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Sin licenses revisited

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ABSTRACT

We analyse attempts to implement personalised regulation in the form of sin licenses (O'Donoghue and Rabin 2003, 2005, 2007) to correct the distortion in the consumption of a harmful good when consumers suffer from varying degrees of self-control problems. We take into account the possibility that consumers may trade the sin good in a secondary market, and show that sin licenses induce only sophisticated individuals with low levels of self-control problems to consume optimally. The consumption of naïve individuals as well as sophisticated individuals with severe self-control problems remains too high, and welfare in equilibrium is decreasing in the level of self-control problems and non-increasing in the level of naivete. Further, we show that introducing a uniform tax on top of a system of sin licenses may improve welfare, whereas a uniform maximum quota would reduce welfare for sophisticates but may increase welfare for naives. Finally, we show that naives would benefit from a scheme where sin licenses are sold for a positive price in the primary market.

JEL Classification: H21, H30, I18

Keywords: self-control problems, sin licenses, secondary markets

[1] Earlier versions of the paper have been circulated under the title "Personalised regulation of sinful consumption".

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1 Introduction

A large body of literature in behavioural economics suggests that consumers sometimes make mistakes. A prominent example is excessive consumption of harmful goods such as alcohol, tobacco and unhealthy food; such excessive consumption can be caused for example by self-control problems. We reconsider the use of so called sin licenses to regulate the consumption of harmful commodities, first suggested by O'Donoghue and Rabin (2003) and also discussed in O'Donoghue and Rabin (2005, 2007).

A recent literature studies consumers' attempts to achieve self-control in the market (Heidhues and Köszegi 2009, DellaVigna and Malmendier 2006, Köszegi 2005). Market mechanisms have the advantage of being voluntary and personalised - each consumer can choose the services that best suit his needs. However, a downside is a lack of commitment: for example, in a competitive market, a consumer may reach a contract with one firm to limit the supply of harmful commodities, but another firm will have an incentive to supply the commodity at marginal cost. Indeed, Köszegi (2005) has argued that market-based mechanisms for correcting the distortions caused by self-control problems are in general likely to be ineffective.[1] Furthermore, market-based commitment mechanisms will in general not achieve the optimal outcome for (partially) naive individuals who are not (fully) aware of their self-control problem.[2]

Given that consumers demand self-control, but the market may fail in providing it, it is reasonable to ask whether government intervention may help in this respect. In principle, the public sector may have two advantages vis-à-vis the private sector as a provider of self-control: First, the public sector may have better commitment-ability than individuals, for example because public policy cannot be changed overnight, whereas consumption decisions are made over a short time span. Second, the public sector should be able to implement an all-encompassing policy that would also reach naive consumers. However, a downside of public sector regulation is that in most cases it takes the form of a one-size-fits-all policy - for example tobacco and alcohol taxes are in practice linear i.e. the tax rate is the same for all individuals and units consumed. Accordingly, the previous literature on using so called sin taxes to

[1] See also Gottlieb (2008) for a related analysis. Heidhues and Köszegi (2010) and Eliaz and Spiegler (2006) analyse firms' incentives to take advantage of consumers' self-control problems. For a review issues related to the use of commitment devices, see Bryan, Karlan and Nelson (2010).

[2] The concepts of sophistication and naivete (complete unawareness of ones' self-control problem), were discussed already by Strotz (1955-6) and Pollak (1968) and have been analysed in numerous papers - see for example O'Donoghue and Rabin (1999) for an analysis of the implications of both sophistication and naivete, and O'Donoghue and Rabin (2001) for a model that introduces a formalisation of the intermediate case of partial naivete.

regulate harmful consumption (see for example O'Donoghue and Rabin (2003; 2006), Gruber and Köszegi (2004), and Haavio and Kotakorpi (2011)) has overwhelmingly concentrated on linear taxes.[3] It is clear that when consumers are heterogenous with respect to self-control problems and/or tastes, a linear scheme will not achieve the first-best outcome: a tax based on some measure of average self-control problems will distort the consumption of individuals without a self-control problem and will be too low for individuals with severe self-control problems. Indeed, many economists remain sceptical about using instruments such as sin taxes to combat problems associated with the lack of self-control.[4]

Sin licenses can be seen as an attempt to combine the positive aspects of market mechanisms and government regulation: they are a form of personalised regulation implemented by the government. The scheme involves consumers purchasing 1 cent licenses that permit them to buy one unit of the sin good in the future tax free, whereas purchases without the license are subject to a prohibitively high tax. Clearly, sin licenses are a form of non-linear personalised taxation, and are also equivalent to personalised quantity regulation or quotas (as we discuss below). O'Donoghue and Rabin (2005) conclude that sin licenses achieve the first-best outcome if individuals can forecast their future tastes accurately. Further, even though many mechanisms that are based on voluntary participation can only be expected to work for sophisticated individuals, sin licenses have the desirable property that they work not only for sophisticates, but also for naives: As a naive person assumes that he will prefer the optimal level of consumption in the future, he would ex ante ask for the optimal amount of sin licenses.

In general, the difficulties associated with implementing non-linear taxation are well-known.[5] The literature on regulating harmful consumption has nevertheless entertained the idea that the regulation of harmful consumption may be a special case in this respect: As sophisticated consumers would like to pre-commit to the optimal

[3]See Kanbur, Pirttilä and Tuomala (2006) for an analysis of sin taxes within the broader context of non-welfarist optimal taxation and Cremer et al. (2010) for a related analysis of commodity taxation under habit formation and myopia.

[4]On this discussion, see e.g. Gregory Mankiw's recent column in the New York Times http://www.nytimes.com/2010/06/06/business/06view.html?_r=1. Further, the possibility of government failure may reduce the effectiveness and desirability of paternalistic policies in general - see for example Glaeser (2006) for a critical view on paternalism.

[5]Non-linear commodity taxation would require personal consumption levels to be observable to the authorities - an assumption that would in most situations be very unrealistic. Rules for optimal non-linear commodity taxation were derived in Mirrlees (1976), but already that paper recognised the difficulty of implementing such a scheme. Much of the subsequent literature on optimal taxation has been restricted to linear commodity taxation (see e.g. Cremer *et al.* 2001).

level of consumption in order to avoid yielding to the temptation of consuming too much in the future, it might be possible to exploit consumer sophistication, and allow consumers to self-select in advance whether they should be subject to regulation, and how strict that regulation should be. This general idea is expressed for example in O'Donoghue and Rabin (2007) and is well illustrated by the following quote: "If our goal is to implement a policy that combats present bias, but we are worried that this policy might hurt people who don't have present bias, why not let people voluntarily select in advance whether to be subject to the policy. If everyone were fully sophisticated, such a scheme can be very effective, because we can count on all agents to choose whatever incentives are best for them." (O'Donoghue and Rabin, 2007).The authors further note that the analysis of the use of voluntary screening devices is an important aspect missing from existing literature.[6]

The optimality results concerning sin licenses rest on the assumption that the sin good cannot be traded between consumers (or there is e.g. perfect policing that will eliminate any secondary or black market activity). However, if the authorities attempted to implement this type of regulation, there would ex post be incentives to create a secondary market, where individuals with serious self-control problems buy the sin good from individuals without self-control problems. This is because, under the first-best scheme, individuals with a low level of self-control problems would be subject to less stringent regulation than individuals with serious self-control problems.

It is therefore interesting and important to reconsider the welfare properties of sin licenses when secondary markets exist: if this type of regulation could nevertheless be implemented, this may lead to substantial welfare gains over the types of linear instruments that are typically used. On the other hand, if the implementability of nonlinear schemes is severely undermined by the existence of secondary markets, it may be that there is no need to look beyond simple, linear instruments for regulating harmful consumption - in much the same vein as governments have restricted themselves to using linear commodity taxes in general.

We show that when secondary markets exist, a scheme involving sin licenses could lead individuals with low levels of self-control problems to consume optimally, but the consumption of individuals with severe self-control problems would be too high even if consumers are fully sophisticated: the simple intuition is that consumers with most severe self-control problems are the ones who are tempted by purchases from a secondary

[6] In addition to O'Donoghue and Rabin's suggestion concerning sin licenses (O'Donoghue and Rabin 2003, 2005, 2007), see Bhattacharya and Lakdawalla (2004) for a scheme involving smoking licenses, and Beshears *et al.* (2005) for a related discussion of schemes involving prospective choices on the part of consumers.

market. Attempts to implement personalised regulation would therefore work well for individuals with low self-control problems, but it would only be a partial solution for individuals with severe self-control problems. We also show that equilibrium welfare under a scheme of sin licenses would be decreasing in the level of self-control problems.

We also examine the implications of imperfect self-knowledge in the form of full or partial naivete. In the case of full naivete, the scheme of sin licenses either works perfectly (all individuals achieve the first-best level of consumption) or fails completely (all individuals consume the laissez-faire amount of the sin good), depending on how easy it is for individuals to resort to secondary market purchases. We also consider intermediate cases of partial naivete, and show that welfare is non-increasing in the level of naivete. Thus (partially) naive individuals are often worse off than sophisticates under a system of sin licenses: unlike in the ideal case where secondary markets do not exist, sin licenses perform worse for naives than for sophisticates when consumer arbitrage is a possibility.

Further, we analyse ways in which the functioning of the system of sin licenses could be improved upon. We show that introducing a uniform tax on top of a system of sin licenses may improve welfare, whereas a uniform maximum quota would reduce welfare for sophisticates. On the other hand, in the case of fully naive individuals, also a maximum quota may lead to a Pareto improvement. In general, naive individuals are more likely to benefit from uniform regulation than sophisticates. Finally, we show that naives, in particular, would benefit from a scheme where sin licenses are sold for a positive price in the primary market (rather than giving them out for free or for a symbolic price of 1 cent).

The rest of the paper proceeds as follows. The model is introduced in Section 2. Section 3 analyses the outcome associated with attempts to implement personalised quotas or sin licences to regulate harmful consumption when the possibility of creating a secondary market for the sin good is taken into account. Section 4 analyses the implications of full and partial naivete. Section 5 analyses various ways in which the system of sin licenses could be improved upon. Section 6 briefly compares the outcomes associated with personalised and linear instruments, as well as discusses some suggestive evidence on whether transaction costs associated with reselling sin goods are likely to be high or low. Section 7 concludes.

2 The model

We consider a model where consumers have a quasi-hyperbolic discount function (Laibson 1997), using a set-up that is similar for example to O'Donoghue and Rabin (2003; 2006). In the model, consumers suffer from varying degrees of self-control problems. Life-time utility of an individual is given by

$$U_t = (u_t, ..., u_T) = u_t + \beta_i \sum_{s=t+1}^{T} \delta^{s-t} u_s, \tag{1}$$

where $\beta_i, \delta \in (0,1)$ and u_t is the periodic utility function. We assume that the quasi-hyperbolic discount factor β has a distribution function $F(\beta)$ with mean $E(\beta)$ and median β_{med}. Throughout the paper we consider the general case where β has the support $[\beta_L, \beta_H]$, with $0 \leq \beta_L < \beta_H \leq 1$. Quasi-hyperbolic discounting implies that preferences are time-inconsistent: discounting is heavier between today and tomorrow, than any two periods that are both in the future.

We assume that utility is quasilinear with respect to a composite good (z). Consumer utility is also affected by the consumption of another good (x), which is harmful in the sense that it yields positive utility in the short-run, but has some negative effects in the long-run. Specifically, we assume that periodic utility is given by

$$u_t(x_t, x_{t-1}, z_t) = v(x_t; \gamma) - h(x_{t-1}) + z_t, \tag{2}$$

where $v' > 0, v'' < 0$ and the harm function[7] is characterised by $h' > 0$ and $h'' \geqslant 0$. We therefore assume that the harm function is either linear or convex, so that incremental consumption of sin goods is more harmful at high levels of consumption. We allow individuals to differ in their preferences for the sin good: this heterogeneity is captured by the parameter γ, where a higher value of γ is taken to imply a higher taste for the sin good ($v_{x\gamma} > 0$).

We assume that there is no borrowing or lending. Given this assumption and our specification for the periodic utility function in (2), in each period t an agent whose objective is to maximise (1) chooses x_t so as to maximise $u(x_t) = v(x_t) - \beta_i \delta h(x_t) + z_t$.

[7] As in O'Donoghue and Rabin (2006), we assume that the marginal benefits and marginal costs of consumption are independent of past consumption levels. In such a setting, it is not essential that the harm is modelled as occuring only in the period following consumption - h can be thought of as the discounted sum of harm occurring in all future periods. See Gruber and Köszegi (2004) for an analysis where past consumption affects current marginal utility.

Maximisation is subject to a per-period budget constraint $qx_t + z_t \leq B + S$. We assume that product markets are competitive and normalise the producer price to 1, τ is a possible per unit tax on good x, and $p = 1 + \tau$ denotes the consumer price of good x. B is the consumer's income (taken to be exogenous) and S is a possible lump-sum subsidy received by the consumer from the government. Taxes and subsidies will be modelled in more detail in later sections. Given the above specification, the demand for good x satisfies[8]

$$v'(x^*; \gamma) - \beta_i \delta h'(x^*) = p. \tag{3}$$

However, the time-inconsistency in preferences implies that the consumer would like to change his behaviour in the future: Maximising (1) from the next period onwards would amount to maximising $u^o(x) = v(x) - \delta h(x) + z$ each period.[9] Therefore, when thinking about future decisions, the consumer would like to choose consumption levels that maximise $u^o(x)$.

In general the issue of how to conduct welfare analysis when consumers have time-inconsistent preferences is far from straight-forward, and this question has received considerable attention in the literature. In the current paper, we take the so-called "long-run criterion" as the appropriate welfare criterion - that is, we take the utility function $u^o(x)$ to be the one that is relevant for welfare evaluation. This has been a standard choice in the literature on sin taxes based on models of quasi-hyperbolic discounting (see for example Gruber and Köszegi (2004), O'Donoghue and Rabin (2003; 2006)). There are clear reasons that justify this choice of welfare criterion in the present setting: Firstly, we assume that regulation is implemented from the period after the policy decision is made. Therefore, consumers themselves in any given period agree that $u^o(x)$ is the relevant utility function from the point of view of making regulatory policy. Secondly, $u^o(x)$ is the utility function that applies to all periods except for the present one. Since we consider an infinite number of periods, the weight of any single period should be negligible as long as periods are sufficiently short.[10] This latter consideration applies irrespective of the timing of the model.[11]

[8] We have dropped the time index t, since with our specification consumption is constant accross periods.

