Davis *et al.*, 2003; Kim, 2003; Traxler, 2010); (ii) the average post-tax consumption level (Goerke, 2013); (iii) the level of evasion as a share of GDP (Dell'Anno, 2009); or (iii) the average tax payment (Mittone and Patelli, 2000; Panadés, 2004).

While reducing social information to a single statistic known to all taxpayers has a benefit in terms of analytical tractability, it is problematic in a number of 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 consumption of every other taxpayer. As we adopt the convention that a link from i to j signifies that i can observe j's consumtion, 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, such features of social networks may matter for the targeting of tax audits (Andrei *et al.*, 2014).

The only literature that has enriched the introduction of social information is that which uses agent-based simulation techniques as an alternative to analytical methods. Even here, however, representations of social networks 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 consumption 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). Social networks also exhibit a form of assortative matching, known as homophily, which too is not captured by existing work. 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.[3] Where we perform simulation analysis, we do so on a class of generative networks that are not subject 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 has allowed simultaneously for both self and social comparison in the tax evasion decision. Goerke (2013), however, assumes an explicit

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[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]By extending analytical understanding of network effects upon tax evasion – in particular being able to prove formal comparative statics properties of the model – we assist the interpretation of simulation output from related agent-based models.

(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 nonetheless react to social information because they experience social stigma – the extent of which depends on the evasion of other taxpayers – if revealed to be evading.[4] 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 small literature relating to this point in the context of tax evasion supports the notion that social information impacts compliance behavior (Alm *et al.*, 2017; Alm and Yunus, 2009), 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 taxpayers are myopic, and habit reflects only recent consumption outcomes, whereas these authors consider far-sighted taxpayers and habit reflects the whole history of consumption. Stronger habit is associated with higher evasion in our model, 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, Bernasconi *et al.* find that stronger self comparison improves tax compliance.

The paper proceeds as follows: section 2 develops a formal model of tax evasion on a social network. Section 3 analyses the predictions of the model – using both formal and simulation methods – for optimal evasion, and for understanding the effects of tax audits. Section 4 concludes. All proofs are in the Appendix.

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[4]Our model can readily allow the inclusion of a cost due to social stigma. To understand the marginal effect of allowing for social comparison on a network, however, we omit such a cost in what follows.

2 Model

Let $\mathcal{N}$ be a set of taxpayers of size N. A taxpayer $i \in \mathcal{N}$ has an (exogenously earned) income $W_i > 0$. If a taxpayer were to pay income tax on their gross income W_i, they would receive a net disposable income $X_i \equiv X_i(W_i)$. As W_i enters the model only through X_i, we shall typically treat X_i as a primitive. Taxpayers can, however, choose to evade 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, where this specification allows that the tax authority may condition its audits upon observable features of the taxpayer. Random auditing is the special case in which $p_i = p$ for all i. Following Yitzhaki (1974), audited taxpayers face a fine at rate $f > 1$ on all undeclared tax.

Taxpayers are assumed to derive utility from their level of consumption, the random variable $\tilde{C}_{it}$, relative to a reference level R_{it} (the determination of which we shall come to 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 behaviour could be the result of cognitive limitations of the part of taxpayers. Consistent with this notion, and our emphasis on social network, Manski (1991) and McFadden (2006), each 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

$$\mathbb{E}(U_{it}) \equiv [1 - p_i] U(C_{it}^n - R_{it}) + p_i [U(C_{it}^a - R_{it}) - sE_{it}], \tag{1}$$

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 omit it here for simplicity and emphasis.[6] Optimal evasion in period t is the solution to the problem $\max_{E_{it}} \mathbb{E}(U_{it})$

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

[6]In international studies, subjective wellbeing measures 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). Since most citizens of developed countries lie above this threshold, our model may be a reasonable approximation in such cases.

