The Political Economy of Sin Taxes

MARKUS HAAVIO
KAISA KOTAKORPI

CESIFO WORKING PAPER NO. 2650
CATEGORY 1: PUBLIC FINANCE
MAY 2009

PRESENTED AT CESIFO AREA CONFERENCE ON PUBLIC SECTOR ECONOMICS, APRIL 2009

CESifo *Working Paper No. 2650*

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Abstract

We analyse the determination of taxes on harmful goods when consumers have self-control problems. We show that under reasonable assumptions, the socially optimal corrective tax exceeds the average distortion caused by self-control problems. Further, we analyse how individuals with self-control problems would vote on taxes on the consumption of harmful goods, and show that the equilibrium tax is typically below the socially optimal level. When the redistributive effects of sin taxes are taken into account, the difference between the social optimum and equilibrium is small at low levels of harm, but becomes more pronounced when consumption is more harmful.

JEL Code: H21, H30, D72.

Keywords: excise taxation, voting, self-control.

Markus Haavio
Bank of Finland
markus.haavio@bof.fi

Kaisa Kotakorpi
University of Tampere
Department of Economics and Accounting
33014 University of Tampere
Finland
kaisa.kotakorpi@uta.fi

May 11, 2009
We would like to thank Tomer Blumkin, Essi Eerola, Pierre Pestieau, Jukka Pirttilä, Panu Poutvaara, Theis Theisen as well as seminar participants at the 1st World Meeting of the Public Choice Society, the 63rd Congress of the International Institute of Public Finance, CESifo Area Conference on Public Sector Economics 2009 and at HECER for comments. This work was initiated while Kotakorpi was visiting the LSE. Kotakorpi thanks the LSE and STICERD for their hospitality, as well as Tim Besley and Erik Eyster for helpful comments on an early version of the paper. All remaining errors are ours. Kotakorpi gratefully acknowledges financial support from the FDPE, the European Commission and the EDNET network, Yrjö Jahnsson Foundation and the Foundation for Economic Education.

1 Introduction

We analyse the determination of taxes on goods whose current consumption causes utility costs (for example negative health effects) in the future. When consumers have time-inconsistent preferences, they consume too much of such goods. Using "sin taxes" to correct distortions in the consumption of harmful goods when consumers have self-control problems has also been considered in O'Donoghue and Rabin (2003; 2006).[1]

Market-based mechanisms for correcting the distortion caused by self-control problems are likely to be ineffective (see Köszegi (2005)), and consumers might thus value sin taxes as a commitment device. In addition to the monetary cost of taxation, sin taxes affect individual utility due to the corrective nature of the tax when preferences are time-inconsistent. If this positive effect outweighs the monetary cost, sin taxes can improve individual welfare - see Gruber and Köszegi (2004) and Kotakorpi (2008) for theoretical analyses and Gruber and Mullainathan (2005) for empirical evidence.

The main purpose of the current paper is to analyse how sin taxes are determined in political equilibrium, and to compare the equilibrium tax with the socially optimal level. Previous literature has focused on optimal taxes, and our analysis of equilibrium sin taxes is therefore an important extension to the literature. Putting the paper in a broader context, it provides a contribution to the nascent field of behavioural political economy. We are aware of only a few earlier contributions in this field (Bassi 2008; Cremer *et al.* 2007; Frogneux 2009; Eisensee and Strömberg 2007; Osborne and Rubinstein 2003). In a recent survey of literature in behavioural economics, DellaVigna (2007) identifies political economics as one of the most promising fields of further research where behavioural economics could be more extensively applied.

In order to obtain a reference point to which the equilibrium sin tax is to be compared, we first derive an expression for the optimal sin tax in a second-best setting: That is, we assume that individuals differ in their degree of self-control problems, but a uniform tax is applied. Many economists have been concerned that sin taxes as well as other paternalistic policies aimed at helping irrational individuals[2] are often detrimental for the welfare of rational individuals.[3] This has resulted in an emphasis on

[1] For an analysis of sin taxes within the broader context of non-welfarist optimal taxation, see Kanbur, Pirttilä and Tuomala (2006).