[9] See equation (1) and think of a consumer in period t, making consumption decisions for period $t + 1$ onwards.

[10] See also Bernheim and Rangel (2007, p.14) for a similar argument.

[11] In situations involving time-inconsistent preferences, either the long-run criterion or the multiself Pareto criterion have typically been used for welfare analysis. The latter views the different preferences of the individual at different points in time in terms of different "selves", and applies the Pareto

Given the above assumptions, the optimal level of consumption satisfies

$$v'(x^o) - \delta h'(x^o) = p. \tag{4}$$

Because of quasi-hyperbolic discounting ($\beta < 1$), the equilibrium level of consumption of the harmful good (x^*) is higher than the optimal level (x^o).

3 Sin licenses in the presence of secondary markets

3.1 Sin licenses

If consumers are sophisticated, i.e. if they are aware of their self-control problem, they would like to be able to pre-commit to the optimal level of consumption. It therefore appears that it might be possible to exploit consumer sophistication, and allow consumers to self-select in advance whether their future purchases of the sin good should be subject to regulation, and how strict that regulation should be.

Consider the following mechanism, which is a simple continuous-demand generalisation of O'Donoghue and Rabin's system of sin licenses (O'Donoghue and Rabin 2005)[12]: (i) The social planner asks each individual i in period t to state a quota, $y_{i,t} > 0$, which places an upper bound on his personal tax-free purchases of the sin good in the next period.[13] Purchases beyond $y_{i,t}$ incur a prohibitively high tax. (ii) Each consumer is issued a card that carries information on $y_{i,t}$, which they should present each time they purchase the sin good (with purchases recorded on the card).[14] (iii) Consumption takes place.

The above system of sin licenses is obviously identical to a system of personalised

criterion in this multiself-setting. See e.g. O'Donoghue and Rabin (2006, p. 1829) and O'Donoghue and Rabin (2007, p. 220) for arguments supporting the long-run criterion and Bhattacharya and Lakdawalla (2004) for an anlysis using the Pareto criterion. Note that the optimal policy (derived according to the long-run criterion) in our setting is part of the set of multiself Pareto optimal policies, since deviating from this policy would make the current self worse off. It is also very close to being optimal for each future self as long as periods are sufficiently short. Bernheim and Rangel (2009) build a choice-based framework for conducting welfare analysis with behavioural individuals, and show that in general their framework does not lead to either of these commonly used welfare criteria. Nevertheless, their framework, with some refinements, gives a justification for the long-run criterion in settings such as ours (see Theorem 11 in their paper). On the other hand, the literature is not even unanimous on whether behavioural welfare analysis can be based (solely) on choices (see e.g. Köszegi and Rabin (2007) and Sugden (2004)).

[12] O'Donoghue and Rabin (2005) discuss sin licenses in the context of unit demands.

[13] Similar results would hold if the quota was applied in all future periods.

[14] For a discussion of alternative ways of implementing personalised quotas for consumption of sin goods, see Beshears et al. (2005, pp. 47-8).

tax-free quotas.[15] In what follows, we use the words license and quota interchangeably. Alternatively, sin licenses can be thought of as a form of personalised, non-linear taxation, as each individual i faces a zero tax up to the consumption level $y_{i,t}$ and a very high tax thereafter. As has been noted by O'Donoghue and Rabin (2005), sin licenses achieve the first-best level of consumption for both sophisticated and naive individuals. However, as we will show, this optimality result depends crucially on assuming that there is no secondary market for the sin good. For most of the analysis we concentrate on sophisticates, and turn to (partially) naive individuals in section 5.

Ex ante, individuals make decisions concerning next-period sin licenses according to their long-run utility function[16]

$$V(1;\gamma,\beta) = v(y(1;\gamma,\beta),\gamma) - \delta h(y(1;\gamma,\beta)) - y(1;\gamma,\beta) + B,$$

and would therefore prefer the quota that satisfies $v'(y(1;\gamma,\beta),\gamma) - \delta h'(y(1;\gamma,\beta),\gamma) = 1$. We thus have that ex ante, individuals prefer the quota that implements the optimal level of consumption, that is, $y(1;\gamma,\beta) = x^o(1;\gamma)$ (see equation (4)); this holds for all individuals regardless of their level of self-control problems. This finding lies behind the optimality of personalised quotas or sin licenses in the absence of secondary markets.

3.2 Secondary market

Consider a situation where the sin good can be traded ex post between consumers, and such trades incur a transaction cost k per unit of the sin good traded. Note that when consumption decisions are made (in the period after the sin licenses were assigned), the marginal utility of an extra unit of consumption is $v'(x^o(1;\gamma),\gamma) - \beta\delta h'(x^o(1;\gamma)) \geq 1$. Therefore, ex post, individuals with self-control problems ($\beta < 1$) have a willingness to pay for the sin good that exceeds the free market price (which is equal to one). There may thus be incentives to create a secondary market, where individuals without self-control problems ask for a higher quota than the one that would satisfy their own demand, and sell the sin good ex post to consumers with self-control problems.

We solve for the equilibrium in the presence of secondary markets by backwards

[15] In what follows, we model the sin licenses as being free. Strictly speaking, this would lead to some indeterminancy as individuals without self-control problems ($\beta = 1$) as well as naifs would then be indifferent between the quota $y(1;\gamma,1) = x^o(1;\gamma)$ and any quota exceeding $x^o(1;\gamma)$. This indeterminacy is solved if consumers have to pay an arbitrarily small amount for the quota, as is assumed for example in O'Donoghue and Rabin (2005) who discuss one-cent licenses.

[16] In what follows, we drop the individual and time indices i and t.

induction: First, we analyse individual behaviour in the secondary market. Second, in the next subsection, we analyse what this implies for individuals' actions ex ante, i.e. when the allocation of sin licenses is decided upon.

Assume that secondary markets would be perfectly competitive. Consider first the supply side. For perfectly rational consumers to be willing to obtain a quota that exceeds their optimal level of consumption and to act as sellers in the secondary market, the market price would simply have to be high enough to cover the transaction cost (i.e. it would have to be equal to $1+k$). For these individuals, there are no other costs associated with acting as sellers. For any less-than-rational individual to be willing to act as seller in the secondary market, on the other hand, the secondary market price would have to exceed $1+k$: purchasing a higher than optimal quota ex ante would cause them to lose some of the self-control benefits of the mechanism, as they know that they would be tempted to consume (some of) the higher quota themselves ex post. In order for these consumers to have incentives to participate in the secondary market as sellers, this loss of self-control would have to be compensated for, and the market price would therefore have to exceed $1+k$.

Assume that there are enough rational sellers to act as suppliers in the secondary market, so that the price in the secondary market would be equal to $1+k$.[17] In this situation, all individuals for whom $v'\left(x^{o}\left(1;\gamma\right),\gamma\right)-\beta\delta h'\left(x^{o}\left(1;\gamma\right)\right)-1=(1-\beta)\delta h'(x^{o}\left(1;\gamma\right))>k$, would buy the sin good from the secondary market: These are the consumers with the most severe self-control problem, and therefore the highest temptation to resort to purchases from the secondary market ex post. On the other hand, for those consumers for whom $(1-\beta)\delta h'(x^{o}\left(1;\gamma\right))\leq k$, the transaction cost associated with secondary market purchases is high enough to overcome the temptation of resorting to purchases in the secondary market. They will therefore not participate in the secondary market as either buyers or sellers.

A further comment on the assumption that there are enough rational individuals to cover the demand in the secondary market is in order. It should be noted that this in fact turns out not to be a very strong assumption in our case, as there will be no trading in the secondary market in equilibrium (see the next subsection). Hence the secondary market will only have to be able to satisfy the demand of any single individual who may consider deviating from the equilibrium outcome. Even though there is no trade in the secondary market in equilibrium, we show below that the pure potential of creating such a market causes the regulatory mechanism to fail.

[17] We discuss this assumption further below.

3.3 Equilibrium

From the above discussion it is clear that individuals with severe self-control problems do not have the right incentives even ex ante, when the decisions on the allocation of sin licenses are made: for these consumers, the potential of creating a secondary market implies that sin licenses have only limited commitment power. These individuals will therefore understate their self-control problem in order to obtain a quota that enables them to satisfy their own (ex post) demand in the primary market ($y(1;\gamma,\beta) = x^*(1+k;\gamma,\beta)$). That is, individuals for whom $(1-\beta)\delta h'(x^o(1;\gamma)) > k$ will ask for the quota that satisfies $v'(x^*(1+k;\gamma,\beta),\gamma) - \beta\delta h'(x^*(1+k;\gamma,\beta)) = 1+k$, i.e. for the quota that equals their equilibrium consumption at price $1+k$.[18]

This level of consumption is, however, higher than their optimal level of consumption: Note that the outcome corresponds to a situation where a uniform tax equal to k was implemented. However, the tax that would fully correct the distortion in consumption would be equal to

$$\tau^o(\gamma,\beta) = (1-\beta)\,\delta h'(x^o(\gamma)). \tag{5}$$

If the tax rate were (5), $x^*(q;\gamma,\beta) = x^o(1;\gamma)$ (see equations (3) and (4)). However, $(1-\beta)\delta h'(x^o(1;\gamma)) > k$ implies that $\tau^o(\gamma,\beta) > k$, and consumers with a severe self-control problem therefore consume too much.

Consumers with a low level of self-control problems ($(1-\beta)\delta h'(x^o(1;\gamma)) \le k$), on the other hand, achieve an optimal level of consumption: as they know ex ante that they will have no incentive to buy the sin good from the secondary market ex post, sin licenses constitute an effective self-control mechanism for them, and they therefore choose the quota that achieves the optimal balance between sin good consumption and the consumption of other goods according to their long-run preferences $u^o(x(q;\gamma,\beta))$ and thus ask for the optimal quota. The relationship between the severity of self-control problems (β) and equilibrium consumption is illustrated in Figure 1.

[Figure 1 here.]

To characterise the outcome further, note that a consumer is not tempted by the secondary market, if

$$k > \Phi(\beta,\gamma) \equiv (1-\beta)\,\delta h'(x^o(\gamma))$$

where $x^o(\gamma)$ is the optimal (rational) level of consumption, given preferences. Now, we

[18] Doing so will enable the consumer to obtain his consumption at the primary market price of 1, and he will save the transaction cost that he would have to pay in the secondary market.

have that

$$\frac{\partial\Phi\left(\beta,\gamma\right)}{\partial\beta}=-\delta h'\left(x^{o}\left(\gamma\right)\right)<0,\quad\frac{\partial\Phi\left(\beta,\gamma\right)}{\partial\gamma}=\left(1-\beta\right)\delta h''\left(x^{o}\left(\gamma\right)\right)\frac{dx^{o}\left(\gamma\right)}{d\gamma}\geq0.$$

A consumer is therefore more likely to consume the optimal (rational) amount of the sin good if (i) he has a relatively mild self-control problem (high β) and/or (ii) he does not have a strong preference for the sin good. Conversely, personalised regulation is typically not a complete fix for heavy-users, whether high consumption results from a weak will (low β) or from a strong taste for the sin good (high γ).

It is important to note that there is in fact no trading in the secondary market in equilibrium. Nevertheless, the possibility of creating such a market affects the choices made by consumers with severe self-control problems: they ask for a quota that exceeds their optimal level of consumption. Therefore, the pure potential of creating a secondary market makes the regulatory mechanism lose some of its effectiveness.

One implication of this analysis is that the outcome associated with attempting to implement personalised regulation has the following unfortunate property: regulation fails to achieve the first-best outcome for individuals with severe self-control problems, that is, precisely those individuals who would stand the most to benefit from regulation. We show in the appendix that welfare in equilibrium is decreasing in the level of self-control problems. This is understandable, since the more severe an individual's self-control problem is, the further away the de facto level of regulation (given by the price in the secondary market, k) is from regulation that would be optimal from his point of view: for a consumer of type (γ,β), this difference is given by $\max\{\tau^{o}\left(\gamma,\beta\right)-k,0\}$, which is clearly increasing in the level of self-control problems.

The above results are summarised in the following Proposition:

Proposition 1 *Assume that consumers are sophisticated, and the social planner asks each consumer in period t to choose a personalised quota ($y_i>0$) of tax free sin licenses for consumption of the sin good, to be implemented in period $t+1$. Purchases beyond this quota incur a prohibitively high tax. Assume that the sin good can be traded between consumers at cost k. Consumers with a low level of self-control problems ($(1-\beta)\delta h'(x^{o}\left(1;\gamma\right))\leq k$) consume optimally, whereas consumers with a high level of self-control problems ($(1-\beta)\delta h'(x^{o}\left(1;\gamma\right))>k$) choose a quota equal to $x^{*}\left(1+k;\gamma,\beta\right)$ and consume too much. In equilibrium, welfare is decreasing in the level of self-control problems.*

Proof. See the appendix. ■

From the above analysis, the results for the polar cases of a perfect secondary market and no secondary market are obtained special cases. In the case of a perfect secondary market ($k = 0$), all consumers for whom $\beta < 1$ are tempted by the secondary market. Sin licenses then have no commitment power and knowing this, there are no incentives to ask for the optimal number of licenses even ex ante. Instead, all consumers ask for the quota that equals their equilibrium level of consumption $x^* (1; \gamma, \beta)$. We then obtain the stark conclusion that the regulatory mechanism fails completely and the outcome resembles zero regulation. On the other hand, if k is prohibitively high, that is if $k > \max_{\beta,\gamma} [(1-\beta)\delta h'(x^o (1; \gamma))]$, no consumer will be tempted by the secondary market. In this case, personalised quotas constitute a perfect self-control mechanism and all individuals consume optimally:

Corollary 2 *Assume that consumers are sophisticated, and the social planner asks each consumer in period t to choose a personalised quota ($y_i > 0$) of tax free sin licenses for consumption of the sin good, to be implemented in period $t+1$. Purchases beyond this quota incur a prohibitively high tax. (i) If there is a perfect secondary market for the sin good ($k = 0$), the outcome corresponds to zero regulation, i.e. each individual chooses a quota equal to their equilibrium level of consumption $x^* (1; \gamma, \beta)$. (ii) if there is no secondary market for the sin good ($k > \max_{\beta,\gamma} [(1-\beta)\delta h'(x^o (1; \gamma))]$) this mechanism implements the first-best.*

4 Naivete

So far, we have assumed that all consumers are sophisticated. This is a natural starting point, since mechanisms that involve an element of voluntary participation are in general likely to work best for sophisticates. However, previous literature has established that sin licenses have the important special feature that (in the absence of secondary markets) they implement the first-best also for naives (O'Donoghue and Rabin 2005): As a naive person assumes that he will prefer the optimal level of consumption in the future, he would ex ante ask for the optimal amount of sin licenses.