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

$$[1 - p_i] U'(C_{it}^n) - p_i [fU'(C_{it}^a) + s] = 0, \tag{3}$$

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 a taxpayer's consumption is observed by a non-empty set of taxpayers $\mathcal{R}_{it} \subset \mathcal{N}$, a set we term the *reference group*. A taxpayer, i, is *observed* if their consumption is seen by at least one other taxpayer, i.e., $i \in \cup_{j \in \mathcal{N} \backslash i} \mathcal{R}_{jt}$.

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, which can be allowed to update over time, is represented as an $N \times N$ (adjacency) matrix, $\mathbf{G}_t$, of subjective comparison intensity weights $1 \geq g_{ijt} \geq 0$, where $g_{iit} = 0$. For convenience, when i is outward linked, we shall also normalize the g_{ijt} for each taxpayer to sum to unity: $\sum_{j \in \mathcal{R}_{it}} g_{ijt} = 1$.

Taxpayer i is *linked* to taxpayer j if $g_{ijt} > 0$. Accordingly, the reference group of taxpayer i is the set of all taxpayers to whom i is linked: $\mathcal{R}_{it} = \{j \in \mathcal{N} : g_{ijt} > 0\}$. A network, $\mathbf{G}_t$, 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 $\mathbf{G}_t \in \mathcal{C}$ is that all taxpayers belonging to $\mathcal{N}$ are observed.

People predominantly compare with others who are similar to them on prescribed dimensions (McPherson *et al.*, 2001), perhaps because these comparisons are the most informative (Clark and Senik, 2010). It follows that changes in the psychological weight attached to different comparator taxpayers in the network may arise, for instance, as a response to recent changes in consumption (perhaps as a consequence of having been audited). A simple way to capture this effect is to suppose the g_{ijt} can evolve as functions of lagged absolute consumption differences, $|C_{i,t-1} - C_{j,t-1}|$, so that comparison is more intensive between taxpayers i and j the closer are $C_{i,t-1}$ and $C_{j,t-1}$.

Define expected consumption as $\mathbb{E}(\tilde{C}_{it}) = X_i + [1 - pf]E_{it}$. We then write reference consumption as $R_{it} \equiv R_{it}(Z_{it})$, where $R_{it}(.)$ is a non-decreasing function and Z_{it}, which drives

the evolution of R_{it}, reflects self and social comparsion. Specifically we write

$$Z_{it} \equiv Z(h_{it}, q_{-i,t}) = \iota_h h_{it} + \iota_s q_{-i,t},$$

where $q_{-i,t} \equiv \sum_{j \in \mathcal{R}_{it}} g_{ijt} \mathbb{E}(\tilde{C}_{jt})$ is the weighted mean over the reference group of expected consumption (reflecting social comparison) and h_{it} is the "habit" level of consumption (reflecting self comparison), which reflects positively past consumption levels. Thus, Z_{it} is a sum of a level of consumption reflecting self comparison (weighted by $\iota_h > 0$), and a level of consumption reflecting social comparison (weighted by $\iota_s > 0$). To form reference consumption, we adopt a simple linear specification for $R_{it}(.)$ given by

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

Under the specification in (4) the reference level adjusts towards Z_{it} in each period, which the strength of this adjustment reguated 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 and $R_{it} = Z_{it}$, whereas, when $\varsigma_R = 0$, R_{it} is fixed at its initial value 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 *For a network with (weighted) adjacency matrix* $\mathbf{G}$, *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.*

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 by 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 magnitude of the local externality that a taxpayer's evasion imparts upon other

taxpayers cannot be too large. 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 large, 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) $\mathbf{I} > \rho(\mathbf{M}_t)\boldsymbol{\beta}$;

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

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

where

$$
\begin{aligned}
m_{ijt} &= \frac{[1 - p_i f][1 - p_j f]\varsigma_R}{\zeta_i} g_{ijt}; \\
\beta_{ii} &= \iota_s; \\
\alpha_{i1t} &= \frac{1 - p_i f}{a\zeta_i}\left\{b - a\left[X_i - R\left(h_{it}, X_{-i}\right)\right]\right\}; \\
\zeta_i &= [1 - p_i f]^2 + p_i[1 - p_i]f^2 > 0.
\end{aligned}
$$

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 $\mathbf{M}_t$, weighted to reflect a taxpayers marginal utility of consumption. By this measure, *taxpayers that are more central in the social network evade more.*[7] The uniqueness of equilibrium evasion follows intuitively from 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 $\mathbf{M}_t$ 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 the probability of audit across taxpayers. It follows that, in the special case that all taxpayers face a common audit probability, i.e., the case of random auditing, no adjustment to the underlying comparison intensity weights is warranted.