[2] Throughout the paper, we refer to individuals with a self-control problem as irrational, as they behave in an inconsistent manner and make consumption decisions that fail to maximise their own life-time utility. Similar terminology has been used for example by O'Donoghue and Rabin (2006).

[3] Beyond this concern, some economists remain sceptical about paternalism for more general reasons - see for example Glaeser (2006) for a critical view. For example, the possibility of government failure may reduce the effectiveness and desirability of paternalistic policies. Despite the importance of this consideration, we abstract from this issue in the current paper. On the other hand, we show that

a search for policies that help irrational individuals while having only a small or no impact on those who are rational.[4]

However, it seems natural that economists should not restrict themselves to studying minimal interventions, but we should also engage in analysing *optimal* paternalistic policies. Indeed, there has recently been a move in this direction - see in particular O'Donoghue and Rabin (2006), who examine the conditions under which the optimal utilitarian sin tax is positive, and provide some comparative statics of the optimal sin tax when there are changes in the distribution of self-control problems. They also analyse whether sin taxes can yield Pareto improvements (compared to zero taxes).

We analyse the trade-off between benefits to irrational individuals and costs to rational individuals further, and find the optimal balance between them by deriving a formula for the socially optimal utilitarian sin tax. We find that even though the social planner sets the corrective tax to maximise the expectation of individual welfare, the second-best optimal sin tax exceeds the average distortion caused by self-control problems in the economy. The reason is right at the heart of the recent discussion on paternalism: for reasonable assumptions about the form of the demand function, sin taxes have a relatively small (negative) effect on the utility of (close to) rational individuals, who consume relatively little of the good. On the other hand, irrational consumers with a very high level of consumption gain a lot from sin taxes.

We then turn to analyse the majority voting equilibrium. We assume that individuals are fully aware of their self-control problem, and vote on the sin tax to be implemented from the next period onwards. Taxation can then provide a commitment device that helps individuals move their consumption closer to its optimal level.

Sin taxes have two effects on consumer welfare and thus there are two mechanisms that affect the consumer's voting decision: Firstly, sin taxes correct (or distort) consumption decisions (depending on whether the consumer suffers from self-control problems or not). Secondly, linear sin taxes redistribute income from irrational large-scale consumers towards more rational consumers with a low level of consumption. As a benchmark, we consider the case where tax revenue is distributed back to consumers in such a way that the redistributive effects of taxation are eliminated. This setting is unrealistic, as it requires personalised transfers and therefore information on each consumer's type. However, this analysis is useful in disentangling the corrective and

in our model consumers would themselves vote for paternalistic policies: such policies can therefore be the outcome of a democratic decision making process, which has interesting implications for the justification of paternalism.

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

redistributive roles of sin taxes, and in understanding how these two mechanisms affect the determination of equilibrium taxes.

In the setting without redistributive effects, individuals prefer the level of taxes that completely eliminates the distortion in their own consumption, and the political equilibrium is the tax rate that corresponds to the median level of self-control problems. We show that there is a bias in voting behaviour, which tends to make the equilibrium tax too low: the asymmetric effect of sin taxes at different ends of the distribution of self-control problems is not taken into account by the median voter. However, in this setting where sin taxes have no redistributive effects, there is one particular case where the equilibrium and the social optimum coincide: this is when consumption is so harmful that the optimal level of consumption is zero even in the absence of taxation. In this case, it is in the interests of both the consumers and the social planner to eliminate all consumption.

The main part of our analysis concerns the more realistic case where redistributive effects of sin taxes are taken into account. On the one hand, an individual without self-control problems will prefer a low tax, as high taxation would distort his consumption choice. On the other hand, however, the redistributive effects of sin taxes provide a reason for consumers with no self-control problems to vote for a high tax. Despite these counteracting motives, we show that a majority voting equilibrium exists also in this case, and corresponds to the tax rate preferred by the individual with the median level of self-control problems.