In this section we examine how the situation changes when re-selling the sin good in a secondary market is a possibility. At a first glance it might seem that in the presence of secondary markets, sin licenses might even work better for naives than for sophisticates: As naives assume that they will stick to their optimal consumption plan in the future, perhaps secondary markets are irrelevant from their point of view, and they might still ask for the optimal amount of licenses ex ante? Below we show, however, that naives are often worse off than sophisticates under a scheme of sin licenses when secondary markets exist.

In what follows, we denote the consumer's perceived degree of self-control problems by $\hat{\beta}$. The model therefore now features imperfect self-knowledge ($\hat{\beta} < \beta$) in addition to imperfect self-control ($\beta < 1$). Note that all ex ante decisions (notably decisions in period t concerning the consumer's quota of sin licenses for period $t+1$) will be made based on the perceived degree of self-control problems, $\hat{\beta}$, whereas all ex post decisions (decisions on period t consumption made in period t) will be made according to the true level of self-control problems, β.

When consumers were sophisticated, sin licenses failed because consumers were tempted to buy the sin good in the secondary market: foreseeing this, consumers bought the number of licenses corresponding to their equilibrium level of consumption already from the primary market. When consumers are naïve, two further problems arise: First, naive consumers do not foresee the self-control benefit of holding only a small amount of sin licenses. Therefore they may be tempted to hoard extra licenses in the primary market, planning to resell them and make a profit in the secondary market. However, ex post their own demand will be higher than anticipated, and they will end up consuming most of the extra licenses themselves, and consumption will be too high. Second, imperfect self-knowledge may cause welfare losses even to those (partially) naive individuals who do not plan to become sellers: these individuals fail to obtain the correct number of licenses ex ante, and therefore may end up as buyers in the secondary market, where the price is higher than in the primary market.

In this section, we present a simple model to capture the above intuitions about the behaviour of naive consumers. We assume that there is a continuum of individuals differing in both β and $\hat{\beta}$, with $\beta \leq \hat{\beta} \leq 1$. In particular, we assume that there are fully naive individuals ($\beta < \hat{\beta} = 1$), partially naive individuals ($\beta < \hat{\beta} < 1$), as well as sophisticated individuals ($\beta = \hat{\beta} \leq 1$) in the economy.[19] Otherwise the situation is similar to Section 3: In period t individuals ask for a given quota of sin licenses to be used for consumption of the sin good in period $t+1$, but the sin good can be traded between consumers after the licenses have been allocated. Secondary market transactions again incur a cost k per unit of the sin good traded. Further, assume that

[19] Note that in what follows, we assume for simplicity that there are enough fully naive individuals, so that they can cover demand in the secondary market (i.e. in this case, no partially naive individuals have incentives to become sellers). This assumption may in some cases be restrictive, because, unlike in Section 3, there may now be some trade in the secondary market in equilibrium. However, most of our main results are robust to this assumption. We have also analysed the model without this assumption, and we discuss this issue at the end of this section.

there is a (very) small fixed cost ε^k incurred by sellers who enter the secondary market; this is a technical assumption needed to ensure the existence of equilibrium.[20]

The main results of this section are summarised in the following proposition:

Proposition 3 *Assume that the social planner asks each consumer in period t to choose a personalised quota ($y_i > 0$) of tax free sin licenses for consumption of the sin good, to be implemented in period $t+1$. Purchases beyond this quota incur a prohibitively high tax.*

(a) If there is a secondary market for the sin good ($k < \max_{\beta,\gamma}[(1-\beta)\delta h'(x^o(1;\gamma))]$)

(i) Fully naive individuals intend to become secondary market sellers and partially naive individuals for whom $(1-\beta)\delta h'(x^o(1;\gamma)) > k$ will be secondary market buyers.

(ii) The outcome for naive consumers corresponds to zero regulation. Each naive individual chooses the maximum quota $\overline{y}$, and consumes the laissez-faire amount $x^*(1;\gamma,\beta)$.

(iii) Both sophisticated and partially naive consumers with a low level of self-control problems ($(1-\beta)\delta h'(x^o(1;\gamma)) < k$) consume the optimal amount and attain the first-best level of welfare.

(iv) Both sophisticated and partially naive consumers with severe self-control problems ($(1-\beta)\delta h'(x^o(1;\gamma)) > k$) consume the amount $x^*(1+k;\gamma,\beta)$, but partially naive individuals attain lower welfare than sophisticates.

(v) Welfare in equilibrium is non-increasing in the level of naivete $\hat{\beta}$ (for a given β).

(vi) There is a discontinuous drop in welfare between (partially naive) non-sellers and (naive) sellers.

(b) If there is no secondary market for the sin good ($k > \max_{\beta,\gamma}[(1-\beta)\delta h'(x^o(1;\gamma))]$), this mechanism implements the first-best for all consumers.

Proof. See the appendix. ■

When proving part (a.vi) of the proposition we need one extra assumption:

Assumption 1 $\frac{\partial^2 x^*(q;\beta)}{\partial p \partial \beta} > 0$.

In the rest of this section we assume that $\frac{\partial^2 x^*(q;\beta)}{\partial p \partial \beta} > 0$, which holds for commonly used functional forms[21] and is also supported by empirical evidence (see Haavio and

[20] Note that we could introduce a small fixed cost also into the model with sophisticated individuals in Section 3; this would not affect the results obtained there.

[21] Then condition holds for example when v is of the CRRA or CARA-variety or linear-quadratic, and when the harm function is linear, quadratic, exponential or $h(x) = x^s$ where $s \geq 1$.

Kotakorpi (2011)). When this condition holds, the demand of irrational consumers with a high level of consumption is more responsive (in absolute terms) to price changes than the demand of rational consumers with a low or moderate level of consumption. A basic rationale for this feature is that as rational consumers consume relatively little of harmful goods in any case, a higher price cannot reduce their consumption much further. It is important to note that the condition concerns *absolute* changes in demand. Even with this assumption, demand can be less elastic for heavy users than for moderate consumers.

The intuition for the above results can be seen as follows. If a secondary market exists (case (a)), the system of sin licenses provides no self-control benefits for perfectly naive consumers. This result arises, since these individuals *intend* to be sellers in the secondary market.[22] Being completely unaware of their (future) self-control problems, naive consumers do not foresee the self-control costs of holding a large quota of sin licenses. Thus as long as the secondary market price is even slightly above $1+k$ (i.e. primary market price plus trading costs)[23], naive individuals think that their optimal strategy is to ask for the maximum quota $\overline{y}$ of sin licenses[24]. Since we assume that there are enough fully naive individuals to cover the demand in the secondary market, that there is perfect competition among sellers, and that the fixed cost of entering the secondary market as a seller (ε^k) is very small, the equilibrium secondary market price is bound to be very close to $1+k$, that is $q = 1 + k + \varepsilon^q$, where ε^q is positive but very small.

Now think of a naive individual who demanded the maximum quota of sin licenses in the previous period. The individual's opportunity cost of own consumption is equal to the price he would get from selling the good in the secondary market, minus trading costs. That is, the opportunity cost is $q - k = (1 + k + \varepsilon^q) - k = 1 + \varepsilon^q$. Given this opportunity cost, the naive individual consumes the amount $x^* (1 + \varepsilon^q; \gamma, \beta)$. Since ε^q is very small, equilibrium consumption is very close to the laissez-faire level $x^* (1; \gamma, \beta)$.

[22] As we show in the appendix, in the proof of Proposition 3a(i), not all of them will actually participate in the secondary market.

[23] Actually, the conditions under which naive individuals find it optimal to hoard are even less demanding than this. If sin licenses are distributed free of charge, naive consumers think that hoarding licenses is a highly attractive one-sided bet: The licenses can be possibly resold at a profit. Even if this is not the case, the cosumer stands to lose very little, since he got the licenses for free (or paid 1 cent for each); under unfavourable secondary market condition the consumer can simply stay out of the market. Hence, the naive consumer thinks that hoarding sin licenses is worthwhile as long as there are some states of the world where secondary market trade is profitable, i.e. anticipated sale revenues exceed entry costs.

[24] The upper limit $\overline{y}$ may be due to regulation or it may for example reflect limitations in the consumer's storage capacity.

Sophisticated and partially naive individuals, on the other hand, foresee (at least a part of) the self-control costs of holding a large number of sin licenses, and therefore do not become secondary market sellers. Note that equilibrium consumption, which is decided on ex post, only depends on the true level of self-control problems β, not on $\hat{\beta}$, and is therefore equal for sophisticates and partially naive individuals with the same level of β. Sophisticated and partially naive individuals with a low level of self-control problems ($(1-\beta)\delta h'(x^o(1;\gamma)) < k$) are not tempted by the secondary markets, and they consume the optimal amount and attain the first-best level of welfare. On the other hand, sophisticated and partially naive individuals with severe self-control problems ($(1-\beta)\delta h'(x^o(1;\gamma)) > k$) are tempted by the secondary market; as in Section 3, they consume the amount $x^*(1+k;\gamma,\beta)$, which is higher than the optimal level. However, despite having the same level of consumption, partially naive individuals are worse off than sophisticates: sophisticates correctly forecast their future tastes, and buy the amount $x^*(1+k;\gamma,\beta)$ in the primary market, at price 1. Partially naive individuals, on the other hand, fail to obtain the correct amount of sin licenses ex ante: in equilibrium, their level of consumption is higher than anticipated, and they buy part of their consumption in the secondary market, and incur the trading costs associated with secondary market purchases. The more naive the consumer is, the less she buys from the primary market, and therefore the more she ends up buying from the secondary market.

The above results together imply part (v) of Proposition 3: equilibrium welfare is non-increasing in the level of naivete. If self-control problems are mild, the system of sin licenses is robust to partial naivete, and partially naive individuals and sophisticates attain the same level of welfare. If self-control problems are severe, even partial naivete is bad for welfare. Fully naive individuals, on the other hand, are always worse off than sophisticates or partially naive individuals, as long as there is trade in the secondary market. Finally, it is interesting to note that there is in fact a discontinuous drop in welfare between secondary market buyers (in the current model, partially naive individuals) and sellers (fully naive individuals); this result is quite general, and it does not hinge on the assumption that all sellers are fully naive (see the discussion at the end of this section): The reason why secondary market sellers are quite generally worse off than buyers, is that in equilibrium, sellers consume more than buyers. This is because trading in the secondary market involves transaction costs (k), and thus the effective price $q-k$ the sellers receive is lower than the price the buyers pay, q. To put it differently: as the price of the sin good in the secondary market is what determines the de facto degree of regulation (see the discussion in section 3.3), sellers face less stringent regulation than buyers. Ex ante choices of individuals, whether or not they intend to become secondary market sellers, therefore have large implications for welfare.

On the other hand, if there is no trade in the secondary market (part (b) of Proposition 3), all consumers achieve the first-best outcome under a system of sin licenses, regardless of the level of naivete. When does this ideal outcome arise? Naturally, this happens when no consumer is tempted to be a buyer in the secondary market. Similar to section 3, no consumer is tempted by the secondary market if $k > \max_{\beta,\gamma}(1-\beta)\delta h'(x^o(1;\gamma))$. In this case, naive individuals see that they have no prospects as secondary market sellers, and find it optimal to ask for the number sin of sin licenses that corresponds to their perceived consumption $x^*\left(1;\widehat{\beta},\gamma\right)$, which is equal to the rational level of consumption $x^o(1;\gamma)$. Thus under these circumstances, the system of sin licenses implements the first best for all consumers.

A note on alternative assumptions Above, we assumed that there are enough fully naive individuals in the economy to cover the demand in the secondary market. We have also analysed the model under alternative assumptions on the distribution of $\hat{\beta}$.[25]

One possible assumption to make is that (almost) all individuals are fully naive. This is an interesting special case, as it allows examining the robustness of O'Donoghue and Rabin's (2005) claim that sin licenses achieve the first best also when individuals are naive. Note that in this case, to analyse the implications of secondary markets, we nevertheless need to assume that the mass of partially naive individuals is positive (even though very small), so that there are at least some (potential) buyers in the secondary market. In this case we obtain the following, rather drastic predictions, showing that the system of sin licenses is very vulnerable to the existence of secondary markets, when individuals are fully naive: if there is trade in the secondary market, the system of sin licenses fails completely, and all fully naive individuals consume the laissez-faire amount. The intuition is that all naive individuals plan to become sellers in the secondary market, and therefore hoard sin licenses in the primary market (but end-up consuming the licenses themselves, as above). On the other hand, if there is no trade in the secondary market, sin licenses implement the first-best outcome for all individuals; this latter situation is the one envisioned by O'Donoghue and Rabin (2005).

Another possible assumption is that there are not enough fully naive individuals in

[25]The proofs of these additional results are available from the authors upon request.

the economy to cover demand in the secondary market. In this case, also some partially naive individuals may become sellers. The main result, that welfare is non-increasing in the level of naivete still holds. Further, the welfare implications of partial naivete are then as indicated in Proposition 3 above, but *only up to some threshold value* $\hat{\beta}^* > \beta$. Consumers with $\hat{\beta} > \hat{\beta}^*$ plan to become secondary market sellers, and there is a sharp decline in welfare at $\hat{\beta}^*$. The reason for this is, as we discussed above, that secondary market sellers have a lower opportunity cost of own consumption than buyers, and their consumption of the sin good is therefore higher.

5 Modifying the system of sin licenses

In the previous sections we have shown that a system of sin licenses cannot implement the first-best outcome when consumers have the opportunity of trading the sin good between themselves in a secondary market. An interesting question then arises, whether the outcome can be improved by, for example, introducing some uniform ("one-size-fits-all") instruments on top of the system of personalised regulation.[26]

There are four building blocks in the basic system of sin licenses: i) with licenses, sin goods can be bought tax-free; ii) licenses are practically given out for free (cost 1 cent); iii) consumers can freely choose the amount of licenses to obtain; iv) purchases without the license are subject to a prohibitively high tax. In what follows, we ask whether the functioning of the system of sin licenses can be improved by modifying each of these basic building blocks in turn.