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[7]Our interpretation of the matrix of weights, $\boldsymbol{\alpha}_t$, follows from noting that 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. The latter utilises the weighted average of legal consumption of the members of the reference group.

In this case, therefore, optimal evasion is a weighted Bonacich centrality measure on the untransformed network $\mathbf{G}_t$:

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 $\mathbf{E}_t = \mathbf{b}(\mathbf{G}_t, \boldsymbol{\beta}, \boldsymbol{\alpha}_t)$, where*

$$
\begin{aligned}
G_{ijt} &= g_{ijt}; \\
\beta_{ii} &= \frac{\iota_s \varsigma_R [1 - pf]^2}{\zeta}; \\
\alpha_{i1t} &= \frac{1 - pf}{a\zeta} \{b - a [X_i - R(h_{it}, X_{-i})]\}; \\
\zeta &= [1 - pf]^2 + p[1 - p]f^2 > 0.
\end{aligned}
$$

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

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

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

3   Analysis

The model of the previous section is sufficiently rich that it may be used to address a wide range of questions of interest to academics and practitioners in tax authorities. Here we limit ourselves to a focus on three such questions: first, we investigate how changes in the exogenous parameters affect evasion; second, we explore how the various direct and indirect marginal revenue effects that arise from performing one extra audit vary across taxpayers with different levels of network centrality; and last we consider the dynamic profile of behavioral responses to an audit.

To study the questions above requires a controlled environment that, in particular, extracts from the stochastic peterbations of the system owing to tax authority audits. Accordingly,

we define the notion of steady state – the state the model enters if the exogenous consumption shocks induced by tax authority auditing are "turned off". The proceeding Lemma follows directly from Proposition 1:

Lemma 1 *Steady state evasion,* $\mathbf{E}^{SS}$*, is given by the vector of Bonacich centralities,* $\mathbf{b}(\mathbf{M}^{SS}, \boldsymbol{\beta}, \boldsymbol{\alpha}^{SS})$*, where*

$$
\begin{aligned}
m_{ij}^{SS} &= \frac{[1 - p_i f][1 - p_j f]\varsigma_R}{\zeta_i} g_{ij}^{SS}; \\
\beta_{ii} &= \iota_s; \\
\alpha_{i1}^{SS} &= \frac{1 - p_i f}{a\zeta_i} \left\{ b - a \left[X_i - R \left(h_i^{SS}, X_{-i} \right) \right] \right\}.
\end{aligned}
$$

3.1 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 (i.e., sign) implications of changes in the underlying exogenous parameters for an arbitrary social network.[8] We consider a steady state of the model and imagine making a marginal increase in an exogenous variable 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 and network updating are not contemporaneous, the full adjustment to a new steady state (dE_i^{SS}/dz) comprises a contemporaneous component ($\partial E_i^{SS}/\partial z$) and a delayed component. To analyze the sign of the full effect, we first prove a Lemma that relates...

Lemma 2 *For an arbitrary variable* z*, if* $\frac{\partial X_i}{\partial z} \frac{\partial E_{it}}{\partial z} \geq 0$ *then*

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

According to Lemma 2, the sign of the contemporaneous and lagged components of optimal evasion are related. In particular, if $\text{cov}(\tilde{C}_{it}, z) = 0$, such that changes in z affect consumption only through induced equilibrium adjustments in evasion, then it is sufficient to sign the

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

contemporaneous effect. As noted in part (ii) of the Lemma, when z can also influence consumption directly, the sign of the full effect can, in general, only be determined when both the direct and indirect effects on consumption go in the same direction. With Lemma 2 in hand we prove the following Proposition:

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

$$
\begin{aligned}
\frac{\partial E_i^{SS}}{\partial a} &< 0; & \frac{\partial E_i^{SS}}{\partial b} &> 0; \\
\frac{\partial E_i^{SS}}{\partial p_i} &< 0; & \frac{\partial E_i^{SS}}{\partial p_j} &< 0; \\
\frac{\partial E_i^{SS}}{\partial f} &< 0; & \frac{\partial E_i^{SS}}{\partial C_{i,t-1}} &> 0; \\
\frac{\partial E_i^{SS}}{\partial \iota_h} &> 0; & \frac{\partial E_i^{SS}}{\partial \iota_s} &> 0; \\
\frac{\partial E_i^{SS}}{\partial X_i} &\gtrless 0; & \frac{\partial E_i^{SS}}{\partial X_j} &> 0.
\end{aligned}
$$

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 probability of audit lowers optimal evasion, as does an increase in the audit probability of another taxpayer in the social network. When another taxpayer's audit probability increases they decrease their evasion, thereby decreasing the need for other taxpayers seeking to maintain a given level of relative consumption to do likewise. 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 $C_{i,t-1}$

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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 beats $C_{i,t-1}$,which entails attempting greater evasion. 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.

As noted in the Introduction, our finding that a greater concern for 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, and in which habit reflects the whole history of consumption. In this framework our intuition above no longer holds, for taxpayers do not generate unforeseen internalities on their future selves when they consume more in the present.

The result for X_j in Proposition 2 tells us how a taxpayer's evasion responds to changes in the income of other taxpayers. This cross effect is unambiguously positive, 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 relative consumption, other taxpayers must evade more. The role of own-income is the only case where Lemma 2 does not apply, for $\text{cov}(\tilde{C}_{it}, X_i)$ and $\partial E_{it}/\partial X_i$ are of opposite signs. Empirically, evasion and wealth are positively related (Clotfelter, 1983; Baldry, 1987). Accordingly, in the simulation analysis we calibrate the model to be consistent with this evidence.

3.2 Network Structure and Evasion

Conventionally, the tax compliance literature assumes that a tax authority can condition its audit decisions solely on the income declaration contained within a taxpayer's tax return. Might tax authorities also observe links in social networks, however? 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 heavily in big data, but has, to date, been much more reticent in revealing its capabilities.

Accordingly, suppose the tax authority is indeed able to observe some properties of the social network. Is this information of value, in the sense of permitting the construction of measures that correlate with evasion, and how does the strength of these correlations vary with network structure?

THE REMAINDER OF THIS SECTION IS INCOMPLETE, BUT WILL BE FINISHED BY THE TIME OF THE CONFERENCE

3.3 Audit strategy

In this section we investigate – both theoretically and with simulations – the implications of the model for the incorporation of information regarding the social network into tax authority audit selection rules. Conventionally, the literature on optimal auditing assumes that a tax authority can condition its audit decisions solely on the income declaration contained within a taxpayer's tax return. Might, however, tax authorities also 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 heavily in big data, but has, to date, been much more reticent in revealing its capabilities.

Consider a single audit to a taxpayer k that perturbs the steady state of the model. The revenue effects this generates are commonly broken down three ways: the *direct effect* (D_k) is the tax recovered contemporaneously with the audit that would otherwise have been evaded; the *own indirect effect* (D_k^{OWN}) refers to the expected additional revenue, per unit of the direct effect, that arises from future changes in evasion behavior by the audited taxpayer, while the *other indirect effect* (D_{kl}^{OTH}) refers to the expected additional revenue, per unit of the direct effect, that arises from spillover to the evasion behavior of the non-audited taxpayer l $(l \neq k)$. The *aggregate indirect effect*, D_k^{OTH}, is the sum of the indirect effects across $\mathcal{N}$, $D_k^{OTH} = \sum_{l \in \mathcal{N} \setminus k} D_{kl}^{OTH}$. The vector of direct effects, $\mathbf{D}$, evidently corresponds exactly to $\mathbf{E}^{SS}$, as defined in Lemma 1. Hence, it what follows, we focus on $\mathbf{D}^{OWN}$ and $\mathbf{D}^{OTH}$.