In subsection 5.1 we turn to modifying (i) and show that (i') introducing a universal sin tax on top of a system of sin licenses (i.e. purchases with a license are subject to a small uniform sin tax) yields a Pareto improvement over a pure system of sin licenses under quite general conditions. In subsection 5.2 we discuss an alternative scenario where (ii') the government charges a price ℓ (greater than 1 cent) for the licenses. Such a system is identical to the system (i') for sophisticates, but tends to outperform it for naives. In subsection 5.3 we then turn to a system where (iii') purchases of sin licenses are subject to a maximum quota, and show that a maximum quota may in fact cause a Pareto worsening for sophisticated consumers. Finally, in subsection 5.4 we assume

[26] Christiansen and Smith (2012) conduct a related analysis, where they consider combining different instruments for regulating an externality-generating commodity when uniform taxation is an imperfect instrument for correcting the externality (either because different units of consumption yield different externalities, or because some consumption avoids the tax). They consider supplementing uniform taxation by regulation that reduces the utility from consuming the externality-generating commodity, thereby lowering the level of consumption.

that the government attempts to kill the secondary market by (iv') allowing purchases of the sin good without a license, at a price $p = 1 + k$. We argue, however, that this solution would be very hard to implement. Taking the above considerations together, the system with costly licenses (assumption ii') appears to be the most promising alternative.

5.1 Sin licenses combined with a universal sin tax

Let us first consider introducing a small universal sin tax when a system of sin licenses is already in place, and there is also an opportunity to trade the sin good in a secondary market. We conduct the main part of the analysis assuming that all consumers are sophisticated, and turn to the implications of (partial) naivete at the end of the subsection.

The analysis in this subsection is closely related to O'Donoghue and Rabin (2006), who show that a small universal sin tax combined with a uniform transfer can lead to a Pareto improvement compared to no regulation.[27] Therefore, combining their result with the analysis of section 3.2 immediately yields the conclusion that if secondary markets are perfect, a small uniform sin tax plus a uniform transfer can lead to a Pareto improvement; this result follows as we have shown that the outcome of personalised regulation is identical to no regulation when there is a perfect secondary market for the sin good.

In the appendix, we generalise the analysis to cover the case of imperfect secondary markets, and show that a small uniform sin tax can lead to a Pareto improvement also in this case. This result holds both if the sin tax is combined with a personalised subsidy (where each consumer receives a transfer equal to whatever amount he paid in taxes in the first place), as well as in the case where tax revenue is divided equally between consumers.

A personalised compensation scheme is possible if individual pre-tax consumption levels are observable. This is the case for example if the purchases of sin licenses have been registered.[28] In this case, a small uniform sin tax has no effect on consumers with

[27]For the pareto improvement to be realised, a condition on the price responsiveness of demand is required - if consumers with self-control problems do not respond to prices very much, a uniform sin tax combined with a uniform transfer provide only modest self-control benefits but imply relatively large income losses for consumers with severe self-control problems.

[28]Note however that in the case of free quotas there may be an ambiguity in the case of consumers without self-control problems, who are indifferent between the quota $x^o(1;\gamma)$ and any quota exceeding this level. Below, we therefore also consider the case where the subsidy scheme does not rely on knowledge about personal consumption levels, but tax revenue is uniformly distributed back to consumers.

a low level of (or no) self-control problems ($k \geq (1-\beta)\,\delta h'(x^o)$): these consumers face no incentives to trade in the secondary market. As these individuals' consumption is at an optimal level already due to the system of sin licenses, a small change in consumption caused by a small sin tax has no effect on their utility. On the other hand, for individuals with severe self-control problems ($k < (1-\beta)\,\delta h'(x^o)$) who are tempted to buy the sin good in the secondary market, pre-tax consumption is too high, and a small sin tax unambiguously raises welfare when the income loss associated with the tax is fully compensated through the transfer scheme.

In the case where tax revenue is uniformly distributed back to consumers, the redistributive effects of sin taxes have to be taken into account. Each consumer then receives a subsidy equal to $S(q) = \tau\overline{x}$, where $\overline{x}$ is mean consumption. For consumers with low self-control problems, there is again no consumption distortion associated with a small sin tax, as their consumption is at an optimal level to start with. They therefore benefit as long as they receive a positive net transfer; this occurs if their consumption level is lower than average, which is very likely to be the case.[29] On the other hand, consumers with relatively high self-control problems benefit if the (unambiguously positive) self-control benefit of the small tax outweighs the (possibly negative) income effect of the tax-subsidy scheme. The precise condition for consumers with relatively severe self-control problems to benefit is

$$[(1-\beta)\,\delta h'(x^*(1+k;\gamma,\beta)) - k]\,|\eta|\,x^*(1+k;\beta,\gamma) + \overline{x} - x^*(1+k;\beta,\gamma) > 0.$$

where $|\eta|$ is the (absolute value of) price elasticity of demand for the sin good. This condition tends to hold if (i) the consumer has severe self-control problems (small β), (ii) trading in the secondary market does not involve large costs (small k) and (iii) demand for the sin good is price responsive ($|\eta|$ is sufficiently large, or at least differs from zero). If these conditions are met, the self-control benefits from a small uniform tax (captured by the term $[(1-\beta)\,\delta h'(x^*(1+k;\gamma,\beta)) - k]\,|\eta|\,x^*(1+k;\beta,\gamma)$) outweigh the monetary costs (given by the term $\overline{x} - x^*(1+k;\beta,\gamma)$).

These results are summarised in the following proposition:

Proposition 4 *Assume that a system of sin licenses is in place and there is a transaction cost k of reselling a unit of the sin good in a secondary market. Assume that all*

[29] This condition may fail for some consumers with a very high taste for the sin good and some rather exotic joint-distributions of β and γ where there are few individuals with a low β at high levels of γ. If, for example, the distribution of β is uniform (or right-skewed) at each level of γ, relatively rational individuals always benefit.

consumers are sophisticated.

(a) Consider introducing a small uniform sin tax τ combined with a personalised subsidy $S(q\,;\gamma,\beta) = \tau x^*$. This scheme is unambiguously Pareto-improving.

(b) Consider introducing a small uniform sin tax τ combined with a uniform subsidy $S(q) = \tau\overline{x}$. Consumers with a low level of self-control problems ($k \geq (1-\beta)\,\delta h'(x^o)$) benefit from this scheme if $\overline{x} - x^o(1;\gamma) > 0$ and consumers with a high level of self-control problems ($k < (1-\beta)\,\delta h'(x^o)$) benefit if

$$([(1-\beta)\,\delta h'(x^*(1+k;\gamma,\beta)) - k]\,|\eta| - 1)\,x^*(1+k;\beta,\gamma) + \overline{x} > 0.$$

If these conditions hold, the scheme is Pareto-improving.

Proof. See the appendix. ■

To sum up, a small uniform sin tax provides increased self-control benefits for consumers with severe self-control problems and therefore potentially improves their welfare, whereas the welfare of consumers with a low level of self-control problems is increased in cases where they are net beneficiaries from the revenue collected by sin taxes. Our results also indicate that uniform sin taxes (on top of a system of personalised quotas) are more likely to be beneficial, the lower is the transaction cost associated with trading the sin good in secondary markets; this is intuitive, as these are the cases when personalised regulation is most likely to fail.

Finally, we show that naive and partially naive individuals typically benefit more than sophisticated individuals, when a system of sin licenses is supplemented by a uniform sin tax:

Proposition 5 *Consider introducing a small uniform sin tax τ combined with a uniform subsidy $S(q) = \tau\overline{x}$ on top of a system of sin licenses. (i) Partially naive consumers with mild self-control problems ($k \geq (1-\beta)\,\delta h'(x^o)$) are equally well of as sophisticated consumers with mild self-control problems. (ii) Partially naive consumers with severe self-control problems ($k < (1-\beta)\,\delta h'(x^o)$) benefit more from the tax than sophisticated consumers with severe self-control problems. Benefits are increasing in the degree of naivete. (iii) Fully naive consumers, for given tastes γ, always benefit more than sophisticated or partially naive consumers with a low level of self-control problems ($k \geq (1-\beta)\,\delta h'(x^o)$).*

Proof. See the appendix. ■

5.2 Sin licenses with a price

In this subsection, we consider a case where rather than (effectively) giving the sin licenses for free (i.e. charging a symbolic price of 1 cent), the government sells the licenses at a given price ℓ. First note that for sophisticated consumers, such a system is identical to a system of sin licenses combined with a universal sin tax, which we considered in subsection 5.1. However, for naives, the two systems are not identical, and selling the licenses at a positive price is particularly helpful for naives. To see this, it is useful to have a closer look at the problems in the system of sin licenses, when consumers are naive; we turn to these details below. The gist of the argument is that, essentially, naive individuals do not foresee the commitment costs of hoarding sin licenses. A positive price induces them to internalise (at least a part of) these costs.[30]

When consumers are naive, a key problem in the system of sin licenses is that consumers hoard extra licenses, with the intention to resell them (or the sin goods they have purchased with these extra licenses) in the secondary market. This problem is compounded by the fact that a part of the prospective sellers - or ex ante sellers - do not actually enter the secondary market ex post (see the proof of Proposition 3a(i)). Ex post these wannabe sellers notice that their own consumption is higher than anticipated, making the amount of goods (or licenses) they could sell in the secondary market smaller than anticipated; hence profits from secondary market sales are not enough to cover the entry costs, and entering the market is not worthwhile.

Then it is possible that a large portion of the consumers intend to be sellers ex ante, but in equilibrium there is only relatively little trade in the secondary market. Since all prospective sellers (both actual sellers, who enter the secondary market ex post, and wannabe sellers, who do not enter the secondary market ex post) consume the laissez-faire amount in equilibrium, an outcome where many consumers (prospective sellers) hoard extra licenses is bad for welfare.

The situation changes, if the government charges a positive price ℓ (which is higher than the symbolic 1 cent) for the sin licenses: in equilibrium there are no wannabe sellers. Essentially, if a consumer, who has hoarded extra licenses, ex post decides not to enter the secondary market, he loses not only the secondary market profit margin but also the price of the sin licenses, that he has purchased (if the sin licenses are not used or resold in the current period, they are worthless)[31]. Then if the price of a license

[30] A universal sin tax does not help naives in the same way, as it only takes effect *ex post.* For naives, it is important to alter their *ex ante* incentives or hoarding sin licenses, as they do not foresee their future commitment problem.

[31] Evidently, the consumer could use the unsold licenses to buy sin goods for future consumption or

ℓ is large enough, compared to the (small) entry cost ε^k, the incentives to hoard sin licenses are reduced and there will be no wannabe sellers in equilibrium.

At first sight, the fact that all (ex ante) prospective sellers become (ex post) actual sellers may seem to be bad for welfare: after all secondary market activity is the source of the (additional) distortions (additional compared to the case where all consumers are sophisticated). In fact, however, removing the class of wannabe sellers alleviates the distortions. In equilibrium fewer consumers choose to hoard extra licenses. This is because i) in equilibrium secondary market supply must be equal to secondary market demand and ii) all prospective sellers become actual sellers. (In the baseline case, where licenses are essentially given for free, a large portion of the consumers can choose to be sellers in equilibrium, since only a part of the prospective sellers become actual sellers.) Decreasing the number of prospective sellers is good for welfare.

There is also another way to present the argument for costly licenses. Remember that if sin licenses are distributed free of charge, naive consumers think that hoarding licenses is a highly attractive one-sided bet: The licenses can be possibly resold at a profit. Even if this is not the case, the consumer stands to lose very little, since he got the licenses for free (or paid 1 cent for each); under unfavourable secondary market conditions the consumer can simply stay out of the market.

If the consumer has paid a positive price for the licenses, staying out of the secondary market under less favourable conditions would entail a loss equal to the purchasing price of the licenses. Then the consumer has to consider the down-side as well as the up-side of the secondary market. Since hoarding licenses now involves possible losses, it is no longer that attractive.

To summarise: naive individuals do not foresee the commitment costs of hoarding sin licenses. A positive price is needed to induce them to internalise (at least a part of) these costs. The following proposition summarises the key differences - as well as similarities - between sin taxes and the scheme where the government sells sin licenses for a price.

Proposition 6 *Assume that the population consists of sophisticated, partially naive and fully naive consumers. Consider two possible ways to modify the system of sin licenses: i) the government introduces a small universal sin tax τ and ii) the government sells the licenses at a given price ℓ. Further assume that $\tau = \ell$. Now we have the following results:*

to be resold in future periods. However, (if the consumer has hoarded a large number of sin licenses) this would involve costs of storing. Also, buying a large quantity of sin goods for future use would imply that the consumer would have a non-trivial amount of wealth in the form of alcohol or tobacco, rather than some interest bearing assets.

a) Sophisticated and partially naive individuals consume the same amount of sin goods under both arrangements (i and ii). Sophisticated and partially naive individuals also buy the same amount of sin goods in primary markets and secondary markets under both arrangements.

b) A smaller share of naive individuals become either effective secondary market sellers or wannabe secondary market sellers under arrangement ii) (licenses sold at a price ℓ) than under arrangement i) (sin taxes).

c) Selling sin licenses at a price gives rise to higher aggregate welfare than introducing a universal sin tax on top of the system of sin licenses.

Proof. See the appendix. ■

Finally, one potential caveat with the system of costly licenses should be noted: the system may not be renegotiation-proof. Note that we have assumed that in period $t-1$, the consumer chooses the amount of licenses for period t consumption, but these licenses are only paid for in period t. In period t, it may be in the interest of both the government and the naive consumer to renegotiate, and allow the consumer not to purchase a proportion of the licenses that he asked for ex ante: The naive consumer would avoid the losses from having hoarded too many licenses, and the government would be able to limit secondary market supply. It is easy to show that in the absence of credible commitment, costly licenses are in fact equivalent to a system of free licenses supplemented with sin taxes (arrangement (i) in the above proposition). So a credible commitment on the part of the government is a precondition for the system of costly licenses to work as intended. This may be a reasonable assumption, as it is likely that laws and regulations are hard to change, in particular if this would require renegotiation on an individual basis; in practice, such renegotiation may be so costly and time-consuming that it is not worthwhile in the end.[32]

5.3 Sin licenses combined with a maximum quota

Consider next introducing a maximum quota when a system of sin licenses is already in place, and there is also an opportunity to trade the sin good in a secondary market. For the most part of the analysis, we assume that all consumers are sophisticated, and make a note on naive individuals at the end of the subsection.

Denote the maximum amount of sin licenses that an individual can choose by $\bar{y}$.

[32]Note also that the government has every incentive to attempt to establish credibility, and may will succeed in doing so given that the government and consumers interact repeatedly over several periods.