Proposition 3 *The indirect revenue effects of conducting a single audit that perturbs the steady state of the model satisfy*

(i) $D_i^{OWN} \gtrless D_j^{OWN} \Leftrightarrow b_{i1}(\mathbf{M}^{SS}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS}) \gtrless b_{j1}(\mathbf{M}^{SS}, \boldsymbol{\beta}, \boldsymbol{\rho}_j^{SS});$

(ii) $D_{ik}^{OTH} \gtrless D_{jk}^{OTH} \Leftrightarrow b_{k1}(\mathbf{M}^{SS}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS}) \gtrless b_{k1}(\mathbf{M}^{SS}, \boldsymbol{\beta}, \boldsymbol{\rho}_j^{SS});$

where $\{\mathbf{M}^{SS}, \boldsymbol{\beta}\}$ are defined as in Lemma 1, and where $\boldsymbol{\rho}_l^{SS}$ is an $N \times 1$ vector of weights given by

$$\boldsymbol{\rho}_l^{SS} = \frac{\partial \boldsymbol{\alpha}^{SS}}{\partial C_l^{SS}} + \frac{\partial \mathbf{M}}{\partial C_l^{SS}} \boldsymbol{\beta} \mathbf{E}^{SS}.$$

According to Proposition 3, the relative magnitude of the own indirect effect generated from auditing taxpayers i and j is fully determined by comparison of the ith entry of the vector of Bonacich centralities $\mathbf{b}(\mathbf{M}^{SS}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS})$ with the jth entry of the vector of Bonacich centralities $\mathbf{b}(\mathbf{M}^{SS}, \boldsymbol{\beta}, \boldsymbol{\rho}_j^{SS})$. An analogous result holds for the own others effect, except that one must compare the sum of the remaining entries of $\mathbf{b}(\mathbf{M}^{SS}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS})$ with the sum of the remaining entries in $\mathbf{b}(\mathbf{M}^{SS}, \boldsymbol{\beta}, \boldsymbol{\rho}_j^{SS})$. As an immediate corollary of Proposition 3 the relative sizes of the aggregate indirect effect from auditing distinct taxpayers $\{i, j\}$ satisfies

$$D_i^{OTH} \gtrless D_j^{OTH} \Leftrightarrow \sum_{k \in \mathcal{N} \setminus i} b_{k1}(\mathbf{M}^{SS}, \boldsymbol{\beta}, \boldsymbol{\rho}_i^{SS}) \gtrless \sum_{k \in \mathcal{N} \setminus j} b_{k1}(\mathbf{M}^{SS}, \boldsymbol{\beta}, \boldsymbol{\rho}_j^{SS}).$$

3.4 Dynamic responses to audit

There is growing interest in understanding behavioral responses to audit, both from theoretical (Bernasconi *et al.*, 2014) and empirical (Gemmell and Ratto, 2012; DeBacker *et al.*, 2015, 2017; Advani *et al.*, 2016; Mazzolini *et al.*, 2017) standpoints. These studies find that audits have persistent effects on subsequent compliance behavior, with an effect still discernible four or more years after the initiation of an audit. Typically, these studies emphasize the role of taxpayer learning (about the probability of audit and the effectiveness of the audit process in detecting noncompliance) in accounting for this phenomenon, while Dubin (2007) notes that it could be due to the delayed audit cycle (the audit itself may not conclude for several years, and taxpayers might rationally alter their reporting behavior while an audit is in progress).

In our model the objective audit probability is known (ruling out learning) and audits are instantaneous (ruling out audit cycle effects). In this context it is interesting that, under empirically plausible assumptions concerning the evolution of habit consumption, our model predicts a persistent behavioral effect from an audit, albeit the effect does disappear eventually (i.e., there is no permanent effect). In this sense, we highlight the role of self comparison as an additional explanatory factor (to those so far considered in the literature) in accounting for post-audit compliance behavior.

The best empirical evidence on habit effects is from the behavioral economics literature on the determinants of wellbeing, where Di Tella *et al.* (2010) report adaptation effects to income changes persisting for four years. For this part of the analysis, therefore, periods are interpreted as years. Accordingly, we here generalize habit consumption from being just the first lag of consumption to being an autoregressive function of the first four lags of realized consumption, with decreasing psychological weights, $w_{t-1} > w_{t-2} > \ldots > w_{t-4}$, attached to each lag. To focus on the role of habit effects, we again eliminate other sources of heterogeneity in the taxpayer's evasion decision ($W_i = W$, $p_i = p$).

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4   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. In our model, taxpayers compare their consumption with others in their social network, and also to their own consumption in the recent past. Unlike earlier models that allow only for social comparisons at the aggregate level, 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 raise their consumption relative to others, and 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 the tax authority, will influence evasion behavior. Although optimal evasion depends in quite a complex way on the underlying parameters, we are able in many cases to sign unambiguously its comparative statics. We also simulated the model to investigate its implications for audit policy and for the dynamics of behavioral responses to tax authority audits. Our results show that there are objective grounds for tax authorities to target taxpayers who are central in the network. In particular, the revenue raised from other taxpayers following an audit displays increasing returns as a function of network centrality. We also show how the lagged adjustment of habit consumption can lead tax authority audits to have a relatively persistent effect on evasion behavior, which does not return to baseline until around five years after the audit has taken place.

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.

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Appendix

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

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

where $\zeta_i > 0$ is defined in the Proposition. Given that marginal utility, $b - a \left[X_i - R_{it} \right]$, is positive by the assumed restrictions on a, the expression for optimal evasion in (A.1) satisfies $E_{it} \in (0, W_i - X_i)$ for all i if

$$0 < 1 - f \max_{i \in \mathcal{N}} \{p_i\} < \min_{i \in \mathcal{N}} \left\{ \frac{a \zeta_i \left[W_i - X_i \right]}{b - a \left[X_i - R_{it} \right]} \right\}. \tag{A.2}$$

Using (4), and noting that $\sum_{j \in \mathcal{R}_{it}} g_{ijt}[1 - p_i f]E_{jt} = \sum_{j \in \mathcal{N}} g_{ijt}[1 - p_i f]E_{jt}$, optimal evasion in (A.1) is written in full as

$$E_{it} = \frac{1 - p_i f}{a \zeta_i} \left\{ b - a \left[R\left(h_{it}, X_{-i}\right) + \iota_s \sum_{j \in \mathcal{N}} g_{ijt}[1 - p_i f]E_{jt} \right] \right\}. \tag{A.3}$$

Then the set of N equations defined by (A.3) for taxpayers $i \in \mathcal{N}$ can be written in matrix form as $\mathbf{E}_t = \boldsymbol{\alpha}_t + \mathbf{M}_t \boldsymbol{\beta} \mathbf{A}_t$ where the elements of $\{\boldsymbol{\alpha}_t, \boldsymbol{\beta}, \mathbf{M}_t\}$ are as in Proposition 1. It follows that $[\mathbf{I} - \mathbf{M}_t \boldsymbol{\beta}] \mathbf{E}_t = \boldsymbol{\alpha}_t$, so $\mathbf{E}_t = [\mathbf{I} - \mathbf{M}_t \boldsymbol{\beta}]^{-1} \boldsymbol{\alpha}_t \equiv \mathbf{b}(\mathbf{M}_t, \boldsymbol{\beta}, \boldsymbol{\alpha}_t)$. ∎