Now define

$$\widetilde{X} = \max_{\beta,\gamma} x^* \left(1 + k; \beta, \gamma\right).$$

That is, $\widetilde{X}$ is the maximum amount of the sin good that an individual member of the economy (the ultimate heavy-user) is willing to buy at the secondary market price $1+k$. It is easy to see that if the maximum quota $\bar{y} > \widetilde{X}$, all consumers can meet their needs from the primary market (at price 1) and there will be no trade in the secondary market. Then a maximum quota has no effect.

However, if $\bar{y} < \widetilde{X}$, the maximum quota is binding for some consumers, and there is trading in the secondary market. In accordance with studying a very small sin tax in subsection 5.1, we now consider a minimal intervention, i.e. a maximum quota only slightly below $\widetilde{X}$. We again assume that perfectly rational sellers can cover the demand in the secondary market. We show in the appendix that such a scheme will in fact lead to a Pareto-worsening, compared to a case where only a system of personalised quotas is in place.

The intuition for this result can be seen as follows. Firstly, we have assumed that secondary markets are perfectly competitive. Therefore, secondary market sellers do not benefit from the introduction of the maximum quota, as there are no profits to be made in the secondary market. Secondly, consumers who have a high level of self-control problems and therefore act as buyers in the secondary market lose out from the scheme: As there is perfect competition, price in the secondary market does not change due to a tighter quota. As a result there are no self-control gains: irrational consumers still buy the same amount $x^* \left(1 + k; \gamma, \beta\right)$ as they did under the system of sin licenses (with no maximum quota), but they have to purchase a larger share of their consumption from the secondary market, where the price $1+k$ is higher than the primary market price 1.

We therefore have the following proposition:

Proposition 7 *Assume that a system of sin licenses is in place and there is a transaction cost k of reselling a unit of the sin good in a secondary market. Assume that all consumers are sophisticated. Denote $\widetilde{X} = \max_{\beta,\gamma} x^* \left(1 + k; \beta, \gamma\right)$. Consider introducing a maximum quota slightly below $\widetilde{X}$. This scheme has no effect on individuals with a low level of self-control problems ($k \geq \left(1 - \beta\right) \delta h' \left(x^o\right)$) whereas individuals with severe self-control problems ($k < \left(1 - \beta\right) \delta h' \left(x^o\right)$) lose out. Therefore the maximum quota leads to a Pareto-worsening.*

Proof. See the appendix. ■

A maximum quota therefore lowers welfare in the Pareto-sense, and we have also shown in the appendix that the welfare loss is directly related to the transaction cost k in the secondary market. Quite simply, the maximum quota implies that trade shifts from primary markets to secondary markets, where resources are wasted due to transaction costs.

Finally, note that in the case of fully naive individuals, a maximum quota will in fact lead to a Pareto improvement: it will limit the consumption of the ultimate heavy-users in the economy (who plan to become secondary market sellers and hoard the maximum amount of licenses from the primary market, but end-up consuming the entire quota themselves), while having no effect on anyone else.

5.4 Killing the secondary market

Finally, another potential fix to the hoarding problem of naive consumers is that iv') the government allows purchases of the sin good without a license, and thereby attempts to kill the secondary market. In particular, even when a consumer does not have sin licenses, (s)he could buy the sin good from the primary market at price $p = q = 1 + k$, where k is equal to the secondary market transaction cost. This would eliminate profitable trading opportunities in the secondary market, and there would therefore be no reason to hoard sin licenses.

This fix, however, is likely to be problematic in practice. For consumers, the only relevant information is the equilibrium price q in the secondary market. The government, on the other hand, would need more intricate information than this, to determine the right price p that would eliminate all secondary market activity. Assume, for instance, a more realistic situation where potential secondary market sellers differ in their transaction costs k_i. Now, if the government set $p = q$, it may be able to eliminate secondary market supply from those sellers whose transaction costs k_i are the highest. However, sellers with smaller transaction costs would continue to be sellers in the secondary market. In order to kill the secondary market, the government would therefore need to set $p < q$, but it is likely to lack the information required to determine the right level of p. If p is too high, the government does not succeed in killing the secondary market. On the other hand, if p is too low, the commitment power of the system of sin licenses in weakened.

6 Discussion

6.1 Comparison between personalised and uniform regulation

As we have seen that personalised regulation does not lead to the first-best outcome, an interesting question for further research would be to analyse the conditions under which uniform regulation such as a uniform, linear sin tax in fact yields superior outcomes compared to attempts to implement personalised regulation.[33] This question is relevant in particular due to the simplicity of implementing uniform regulation, compared with the likely administrative burden of personalised schemes.

In addition to the costs of implementation, the welfare properties of uniform vis-a-vis personalised regulation are likely to depend on a number of factors. First, the relative merits of personalised regulation will naturally depend on how severe the problem associated with secondary markets is. If transaction costs in the secondary market are prohibitively high, personalised regulation is clearly superior to uniform regulation. In fact, personalised regulation is preferable to uniform regulation for all levels of k exceeding the second-best optimal uniform sin tax[34] (a sufficient but not a necessary condition): under a system of personalised quotas, those individuals whose self-control problems would call for a personalised tax $\tau^o(\gamma, \beta)$ smaller than k consume optimally, whereas the consumption of those individuals for whom $\tau^o(\gamma, \beta) > k$ is distorted upwards (see section 3.2). On the other hand, if a uniform tax equal to k was implemented (which we have assumed to be optimal if only uniform instruments are in use), we would have similar upward distortions in consumption for individuals with severe self-control problems, but in addition we would have *downward* distortions for consumers with mild self-control problems.

On the other hand, if transaction costs are very low, it is obvious that uniform, second-best regulation may be superior to personalised regulation: an attempt to implement personalised regulation then leads to zero regulation, and a small uniform sin tax will constitute a Pareto improvement to this outcome under the conditions presented in O'Donoghue and Rabin (2006). Further, Haavio and Kotakorpi (2011) show that the benefit of linear sin taxes to individuals with high self-control problems is likely to exceed the costs to those who are rational,[35] and therefore the optimal uniform sin

[33] See Beshears et al. (2005) for a comparison of the welfare properties of "early decision regulation" that enables a consumer to precommit to a given level of consumption and a linear sin tax. However, this analysis assumes that the sin good cannot be traded ex post between consumers.

[34] See Haavio and Kotakorpi (2011) for an analysis of second-best optimal uniform sin taxes.

[35] The argument regarding Pareto-improvements concerns marginal increases from a zero tax. If we

tax is likely to be relatively high (in the sense that it exceeds the average distortion caused by self-control problems in the economy).

Second, the relative attractiveness of uniform regulation depends on the distribution of self-control problems in the economy. If individuals do not differ much from each other in their level of self-control problems, regulation tailored to the needs of the average person does not involve large efficiency losses. On the other hand, it is clear that the more individuals differ from each other, the more can (potentially) be gained by personalised regulation.

6.2 Evidence

From the point of view of assessing the relevance of our results, it is important to ask whether transaction costs associated with reselling a sin good are likely to be high or low. Firstly, as suggestive indirect evidence, casual observation of real-life pricing practices of profit-maximising firms suggests that secondary markets would likely be a problem for personalised taxation of any type of ordinary consumption good. In general, it would be profitable for firms to attempt to implement personalised pricing through screening consumers, in order to separate those with high willingness to pay for a given product from those with low willingness to pay. (See e.g. Stole 2007). Therefore, we observe practices such as student discounts or discounts for pensioners, available only for individuals holding identification to prove their eligibility status. However, such discounts appear to be common only in the case of services that are hard to re-sell (such as travel), and appear to be very rarely used in the case of ordinary consumption goods. Other types of price discrimination, such as quantity discounts, are also typically used in the case of goods that are hard or impossible to re-sell (such as telephone calls or electricity).

Cowell (2008) has considered the possibility of implementing non-linear commodity taxation with the help of smart-card technology. However, he acknowledges the problem of secondary markets. In accordance with the above observations, he argues that only commodities that are hard to re-sell, typically personal services such as legal advice or medical care, would be suited for non-linear payment schemes. On the other hand, he concludes that commodities that lose little of their value at resale are never going to be suitable for smart-card commodity taxation.

A second, perhaps more interesting piece of suggestive evidence comes from the

consider higher than marginal taxes, the consumption of rational individuals will be distorted, and sin taxes therefore involve costs for them.

experience of attempts to control alcohol purchases in Finland and Sweden mainly in the 1940s and 1950s. In both countries, official purchases of alcohol were only allowed upon showing a special identity card, and purchases were recorded on the card. Both systems had elements of attempting to implement a crude form of personalised regulation: in Finland, purchases were monitored more closely for those individuals suspected of being prone to alcohol misuse, and high consumption could make a person lose his entitlement to hold a card. In Sweden, a person's quota depended on certain characteristics such as age, gender and family status, and the card entitling a person to purchase alcohol could be completely denied from individuals suspected of misuse. (Häikiö 2007.)

What can the experience with these systems tell us about the pros and cons of personalised regulation? First, it is interesting to note that widespread secondary markets and unofficial trade were important reasons for the collapse of these systems: for instance in Sweden, a large proportion of offences associated with the misuse of alcohol were committed by individuals who did not hold a license to purchase alcohol in the first place. In Finland, a significant proportion of individuals whose license was withdrawn for a fixed period never re-applied for it: this meant that a large proportion of individuals whom the system was targeted at were in fact outside its scope, and it is clear that these individuals had not stopped alcohol consumption but rather found unofficial means of obtaining alcohol more convenient than the official route (Immonen 1980). An overall assessment concerning the Finnish system was that it did not have the intended effects on over-consumption of alcohol and secondary markets were seen as playing a crucial role in the failure of the system (Häikiö 2007.).

On the other hand, during the latter part of the 1940s (when the Finnish system was in full operation) only 30-50% of individuals over the age 20 obtained the license to purchase alcohol each year. (Häikiö 2007.) At the same time, the number of abstainers was relatively high: in 1946, 20 % of Finnish consumers were life-long abstainers (i.e. had never had any alcohol, a rather strict definition of abstinence) and 49 % had not drunk any alcohol within the past month. (Sulkunen 1979.) This suggests that for some individuals, not obtaining a license may indeed have functioned as an effective self-control device. On the other hand, the gap between the number of abstainers and those who held a license again suggests that alcohol was also consumed without a license.[36]

[36] It should be noted however, that to some extent this was legitimate: alcohol was also served in restaurants, where a personal license was not required from customers. However, alcohol consumption in restaurants at the time was not very common, and for example in 1948, purchases with a license accounted for 86 % of total official alcohol consumption in Finland (Häikiö 2007).

To sum up, the above evidence is broadly consistent with our story: it appears that the system of personal licenses may have helped some individuals to limit their alcohol consumption, but may not have worked well in the case of heavy users. Further, the main problems with the system arose because of unofficial trade.

7 Conclusion

A central theme in the economic literature on paternalism has been the concern that paternalistic policies - that is, policies designed to help individuals whose behaviour is affected by self-control problems or other behavioural biases - are detrimental for the welfare of individuals who do not suffer from such biases. For this reason, many papers in the literature have concentrated on a search for asymmetric policies or minimal interventions that help irrational individuals while having only a small or no impact on those who are rational.[37] On the other hand, the more recent literature on linear sin taxes explicitly considers the trade-off between benefits to individuals with self-control problems and the costs to those who are rational, and sets out to find the optimal balance between those benefits and costs.

Nevertheless, the issue of whether we can do better than using simple, linear instruments, has remained an open question in the literature. While the problems with implementing personalised prices in general are well-known from the literature on price discrimination, the question has arisen whether regulating harmful consumption may be special in this respect: as the justification for schemes such as sin taxes arises from time-inconsistency in preferences, it has been argued that it may be possible to exploit this time-inconsistency in order to implement personalised regulation. More specifically, personalised regulation would be in the interest of the consumers themselves in the case of sin goods, and therefore it has been argued that it may be possible to let consumers self-select which type of corrective policy (if any) should be applied in their case.

However, we have shown that the very same feature of preferences - their time-inconsistency - that appears to make personalised regulation feasible in the case of sin goods, in fact in the end hinders their implementability. Ex post, consumers will be tempted to consume more of the sin good than they planned ex ante. Therefore, ex post, consumers will have the incentive to create a secondary market, where consumers with severe self-control problems buy the sin good from consumers without self-control

[37] See for example Camerer *et al* (2003), Thaler and Sunstein (2003) and O'Donoghue and Rabin (1999).

problems. This undermines consumers' incentives to self-select optimally even ex ante, and therefore personalised regulation may fail to implement the first-best level of consumption. Even though personalised regulation may work for sophisticated individuals with a mild self-control problem, it is typically not a complete fix for heavy-users or naive consumers.

We have also explored a number of ways in which the functioning of the system of sin licenses could be improved upon. We show for example that charging a positive price for the licenses rather than (effectively) giving them out for free (or charging a symbolic price of 1 cent), improves welfare. This is in particular the case for naives: naives are not aware of their self-control problem and therefore do not foresee the commitment cost of holding too many sin licenses. A positive price will induce them to internalise at least a part of this cost. Such schemes may be worth considering: sometimes schemes that first may appear to be theoretical curiosities - consider for example the case of tradeable emission permits - are implemented in the real world. Our analysis can help in weighing the pros and cons of these types of more complicated schemes involving personalised regulation of harmful consumption, vis-a-vis the simple, linear instruments that are in use today.

Appendix

Proof of Proposition 1

The proof of the first part of the Proposition is in the text. Here, we show that the benefits from regulation are increasing in the level of self-control problems if $\frac{\partial^2 x^*(q;\gamma,\beta)}{\partial p \partial \beta} > 0$, whereas welfare in equilibrium is unambiguously decreasing in the level of self-control problems.

Consumers with a low level of self-control problems $(k \geq (1-\beta) h'(x^o(\gamma)))$ are not tempted by secondary markets. Their indirect utility, when a system of personalised quotas is in place, is given by

$$\begin{aligned} V^{reg}(\beta,\gamma) &= \widetilde{V}(\gamma) = v(x^o(1;\gamma),\gamma) - \delta h(x^o(1;\gamma)) - x^*(1;\gamma) \\ &= \max_x v(x,\gamma) - \delta h(x) - x. \end{aligned}$$

Note that $V^{reg}(\beta,\gamma) = \widetilde{V}(\gamma)$ does not depend on β.