Proof of Lemma 2. Evasion at $t + v$ $(v > 0)$ can be written as $E_{i,t+v} = \psi_i + \phi_i R_{i,t+v}$, where $\{\psi_i, \phi_i\}$ are positive constants, the identities of which may be inferred from (A.1). By the linearity of $R\left(.\right)$ we may write $R_{i,t+v} = R_{it} + \tau_h \partial h_{i,t+v}/\partial z + \tau_s \partial q_{i,t+v}/\partial z$. It follows that

$$\begin{aligned}
E_{i,t+v} &= \psi_i + \phi_i \left[R_{it} + \tau_h \frac{\partial h_{i,t+v}}{\partial z} + \tau_s \frac{\partial q_{i,t+v}}{\partial z} \right]; \\
&= E_{it} + \phi_i \left[\tau_h \frac{\partial h_{i,t+v}}{\partial z} + \tau_s \frac{\partial q_{i,t+v}}{\partial z} \right].
\end{aligned} \tag{A.4}$$

Hence $E_{i,t+v} - E_{it} = \phi_i[\tau_h \partial h_{i,t+v}/\partial z + \tau_s \partial q_{i,t+v}/\partial z]$. As $E_{i,t+v} - E_{it}$ has the sign of $\partial E_{i,t+v}/\partial z$, it follows that the sign of $\partial \tilde{E}_{i,t+1}/\partial z$ is the sign of $\phi_i[\tau_h \partial h_{i,t+v}/\partial z + \tau_s \partial q_{i,t+v}/\partial z]$. The full adjustment to a new steady state following a change in z at time t is given by $\lim_{v \to \infty} E_{i,t+v} - E_{it}$. Using the chain rule, we may rewrite (A.4) as

$$\lim_{v \to \infty} E_{i,t+v} - E_{it} = \lim_{v \to \infty} \phi_i \left[\frac{\partial C_{it}}{\partial X_i} \frac{\partial X_i}{\partial z} + \frac{\partial C_{it}}{\partial E_{it}} \frac{\partial E_{it}}{\partial z} \right] \left[\tau_h \frac{\partial h_{i,t+v}}{\partial C_{it}} + \tau_s \frac{\partial q_{i,t+v}}{\partial C_{it}} \right].$$

Noting that, as no audits are taking place, $\partial C_{it}/\partial X_i = \partial C_{it}^n/\partial X_i = \partial C_{it}/\partial E_{it} = \partial C_{it}^n/\partial E_{it} = 1$ this reduces to

$$\lim_{v \to \infty} E_{i,t+v} - E_{it} = \lim_{v \to \infty} \phi_i \left[\frac{\partial X_i}{\partial z} + \frac{\partial E_{it}}{\partial z} \right] \left[\tau_h \frac{\partial h_{i,t+v}}{\partial C_{it}} + \tau_s \frac{\partial q_{i,t+v}}{\partial C_{it}} \right]$$

As $\partial h_{i,t+v}/\partial C_{it} > 0$ and $\partial q_{i,t+v}/\partial C_{it} > 0$ for all v, it follows that, if either $\partial X_i/\partial z = 0$ or $\partial X_i/\partial z$ takes the same sign as $\partial E_{it}/\partial z$, then $\lim_{v \to \infty} E_{i,t+v} - E_{it}$ has the sign of $\partial E_{it}/\partial z$. $\blacksquare$

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

$$\frac{\partial^2 \mathbb{E}\left(U_{it}\right)}{\partial E_{it} \partial E_{jt}} = ag_{ijt}\iota_s[1 - p_i f][1 - p_j f] \begin{cases} = 0 & \text{if } g_{ijt} = 0; \\ > 0 & \text{otherwise.} \end{cases}$$