Indirect utility under laissez-faire is given by

$$V(1;\beta,\gamma)=v(x^{*}(1;\beta,\gamma),\gamma)-\delta h(x^{*}(1;\beta,\gamma))-x^{*}(1;\beta,\gamma),$$

where $x^{*}(1;\beta,\gamma)$ is implicitly given by (3). The welfare gain that type (β,γ) obtains from personalised regulation is therefore

$$\Delta V(\beta,\gamma)=V^{reg}(\beta,\gamma)-V(1;\beta,\gamma).$$

In order to analyse how the welfare gain depends on the degree of self-control problems, we need to evaluate

$$\begin{aligned}\frac{\partial\Delta V(\beta,\gamma)}{\partial\beta} &= -\frac{\partial V(1;\beta,\gamma)}{\partial\beta}\\ &= -\left[v'(x^{*}(1;\beta,\gamma),\gamma)-\delta h'(x^{*}(1;\beta,\gamma))-1\right]\frac{\partial x^{*}(1;\beta,\gamma)}{\partial\beta}\\ &= (1-\beta)\,\delta h'(x^{*}(1;\beta,\gamma))\,\frac{\partial x^{*}(1;\beta,\gamma)}{\partial\beta},\end{aligned}\tag{6}$$

where the final form follows from (3). Next, totally differentiating (3) yields

$$\frac{\partial x^{*}(q;\beta,\gamma)}{\partial\beta}=\frac{\delta h'(x^{*})}{v''(x^{*})-\beta\delta h''(x^{*})}<0\tag{7}$$

and we can conclude that

$$\frac{\partial\Delta V(\beta,\gamma)}{\partial\beta}<0.\tag{8}$$

Thus the welfare gain from the system of personalised control grows together with severity of the self-control problem.

*C*onsumers with severe self-control problems $(k<(1-\beta)\,h'(x^{o}(\gamma)))$ are tempted by secondary markets. The consumer's choice when a system of personalised control is applied is determined by

$$v'(x^{*}(1+k;\beta,\gamma),\gamma)-\beta\delta h'(x^{*}(1+k;\beta,\gamma))-1-k=0.\tag{9}$$

Their indirect utility function, when a system of personalised control is in place, is given by

$$V(1+k;\beta,\gamma)=v(x^{*}(1+k;\beta,\gamma),\gamma)-\delta h(x^{*}(1+k;\beta,\gamma))-x^{*}(1+k;\beta,\gamma).$$

When a system of personalised control is in place, consumers with severe self-control problems attain a lower level of (long-run) utility than consumers with mild self-control problems, since

$$\begin{aligned}
\frac{\partial V(1+k;\beta,\gamma)}{\partial\beta} &= \left[v'\left(x^*(1+k;\beta,\gamma),\gamma\right)-\delta h'\left(x^*(1+k;\beta,\gamma)\right)-1\right]\frac{\partial x^*(1+k;\beta,\gamma)}{\partial\beta} \\
&= \left[k-(1-\beta)\,h'\left(x^*(1+k;\beta,\gamma)\right)\right]\frac{\partial x^*(1+k;\beta,\gamma)}{\partial\beta}>0. \qquad (10)
\end{aligned}$$

Proof of Proposition 3

We first prove items *a(i)-a(vi)*. Building on these results, we then characterize the circumstances under which there is (no) trade in the secondary market.

a(i) Since fully naive individuals are completely ignorant of their self-control problems, they want to become secondary market sellers as long as the secondary market price q exceeds $1+k$. Then if fully naive individuals can cover the whole supply side of the secondary market (the frequency mass of perfectly naive individuals is large enough and/or the maximum quota $\overline{y}$ is large enough), it is immediately clear that in equilibrium $q=1+k+\varepsilon^q$, where ε^q is very small (close to zero). It is also clear that fully naive individuals find it optimal to ask for the maximum quota $\overline{y}$: In the previous period $t-1$, the fully naive individual (incorrectly) anticipated his period t demand to be $x^*\left(1+\varepsilon^q;\widehat{\beta}=1,\gamma\right)=x^o(1+\varepsilon^q;\gamma)$. That is, in period $t-1$, the individual finds it optimal to buy the maximum quota if and only if

$$\varepsilon^q*\left(\overline{y}-x^o(1+\varepsilon^q;\gamma)\right)>\varepsilon^k \qquad (11)$$

That is, all individuals with $x^o(1+\varepsilon^q;\gamma)<\overline{y}-\frac{\varepsilon^k}{\varepsilon^q}$ find it optimal to ask for the maximum quota. As long as the dispersion of tastes γ is not too large, this condition holds for all naive consumers.

It is interesting to note, however, that even though all naive consumers plan to become sellers and therefore have the incentive to hoard licenses ex ante, not all naive consumers actually enter the secondary market as sellers ex post. A consumer will enter the secondary market as a seller if

$$\varepsilon^q*\left(\overline{y}-x^*(1+\varepsilon^q;\beta,\gamma)\right)>\varepsilon^k. \qquad (12)$$

This ex post entry condition is more stringent than the ex ante entry condition (11). In equilibrium, the profit margin ε^q is determined in such as way that the ex post entry condition (12) holds for only a certain fraction of naive individuals (those with the smallest own consumption $x^*(1+\varepsilon^q;\beta,\gamma)$). The property that only a fraction of wannabe sellers actually enter the secondary market ex post, will be used for example in subsection 5.2.

Let us next turn to partially naive consumers. Hoarding extra sin licenses, to be resold in the secondary market, involves self-control costs (see items *a(ii)* and *a(vi)*). Since the profit margin in the secondary market (ε^q) is very small, partially naive individuals, who are partially aware of their self-control problems, do not find it optimal to become sellers in the secondary market.[38] As shown in the proof of item *a(iv)* (see below), partially naive individuals with (relatively) severe self-control problems, $(1-\beta)\delta h'(x^o(1;\gamma)) > k+\varepsilon^q$, will be secondary market buyers in equilibrium.

a(ii) Fully naive individuals ask for the maximum quota of sin licenses (see *a(i)*). Their opportunity cost of own consumption is then $q-k=1+\varepsilon^q \approx 1$ (i.e. secondary market price q minus transaction costs k). Thus a naive consumer with true type (β,γ) consumes $x^*(1+\varepsilon^q;\beta,\gamma) \approx x^*(1;\beta,\gamma)$, where $x^*(1;\beta,\gamma)$ is the laissez-faire level of consumption.

a(iii) As shown in Section 3, sophisticated consumers with a low level of (true) self-control problems, $(1-\beta)\delta h'(x^o(1;\gamma)) < k+\varepsilon^q$, are not tempted to buy sin goods in the secondary market, given their true type (β,γ), and they ask for the optimal/rational quota $x^o(1;\gamma)$ of sin licenses. Partially naive individuals ($\widehat{\beta} \in (\beta,1)$) have all the more reason to ask for the optimal/rational quota $x^o(1;\gamma)$. Then the result follows immediately.

a(iv) Consumers with a high level of (true) self-control problems, $(1-\beta)\delta h'(x^o(1;\gamma)) > k+\varepsilon^q$, are tempted by the secondary market, given their true type (β,γ). While a sophisticated ($\widehat{\beta}=\beta$) individual correctly anticipates his consumption in the next period ($x^*(1+k+\varepsilon^q;\gamma,\beta)$), a partially naive individual ($\widehat{\beta} \in (\beta,1)$) underestimates the temptation, and asks for

$$x^p\left(1+k+\varepsilon;\gamma,\widehat{\beta}\right) = \max\left\{x^*\left(1+k+\varepsilon;\gamma,\widehat{\beta}\right), x^o(1;\gamma)\right\}$$

sin licenses. Since $\widehat{\beta} > \beta$, perceived consumption $x^p\left(1+k+\varepsilon;\gamma,\widehat{\beta}\right)$ is lower than true consumption $x^*(1+k+\varepsilon^q;\gamma,\beta)$. The partially naive individual then buys the

[38] The same holds for sophisticated consumers.

difference

$$x^s\left(1+k+\varepsilon^q;\gamma,\widehat{\beta},\beta\right)=x^p\left(1+k+\varepsilon;\gamma,\widehat{\beta}\right)-x^*\left(1+k+\varepsilon^q;\gamma,\beta\right) \tag{13}$$

in the secondary market. While both sophisticated and partially naive individuals (with a given true type (β,γ)) consume the same amount of sin goods, $x^*\left(1+k+\varepsilon^q;\gamma,\beta\right)$, partially naive consumers pay a higher price $q=1+k+\varepsilon^q>1$ for the portion $x^s\left(1+k+\varepsilon;\gamma,\widehat{\beta},\beta\right)$. The naiver the consumer (the bigger is $\widehat{\beta}$), the more he buys in the secondary market. Hence, for consumers with a high level of true self-control problems, welfare is decreasing in the degree of naivete.

a(v) The result follows from *a(iii), a(iv)* and *a(vi)* (see below).

a(vi) Finally we show that there is a discontinuous drop in welfare between (partially naive) non-sellers and (naive) sellers.

The result is obvious, when the consumers have mild self-control problems ($(1-\beta)\delta h'(x^o\left(1;\gamma\right))<k$). Partially naive consumers with a low level of self-control problems consume the optimal amount and attain the first-best level of welfare, while naive consumers consume the laissez-faire amount and attain a lower level of welfare.

Next we consider consumers with severe self-control problems ($(1-\beta)\delta h'(x^o\left(1;\gamma\right))>k$). A naive consumer becomes a seller and consumes the laissez-faire amount in equilibrium. His welfare (given his tastes γ and his true degree of self-control problems β) is

$$V^s\left(1;\beta,\gamma\right)=v\left(x^*\left(1+k;\beta,\gamma\right)\right)-\delta h\left(x^*\left(q;\beta,\gamma\right)\right)-x^*\left(1;\beta,\gamma\right) \tag{14}$$

The welfare of an almost naive secondary market buyer (type (β,γ)) is

$$V^b\left(1+k;\beta,\gamma\right)=v\left(x^*\left(1+k;\beta,\gamma\right)\right)-\delta h\left(x^*\left(1+k;\beta,\gamma\right)\right)-x^o\left(1;\gamma\right)-(1+k)\left[x^*\left(1+k;\beta,\gamma\right)-x^o\left(1;\gamma\right)\right] \tag{15}$$

Next we want to show that $V^b\left(1+k;\beta,\gamma\right)>V^s\left(1;\beta,\gamma\right)$. To do so we first define the indirect utility function

$$\widetilde{V}\left(q;\beta,\gamma\right)=v\left(x^*\left(q;\beta,\gamma\right)\right)-\delta h\left(x^*\left(q;\beta,\gamma\right)\right)-x^o\left(1;\gamma\right)-q\left[x^*\left(q;\beta,\gamma\right)-x^o\left(1;\gamma\right)\right] \tag{16}$$

It is easy to see that $\widetilde{V}\left(q;\beta,\gamma\right)$ nests both $V^s\left(1;\beta,\gamma\right)$ and $V^b\left(1+k;\beta,\gamma\right)$, with $V^s\left(1;\beta,\gamma\right)=\widetilde{V}\left(1;\beta,\gamma\right)$ and $V^b\left(1+k;\beta,\gamma\right)=\widetilde{V}\left(1+k;\beta,\gamma\right)$. Now, to prove that $V^b\left(1+k;\beta,\gamma\right)>V^s\left(1;\beta,\gamma\right)$ we have to show that $\frac{\partial\widetilde{V}(q;\beta,\gamma)}{\partial q}>0$ for $q\in\left[1,1+k\right]$. Differentiating (16) with respect to q yields

$$\begin{aligned}
\frac{\partial \widetilde{V}(q;\beta,\gamma)}{\partial q} &= \left[v'\left(x^*(q;\beta,\gamma)\right) - \delta h'\left(x^*(q;\beta,\gamma)\right) - q\right]\frac{\partial x^*(q;\beta,\gamma)}{\partial q} - \left[x^*(q;\beta,\gamma) - x^o(1;\gamma)\right] \\
&= -(1-\beta)\,\delta h'\left(x^*(q;\beta,\gamma)\right)\frac{\partial x^*(q;\beta,\gamma)}{\partial q} - \left[x^*(q;\beta,\gamma) - x^o(1;\gamma)\right] \qquad (17) \\
&= -(1-\beta)\frac{\partial x^*(q;\beta,\gamma)}{\partial \beta} - \left[x^*(q;\beta,\gamma) - x^o(1;\gamma)\right]
\end{aligned}$$

The second form follows since $x^*(q;\beta,\gamma)$ is defined by $v'(x^*(q;\beta,\gamma)) - \beta\delta h'(x^*(q;\beta,\gamma)) = q$. The third form follows since $\frac{\partial x^*(q;\beta,\gamma)}{\partial q} = \frac{1}{v''(x^*;\gamma)-\beta\delta h''(x^*)} < 0$ and $\frac{\partial x^*(q;\beta,\gamma)}{\partial \beta} = \frac{\delta h'(x^*)}{v''(x^*;\gamma)-\beta\delta h''(x^*)} < 0$, and hence

$$(1-\beta)\delta h'\left(x^*(q;\beta,\gamma)\right)\frac{\partial x^*(q;\beta,\gamma)}{\partial q} = (1-\beta)\frac{\partial x^*(q;\beta,\gamma)}{\partial \beta}. \qquad (18)$$

Next we adopt the notation $\rho \equiv 1-\beta$. Then (17) can be rewritten as

$$\frac{\partial \widetilde{V}(q;\rho,\gamma)}{\partial q} = \rho\frac{\partial x^*(q;\rho,\gamma)}{\partial \rho} - \left[x^*(q;\rho,\gamma) - x^o(1;\gamma)\right] \qquad (19)$$

Next we note that

$$x^*(q;\rho,\gamma) = x^*(q;0,\gamma) + \int_0^\rho \frac{\partial x^*(q;\widetilde{\rho},\gamma)}{\partial \widehat{\rho}}d\widetilde{\rho} = x^*(q;\rho=0,\gamma) + \rho\frac{\partial x^*(q;\rho,\gamma)}{\partial \rho} - \int_0^\rho \widetilde{\rho}\frac{\partial^2 x^*(q;\widetilde{\rho},\gamma)}{\partial \widetilde{\rho}^2}d\widetilde{\rho} \qquad (20)$$

Plugging (20) into (19) yields

$$\frac{\partial \widetilde{V}(q;\rho,\gamma)}{\partial q} = x^o(1;\gamma) - x^o(q;\gamma) + \int_0^\rho \widetilde{\rho}\frac{\partial^2 x^*(q;\widetilde{\rho},\gamma)}{\partial \widetilde{\rho}^2}d\widetilde{\rho} > 0$$

(notice that $x^*(q;\rho=0,\gamma) = x^o(q;\gamma)$).

Finally, $\frac{\partial \widehat{V}(q;\rho,\gamma)}{\partial q} > 0$, since i) $x^o(q;\gamma) < x^o(1;\gamma)$ when $q > 1$, ii) given (18) we have

$$\begin{aligned}
\rho\frac{\partial^2 x^*(q;\rho,\gamma)}{\partial \rho^2} &= -\rho h'\left(x^*(q;\rho,\gamma)\right)\frac{\partial^2 x^*(q;\rho,\gamma)}{\partial q\partial \rho} - \rho h''\left(x^*(q;\rho,\gamma)\right)\frac{\partial x^*(q;\rho,\gamma)}{\partial q}\frac{\partial x^*(q;\rho,\gamma)}{\partial \rho} \qquad (2 \\
&= (1-\beta)\,h'\left(x^*(q;\beta,\gamma)\right)\frac{\partial^2 x^*(q;\beta,\gamma)}{\partial q\partial \beta} + (1-\beta)\,h''\left(x^*(q;\beta,\gamma)\right)\frac{\partial x^*(q;\beta,\gamma)}{\partial q}\frac{\partial x^*(q;\beta,\gamma}{\partial \beta}
\end{aligned}$$

and iii) given (21) and Assumption 1, we have $\rho\frac{\partial^2 x^*(q;\rho,\gamma)}{\partial \rho^2} > 0$.

Now we are ready to characterize the circumstances under which there is (no) trade in the secondary market.

a) Given item *a(i),* fully naive individuals want to be sellers in the secondary market, as long as the secondary market price $q > 1 + k$. There is also demand at price $q > 1 + k + \varepsilon^q$, as long as there are partially naive individuals with (relatively) severe self-control problems. It then follows from item *a(iii),* that there is a secondary market for the sin good if $k < \max_{\beta,\gamma} [(1-\beta)\delta h'(x^o(1;\gamma))]$.

b) If $k > \max_{\beta,\gamma} [(1-\beta)\delta h'(x^o(1;\gamma))]$, all sophisticated and partially naive individuals can commit to the first best (see *a(iii)*): there are no buyers in the secondary market at price $1 + k$ (which is the minimum price needed to cover trading costs). Then naive individuals see that they have no prospects as secondary market sellers, and find it optimal to ask for the number sin of sin licenses that corresponds to their perceived consumption $x^*\left(1;\widehat{\beta}=0,\gamma\right)$, which is equal to the rational level of consumption $x^o(1;\gamma)$. Hence, under these circumstances, the system of sin licenses implements the first best.

Proof of Proposition 4

Assume that a system of personalised quotas is in place. (a) Consider introducing a small uniform sin tax τ combined with a personalised transfer scheme $S(q) = \tau x^*$. The indirect utility function of a consumer with mild self-control problems ($k \geq (1-\beta)\delta h'(x^o)$) is

$$V(q;\beta,\gamma) = \max_x v(x;\gamma) - \delta h(x) - qx + S(q)$$

and the impact of a small increase in the tax rate on his welfare is given by

$$\frac{\partial V(q;\beta,\gamma)}{\partial q} = -x^* + S'(q) = \tau\frac{dx^*}{dq}.$$

If the initial tax rate is zero, a small change in the tax rate has no effect.

The indirect utility function of a consumer with severe self-control problems ($k < (1-\beta)\delta h'(x^o)$) is of the form

$$V(q;\beta,\gamma) = v(x^*,\gamma) - \delta h(x^*) - qx^* + S(q)$$

and the effect of a small increase on his welfare is

$$\frac{\partial V(q;\beta,\gamma)}{\partial q} = [-(1-\beta)\delta h'(x^*(q+k;\gamma,\beta)) + k + \tau]\frac{dx}{dq},$$

which is positive if the initial tax rate is zero. This follows since since $-(1-\beta)\,\delta h'\left(x^*\left(q+k;\gamma,\beta\right)\right)+k<0$ and $\frac{dx}{dq}<0$.

(b) Consider introducing a small uniform sin tax τ combined with a uniform transfer $S(q)=\tau\overline{x}=\tau E[x]$. The impact of a small increase in the tax rate on a consumer with mild self-control problems is

$$\frac{\partial V(q;\beta,\gamma)}{\partial q}=-x^*+S'(q)=\tau\frac{\partial\overline{x}}{\partial q}+\overline{x}-x^*(q;\gamma).$$

If there are initially no taxes, a small tax improves the welfare of a consumer with mild self-control problems and type (γ,β) if

$$\overline{x}-x^*(1;\gamma,\beta)=\overline{x}-x^o(1;\gamma)>0. \tag{22}$$

The effect of a small tax change on consumers with severe self-control problems given by

$$\begin{aligned}\frac{\partial V(q;\beta,\gamma)}{\partial q} &= \left[v'(x^*;\gamma)-\delta h'(x^*)-q\right]\frac{dx^*}{dq}-x^*+S'(q)\\ &= \left[-(1-\beta)\,\delta h'(x^*)+k\right]\frac{dx}{dq}-x^*+S'(q)\end{aligned}$$

Notice that for these consumers $x^*(q;\gamma,\beta)>x^o(q;\gamma)$, and due to the (quasi)convexity of $h(x)$ we know that $h'(x^*)\geq h'(x^o)$. As $(1-\beta)\,\delta h'(x^o(q;\gamma))>k$, also necessarily $(1-\beta)\,\delta h'(x^*(q;\gamma))>k$ and $\left[-(1-\beta)\,\delta h'(x^*)+k\right]\frac{dx}{dq}>0$. A consumer with severe self-control problems and type (γ,β) benefits from a small sin tax combined with a subsidy $S(q)=\tau\overline{x}$ if

$$\left(\left[(1-\beta)\,\delta h'\left(x^*\left(1+k;\gamma,\beta\right)\right)-k\right]|\eta|-1\right)x^*\left(1+k;\beta,\gamma\right)+\overline{x}>0 \tag{23}$$

where $|\eta|$ is the price elasticity of demand.

Proof of Proposition 5

(i) Follows from Proposition 3a(iii). Sin licenses implement the first best for sophisticated and partially naive consumers with mild self-control problems. Adding a sin tax and a uniform subsidy causes a similar distortion in consumption and implies the same net transfer for both types of agents.

(ii) The welfare of a partially naive secondary market buyer is

$$\begin{aligned} V^b\left(1+k+\tau;\beta,\widehat{\beta},\gamma\right) &= v\left(x^*\left(1+k+\tau;\beta,\gamma\right)\right)-\delta h\left(x^*\left(1+k+\tau;\beta,\gamma\right)\right) \\ &\quad -\left(1+\tau\right)x^*\left(1+k+\tau;\widehat{\beta},\gamma\right)+\tau\overline{x} \\ &\quad -\left(1+k+\tau\right)\left[x^*\left(1+k+\tau;\beta,\gamma\right)-x^*\left(1+k+\tau;\widehat{\beta},\gamma\right)\right] \end{aligned} \tag{24}$$

Differentiating yields

$$\begin{aligned} \frac{\partial V^b\left(1+k+\tau;\beta,\widehat{\beta},\gamma\right)}{\partial\tau} &= -\left(1-\beta\right)\delta h'\left(x^*\left(q;\beta,\gamma\right)\right)\frac{\partial x^*\left(q;\beta,\gamma\right)}{\partial q} \\ &\quad -x^*\left(1+k+\tau;\beta,\gamma\right)+k\frac{\partial x^*\left(q;\widehat{\beta},\gamma\right)}{\partial q}+\overline{x} \\ &= \left(\left[\left(1-\beta\right)\delta h'\left(x^*\left(q;\beta,\gamma\right)\right)-k\right]\left|\eta\right|-1\right)x^*\left(q;\beta,\gamma\right) \\ &\quad +k\int_\beta^{\widehat{\beta}}\frac{\partial^2 x^*\left(q;\widetilde{\beta},\gamma\right)}{\partial q\partial\widetilde{\beta}}d\widetilde{\beta}+\overline{x} \\ &= \frac{\partial V\left(1+k+\tau;\beta,\gamma\right)}{\partial\tau}+k\int_\beta^{\widehat{\beta}}\frac{\partial x^*\left(q;\widetilde{\beta},\gamma\right)}{\partial q\partial\widetilde{\beta}}d\widetilde{\beta} \end{aligned}$$

where $V\left(1+k+\tau;\beta,\gamma\right)$ is the indirect utility function of a sophisticated individual with type $\left(\beta,\gamma\right)$. When establishing the second equality, we used the fact that $\frac{\partial x^*\left(q;\widehat{\beta},\gamma\right)}{\partial q}=\frac{\partial x^*\left(q;\beta,\gamma\right)}{\partial q}+\int_\beta^{\widehat{\beta}}\frac{\partial x^*\left(q;\widetilde{\beta},\gamma\right)}{\partial q\partial\widetilde{\beta}}d\widetilde{\beta}$. Now the results follow, since $\widehat{\beta}>\beta$ and by Assumption 1 $\frac{\partial^2 x^*\left(q;\widetilde{\beta},\gamma\right)}{\partial q\partial\widetilde{\beta}}>0$.

(iii) The welfare of a fully naive secondary market seller is

$$\begin{aligned} V^s\left(1+\tau;\beta,\widehat{\beta}=1,\gamma\right) &= v\left(x^*\left(1+\tau;\beta,\gamma\right)\right)-\delta h\left(x^*\left(1+\tau;\beta,\gamma\right)\right) \\ &\quad -\left(1+\tau\right)x^*\left(1+k+\tau;\beta,\gamma\right)+\tau\overline{x} \end{aligned}$$

Differentiating yields

$$\begin{aligned} \frac{\partial V^s\left(1+\tau;\beta,\widehat{\beta}=1,\gamma\right)}{\partial\tau} &= -\left(1-\beta\right)\delta h'\left(x^*\left(1+\tau;\beta,\gamma\right)\right)\frac{\partial x^*\left(1+\tau;\beta,\gamma\right)}{\partial\tau} \\ &\quad -x^*\left(1+\tau;\beta,\gamma\right)+\overline{x} \\ &= \overline{x}-x^o\left(1+\tau;\gamma\right)+\int_\beta^1\left(1-\widetilde{\beta}\right)\frac{\partial^2 x^*\left(1+\tau;\widetilde{\beta},\gamma\right)}{\partial\widetilde{\beta}^2}d\widetilde{\beta} \end{aligned}$$

When deriving the second equality we used the fact that

$$\begin{aligned} x^*(1+\tau;\beta,\gamma) &= x^*(1+\tau;\beta=0,\gamma) - (1-\beta)\frac{\partial x^*(1+\tau;\beta,\gamma)}{\partial\beta} \\ &\quad - \int_\beta^1 \left(1-\widetilde{\beta}\right)\frac{\partial^2 x^*\left(1+\tau;\widetilde{\beta},\gamma\right)}{\partial\widetilde{\beta}^2}d\widetilde{\beta} \\ &= x^o(1+\tau;\gamma) - (1-\beta)\,\delta h'(x^*(1+\tau;\beta,\gamma))\frac{\partial x^*(1+\tau;\beta,\gamma)}{\partial\tau} \\ &\quad - \int_\beta^1 \left(1-\widetilde{\beta}\right)\frac{\partial^2 x^*\left(1+\tau;\widetilde{\beta},\gamma\right)}{\partial\widetilde{\beta}^2}d\widetilde{\beta} \end{aligned}$$

(See the derivations in the proof of Proposition 3 *a(vi)*.) Now the result follows, since Assumption 1 implies that $\frac{\partial^2 x^*\left(1+\tau;\widetilde{\beta},\gamma\right)}{\partial\widetilde{\beta}^2} > 0$ (see the proof of Proposition 3, item *a(vi)*.)

Finally, it is possible that some naive individuals change from secondary market (wannabe) sellers to non-sellers, when a small sin tax is introduced. (Sin taxes lower secondary market demand.) Then it follows from Proposition 3, item *a(vi),* that the welfare of such an individual rises discretely.

Proof of Proposition 6

a) The consumption level of sophisticated and partially naive individuals, as well as the amount of sin goods that they purchase in primary and secondary markets, is determined by the secondary market price of sin goods q. When the fixed entry cost ε^k is very small ($\varepsilon^k \to 0$), also the equilibrium profit margin in the secondary market is very small $\varepsilon^q \to 0$. Then under both arrangements, we have the same secondary market price $q^\tau = 1+k+\tau = 1+k+\ell = q^\ell$.[39]

b) Under the system with sin taxes the ex ante entry condition of (fully naive) secondary market sellers (given perceived type $\left(\widehat{\beta}=1,\gamma\right)$ is

$$\varepsilon^q_\tau\left(\overline{y} - x^o(1+\tau;\gamma)\right) > \varepsilon^k \Leftrightarrow \overline{y} - x^o(1+\tau;\gamma) > \frac{\varepsilon^k}{\varepsilon^q_\tau} \tag{25}$$

[39] Note that we assume that in period $t-1$, individuals choose the amount of sin licenses that the want to purchase for consumption in period t, but the price for the period t licenses is paid in period t.

while the ex post entry condition (given true type (β, γ)) is

$$\varepsilon_\tau^q \left(\overline{y} - x^* \left(1+\tau;\beta,\gamma\right)\right) > \varepsilon_\tau^q \Leftrightarrow \overline{y} - x^* \left(1+\tau;\beta,\gamma\right) > \frac{\varepsilon^k}{\varepsilon_\tau^q} \tag{26}$$

where ε_τ^q is the equilibrium secondary market profit margin, when sin taxes are in place. Notice that while $\varepsilon^k \to 0$ and $\varepsilon_\tau^q \to 0$, their ratio does not go to zero, $\frac{\varepsilon^k}{\varepsilon_\tau^q} \nrightarrow 0$. Since $x^* \left(1+\tau;\beta,\gamma\right) > x^o \left(1+\tau;\gamma\right)$ for all types (β, γ), the ex post entry condition (26) is clearly more stringent than the ex ante entry condition (25): if (26) holds, also (25) holds. Next, we define the following sets of naive consumers:

non-sellers Ω_τ^{ns}	:	ex ante entry condition (25) does not hold
all sellers Ω_τ^{as}	:	ex ante entry condition (25) holds
effective sellers Ω_τ^{es}	:	ex post entry condition (26) holds
wannabe sellers Ω_τ^{ws}	:	(25) holds but (26) does not hold

Clearly, $\Omega^{naives} = \Omega_\tau^{ns} + \Omega_\tau^{as}$ and $\Omega_\tau^{as} = \Omega_\tau^{es} + \Omega_\tau^{ws}$, where Ω^{naives} is the set of all naive individuals.