With this result we are able to utilize the theory of monotone comparative statics. In particular, we establish globally the sign of the derivative $\partial^2 \mathbb{E}\left(U_{it}\right)/\left[\partial E_{it}\partial z\right]$ for each exogenous variable z. It then follows, given our restriction to strongly connected networks, that if $\partial^2 \mathbb{E}\left(U_{it}\right)/\left[\partial E_{it}\partial z\right] \geq 0$ for all i, with $\partial^2 \mathbb{E}\left(U_{it}\right)/\left[\partial E_{it}\partial z\right] > 0$ for at least one such i, then $\partial E_{it}/\partial z > 0$, and if $\partial^2 \mathbb{E}\left(U_{it}\right)/\left[\partial E_{it}\partial z\right] \leq 0$ for all i, with $\partial^2 \mathbb{E}\left(U_{it}\right)/\left[\partial E_{it}\partial z\right] < 0$ for at least one such i, then $\partial E_{it}/\partial z < 0$. Differentiating in (1) we obtain

$$\frac{\partial^2 \mathbb{E}\left(U_{it}\right)}{\partial E_{it}\partial b} = 1 - p_i f > 0;$$

$$\frac{\partial^2 \mathbb{E}\left(U_{it}\right)}{\partial E_{it}\partial f} = -p_i\left[b - a\left\{X_i - R_{it} - 2\left[f - 1\right]E_{it}\right\}\right] < 0;$$

$$\frac{\partial^2 \mathbb{E}\left(U_{it}\right)}{\partial E_{it}\partial p_i} = -f\left[b - a\left\{X_i - R_{it} - \left[f - 2\right]E_{it}\right\}\right] < 0;$$

$$\frac{\partial^2 \mathbb{E}\left(U_{it}\right)}{\partial E_{it}\partial p_j} = -aE_{it}g_{ijt}\iota_s\varsigma_R[1 - p_i f] \begin{cases} = 0 & \text{if } g_{ijt} = 0; \\ < 0 & \text{otherwise;} \end{cases}$$

$$\frac{\partial^2 \mathbb{E}\left(U_{it}\right)}{\partial E_{it}\partial X_i} = -a[1 - p_i f] < 0;$$

$$\frac{\partial^2 \mathbb{E}\left(U_{it}\right)}{\partial E_{it}\partial X_j} = ag_{ijt}\iota_s\varsigma_R[1 - p_i f] \begin{cases} = 0 & \text{if } g_{ijt} = 0; \\ > 0 & \text{otherwise;} \end{cases}$$

$$\frac{\partial^2 \mathbb{E}\left(U_{it}\right)}{\partial E_{it}\partial \iota_s} = a[1 - p_i f]\bar{q}_{-i,t} > 0;$$

$$\frac{\partial^2 \mathbb{E}\left(U_{it}\right)}{\partial E_{it}\partial \iota_h} = a[1 - p_i f]h_{it} > 0;$$

$$\frac{\partial^2 \mathbb{E}\left(U_{it}\right)}{\partial E_{it}\partial h_{it}} = a\iota_h\varsigma_R[1 - p_i f] > 0.$$

The exception is the exogenous variable a, for which we show that $\partial^2 \mathbf{E}\left(U_{it}\right)/\left[\partial E_{it}\partial a\right]$ is signed locally to an interior equilibrium. Under a set of regularity conditions – that utility is C^2 and concave, $U\left(.\right) > 0$ 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 $\partial^2 \mathbb{E}\left(U_{it}\right)/\left[\partial E_{it}\partial a\right]$ 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

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

We now utilize Lemma 2. The variables $z \in \{a, b, f, p_i, p_j, X_j, \iota_h, \iota_s, C_{i,t-1}\}$ satisfy $\mathrm{cov}(\tilde{C}_{it}, z) = 0$, giving the sign of $\mathbb{E}(\partial \tilde{E}_{i,t+1}/\partial z)$ as the sign of $\partial^2 \mathbb{E}\left(U_{it}\right)/\left[\partial E_{it}\partial z\right]$ above. For f we have $\mathrm{cov}(\tilde{C}_{it}, z) < 0$ and $\partial E_{it}/\partial f < 0$, so again the sign of $\mathbb{E}(\partial \tilde{E}_{i,t+1}/\partial z)$ is the sign of $\partial^2 \mathbb{E}\left(U_{it}\right)/\left[\partial E_{it}\partial z\right]$ above. For X_i we have $\mathrm{cov}(\tilde{C}_{it}, z) > 0$ and $\partial E_{it}/\partial X_i < 0$, hence Lemma 2 does not apply. ■