When the government sells sin licenses at a price ℓ, the ex ante entry condition of secondary market sellers is

$$\begin{aligned}\left(\ell + \varepsilon_\ell^q\right)\left(\overline{y} - x^o\left(1+\ell;\gamma\right)\right) - \ell\left(\overline{y} - x^o\left(1+\ell;\gamma\right)\right) &> \varepsilon^k \Leftrightarrow \varepsilon_\ell^q\left(\overline{y} - x^o\left(1+\ell;\gamma\right)\right) > \varepsilon^k \\ &\Leftrightarrow \overline{y} - x^o\left(1+\ell;\gamma\right) > \frac{\varepsilon^k}{\varepsilon_\ell^q},\end{aligned} \tag{27}$$

where ε_ℓ^q is the equilibrium secondary market profit margin, when the government sells sin licenses at a price. The consumer thus compares the revenues from the secondary market with the cost of obtaining extra licenses to be sold, and the fixed cost of secondary market entry. The ex post entry condition, on the other hand, is given by

$$\left(\ell + \varepsilon_\ell^q\right)\left(\overline{y} - x^*\left(1+\ell;\beta,\gamma\right)\right) > \varepsilon^k \Leftrightarrow \overline{y} - x^*\left(1+\ell;\beta,\gamma\right) > \frac{\varepsilon^k}{\ell + \varepsilon_\ell^q}. \tag{28}$$

Importantly, the ex post entry condition now involves the sum $\ell + \varepsilon_\ell^q$, rather than just the profit margin ε_ℓ^q.[40] Now we have $\frac{\varepsilon^k}{\ell+\varepsilon_\ell^q} \to 0$, when $\varepsilon^k \to 0$ (while ℓ is small, it is still an order of magnitude larger than ε^k). Two observations are in order. First, the

[40] The cost of having obtained the licenses is a sunk cost ex post, and hence does not enter the ex post entry condition.The price ℓ paid for the licenses, however, forms a part of the secondary market price, and hence enters the revenue side of the entry condition.

ex post entry condition under arrangement ℓ (28) is clearly less demanding than the ex post entry condition under arrangement τ (26). Second, under arrangement ℓ, the ex post entry condition (28) is not necessarily more demanding than the ex ante entry condition (27), but rather the opposite is likely to be true; in particular if

$$\overline{y} > \max_{\beta,\gamma} x^* \left(1+\ell;\beta,\gamma\right) \tag{29}$$

(so that the maximum quota is large enough to cover the consumption of the ultimate heavy user), the ex post entry condition (28) holds for all consumers. Next, as in the case of sin taxes, we define the following sets of naive consumers

$$\begin{aligned}
\text{non-sellers } \Omega_\ell^{ns} &: \quad \text{ex ante entry condition (27) does not hold} \\
\text{all sellers } \Omega_\ell^{as} &: \quad \text{ex ante entry condition (27) holds} \\
\text{effective sellers } \Omega_\ell^{es} &: \quad \text{both (27) and (28) hold} \\
\text{wannabe sellers } \Omega_\ell^{ws} &: \quad \text{(27) holds but (28) does not hold}
\end{aligned}$$

Clearly, $\Omega^{naives} = \Omega_\ell^{ns} + \Omega_\ell^{as}$ and $\Omega_\ell^{as} = \Omega_\ell^{es} + \Omega_\ell^{ws}$. In particular, if (29) applies, the ex post entry condition (28) holds for all consumers, and as a consequence $\Omega_\ell^{ws} = \emptyset$, and $\Omega_\ell^{as} = \Omega_\ell^{es}$.

Now, to show that a smaller share of naive individuals become effective secondary market sellers or wannabe secondary market sellers under arrangement ii) (licenses sold at a price ℓ) than under arrangement i) (sin taxes), we have to prove that $\Omega_\ell^{as} \subset \Omega_\tau^{as}$. The proof consists of several steps.

Step 1) Since the ex ante entry conditions (25) and (27) only differ with respect to the threshold ($\frac{\varepsilon^k}{\varepsilon_\tau^q}$ and $\frac{\varepsilon^k}{\varepsilon_\ell^q}$, respectively), it is clear that either $\Omega_\ell^{as} \subset \Omega_\tau^{as}$ (if $\frac{\varepsilon^k}{\varepsilon_\ell^q} > \frac{\varepsilon^k}{\varepsilon_\tau^q}$) or $\Omega_\tau^{as} \subseteq \Omega_\ell^{as}$ (if $\frac{\varepsilon^k}{\varepsilon_\ell^q} \leq \frac{\varepsilon^k}{\varepsilon_\tau^q}$). (In other words, there cannot exist two consumers, say A and B, such that $A \in \Omega_\ell^{as}$, $B \notin \Omega_\ell^{as}$ and $A \notin \Omega_\tau^{as}, B \in \Omega_\tau^{as}$.)

Next we prove the claim $\Omega_\ell^{as} \subset \Omega_\tau^{as}$ by contradiction.

Step 2) Assume by contrast that $\Omega_\tau^{as} \subseteq \Omega_\ell^{as}$. This assumption has two direct implications. First, since $\Omega^{naives} = \Omega_i^{ns} + \Omega_i^{as},\ i \in \{\tau, \ell\}$, we have $\Omega_\ell^{ns} \subseteq \Omega_\tau^{as}$. Second, since the ex post entry condition (26) is more demanding than the ex post entry condition (28), it is clear that $\Omega_\tau^{es} \subset \Omega_\ell^{es}$.

Step 3) Since the secondary market price is the same under both arrangements ($q^\tau = 1 + k + \tau = 1 + k + \ell = q^\ell$), the secondary market demand or supply of each consumer is the same, conditional on secondary market status (buyer, seller, absentee). In other words, if a consumer is a secondary market buyer (seller) under both arrangements, his secondary market demand (supply) is the same under both arrangements.

Step 4) Denote aggregate secondary market supply under arrangement $i \in \{\tau, \ell\}$ by S_i and aggregate secondary market demand by D_i. Further denote secondary market demand from partially naive individuals by D_i^{pn} and secondary market demand from fully naive individuals by D_i^{fn}. Clearly $D_i = D_i^{pn} + D_i^{fn}$. Now it follows from Step 2) and Step 3) that $S_\tau < S_\ell$ and $D_\tau^{fn} \geq D_\ell^{fn}$. Furthermore, it follows from item a) of this proposition that $D_\tau^{pn} = D_\ell^{pn}$. Thus $D_\tau \geq D_\ell$.

Step 5) Since $S_\tau < S_\ell$ and $D_\tau \geq D_\ell$, it is clear that the secondary market equilibrium condition $S_i = D_i$ cannot hold for both $i = \tau$ and $i = \ell$. Hence the assumption $\Omega_\tau^{as} \subseteq \Omega_\ell^{as}$ has led to a contradiction, and we can conclude that $\Omega_\ell^{as} \subset \Omega_\tau^{as}$.

c) Aggregate welfare W in the economy is given by

$$W^i = \int \int \int V^i \left(q; \beta, \widehat{\beta}, \gamma\right) f\left(\beta, \widehat{\beta}, \gamma\right) d\beta d\widehat{\beta} d\gamma, \ i \in \{\tau, \ell\},$$

where $V^i \left(q; \beta, \widehat{\beta}, \gamma\right)$ is the utility of type $(\beta, \widehat{\beta}, \gamma)$ under arrangement $i \in \{\tau, \ell\}$ and $f\left(\beta, \widehat{\beta}, \gamma\right)$ is the joint density function of $\beta, \widehat{\beta}$ and γ. Aggregation means that income transfers between individuals (the government collects revenues from sin taxes, or from the sale of sin licenses, and then distributes these revenues back to the consumers according to some principles) do not affect the welfare measure W. Aggregate welfare then depends on i) (the distribution of) individual levels of sin good consumption, and ii) the amount of sin goods bought in the secondary market (since resources are wasted in secondary market trade, due to transaction costs k).

Since the secondary market price is the same under both arrangements, $q^\tau = q^\ell$, an individual's consumption level and secondary market purchases are the same under both arrangements, as long long as the secondary market status remains the same. Then the only group we have to study is fully naive consumers: as noted in item b) some naive consumers are secondary market sellers (either effective sellers or wannabe sellers) under arrangement τ, but non-sellers under arrangement ℓ. (By contrast all sophisticated consumers and partially naive consumers have the same secondary market status under both arrangements.) Now, it follows from Proposition 3, item *a(vi)* that there is a discrete rise in the utility of naive individuals, who shift from secondary market sellers (either effective sellers or wannabe sellers) to non-sellers. (Since we assume that $\tau = \ell$ is small, the same proof applies here.)

There is still a small twist before we can conclude that the rise in the welfare of (some) naive consumers translates into higher aggregate welfare. Since a non-seller consumes less than a seller ($x^{non-seller}(\beta,\gamma) = \max\{x^o(1+\ell;\gamma), x^*(1+\ell+k;\beta,\gamma)\} < x^{seller}(\beta,\gamma) = x^*(1+\ell;\beta,\gamma)$), the payments from the naive individual to the government decrease by the amount

$$\tau\left[x^{seller}(\beta,\gamma) - x^{non-seller}(\beta,\gamma)\right] = \ell\left[x^{seller}(\beta,\gamma) - x^{non-seller}(\beta,\gamma)\right]$$

. While paying less to the government improves the naive individual's welfare, it does not improve aggregate welfare (since lower government revenues from the naive individual mean lower transfers to other consumers). Thus for aggregate welfare W to rise, the improvements in the naive individual's utility must exceed $\tau\left[x^{seller}(\beta,\gamma) - x^{non-seller}(\beta,\gamma)\right]$ (the fall in government revenues, and transfers to other consumers). However, since there is a discrete jump in the naive individual's utility (Proposition 3, *item a(vi)*), this condition is met, as long as $\tau = \ell$ is small (making the drop in government revenues from the naive individual, and transfers to other consumers, small).

Proof of Proposition 7

Assume that a system of personalised quotas is in place. Define $\widetilde{X} = \max_{\beta,\gamma} x^*(1+k;\beta,\gamma)$ and consider introducing a maximum quota $\bar{y} < \widetilde{X}$. Assume that there is a mass point at $\beta = 1$ and let $\widehat{X}$ be the minimum value of the quota $\bar{y}$ such that perfectly rational sellers can cover the whole secondary market. When $\bar{y} > \widehat{X}$, the secondary market price $q^s = 1+k$, and a marginal change in the quota $\bar{y}$ does not change the secondary market price. Consider a quota

$$\bar{y} \in (\widehat{X}, \widetilde{X}].$$

The indirect utility function of irrational buyers is given by

$$V(\bar{y};\beta,\gamma) = v(x^*;\gamma) - \delta h(x^*) - x^p - (1+k)x^s$$

where

$$x^p = \max\{x^*(1+k;\gamma,\beta), \bar{y}\}$$

is the amount of the sin good purchased in the primary market, and

$$x^s(1+k;\gamma,\beta) = \max\{x^*(1+k;\gamma,\beta) - \bar{y}, 0\} \tag{30}$$

is the amount of the sin good purchased in the secondary market.

Assume that a consumer (γ,β) buys a positive amount from the secondary market.

Then the effect of a tighter maximum quota on the consumer's welfare is given by

$$\frac{\partial V\left(\bar{y};\beta,\gamma\right)}{\partial\bar{y}}=-1-\left(1+k\right)\frac{dx^{s}}{d\bar{y}}=k, \tag{31}$$

that is, a tighter maximum quota (smaller $\bar{y}$) decreases the consumer's welfare. In deriving the result (31) we exploited the observation that the consumer's aggregate purchases of the sin good does not change: $x^{*}\left(1+k;\gamma,\beta\right)$ depends on the secondary market price $q^{s}=1+k$, which remains unaltered. Due to the tighter quota $\bar{y}$ the consumer can buy less from the primary market, but this is fully compensated by larger purchases from the secondary market. That is,

$$\frac{dx^{*}}{d\bar{y}}=0 \tag{32}$$

and from (30) and (32) it then follows that

$$\frac{dx^{s}}{d\bar{y}}=\frac{dx^{*}}{d\bar{y}}-1=-1$$

The sellers do not benefit from the quota either. Since there is perfect competition in the secondary market, no profits are made.

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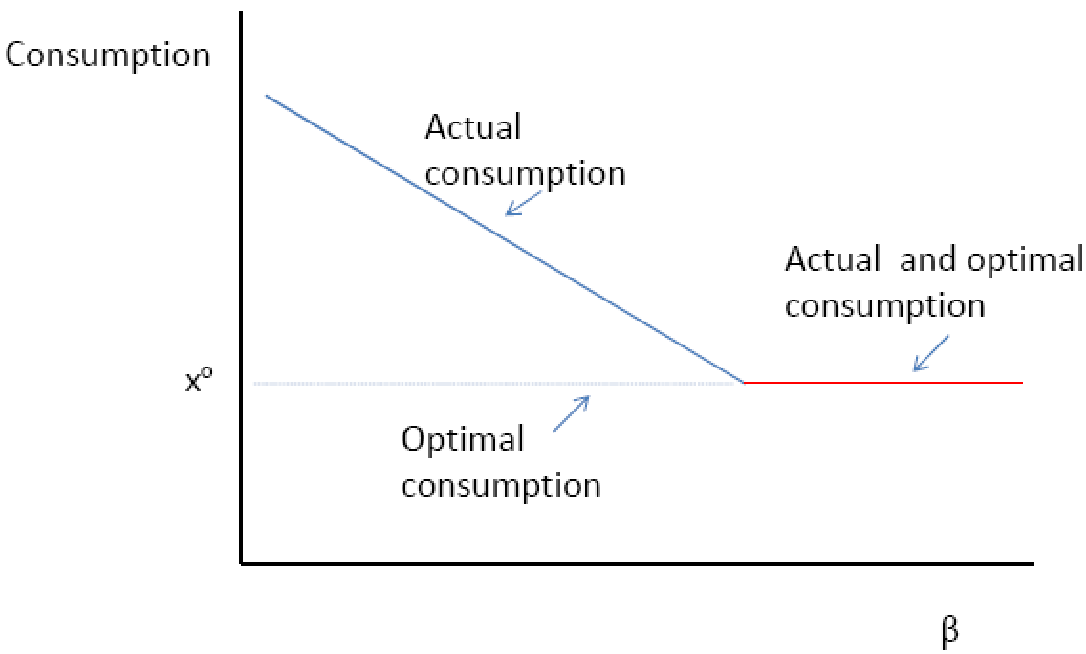

Figure 1: The degree of self-control problems and equilibrium consumption

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