Further, we show that when harmful health effects are mild, the redistributive effects of sin taxes work rather well in aligning the median voter's preferences with those of the utilitarian social planner: even though equilibrium taxes are still typically below the socially optimal level, the difference is small both in absolute terms and also compared to the level of taxes. However, the mechanism seems to work well only at low levels of harm, and the difference between the equilibrium and the optimum becomes more pronounced when consumption is more harmful. Importantly, we show that when redistributive effects of sin taxes are taken into account, the equilibrium tax rate tends to be below the socially optimal level *regardless* of the level of harm from consumption. Perhaps paradoxically, the redistributive motive for taxation implies that equilibrium taxes are below the social optimum even when consumption is extremely harmful: in this case the median voter does not consume the good in equilibrium, and simply wants to maximise redistribution from irrational individuals towards himself. On the other hand, the social planner wants to completely eliminate consumption.

One aim of our analysis is to contribute to the policy discussion on the taxation of harmful goods. In European countries, tobacco products are taxed much more heavily than alcohol: the excise duty on the most popular brand of tobacco was on average approximately 60 % of the total retail price in the EU-15 member states in 2003 (Cnossen and Smart 2005), whereas the corresponding figure was 19 % for beer, 14 % for wine and 39 % for spirits (WHO 2004).[5] It might appear that cigarette taxes are too high from a social point of view, particularly as cigarette taxes in most countries seem to exceed the external costs of smoking (Cnossen and Smart 2005).[6] However, considering not only negative externalities, but also harm experienced but not taken into account by the consumer himself, optimal taxes should indeed exceed the level that would be appropriate if only externalities were taken into account. As our analysis shows, the redistributive motive for taxation implies that equilibrium taxes on highly harmful goods such as cigarettes may be too low from a social point of view.[7]

In addition to the previous literature on taxation when consumers have self-control problems, our analysis has similarities with the analysis of commodity taxation in the presence of externalities: negative health effects (in the case of consumers with self-control problems) or "internalities"[8], as well as negative externalities, are both harmful effects not taken into account by consumers, and governments might wish to alleviate these effects through taxation. Diamond (1973) has analysed optimal taxation of externality-generating goods when individuals give rise to different (marginal) externalities.[9] In the case of externalities, however, there is no natural assumption to make about how the magnitude of the marginal externality should be correlated with individual demand. In our context, on the other hand, a high marginal internality is naturally associated with high consumption, since consumers with a more severe self-control problem have a higher level of consumption, *ceteris paribus.* This correlation is the mechanism that drives many of the key results in this paper.

The rest of the paper proceeds as follows. We introduce the model in Section 2 and derive the second-best optimal sin tax in Section 3. The political equilibrium is

[5]The figures for alcoholic drinks were calculated using data for 9 countries only, as the figures for the rest of the EU-15 were not reported (see WHO 2004, 54). The average total tax collections in the EU-15 member states were approximately 100 euros per adult in the case of alcohol, and around 280 euros per capita in the case of tobacco (see for example Cnossen (2006) and (2007)).

[6]In the case of alcohol, on the other hand, taxes appear to be lower than the level that would be mandated even by externality considerations alone (Cnossen 2007).

[7]The relatively low prevalence of smoking suggests that cigarettes fit our category of highly harmful substances (where most people abstain from consumption): smoking prevalence is around 20-30% in most EU countries, whereas only around 15% of adult Europeans abstain from alcohol consumption (Anderson and Baumberg 2006, European Commission 2004).

[8]See Herrnstein *et al* (1993).

[9]See Eerola and Huhtala (2008) for a recent contribution to the literature on the political economy aspects of environmental policy.

analysed in Section 4, where we first study the benchmark case where sin taxes have no redistributive effects, and then extend the analysis to account also for the redistributive effects of sin taxes. Section 5 briefly discusses the possibility of using other mechanisms besides linear taxes and lump-sum transfers to regulate the consumption of sin goods. We also discuss the case where sin taxes not only have a corrective role, but are also used for revenue raising purposes, and point out that our results hold also in this setting. Section 6 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 to O'Donoghue and Rabin (2003; 2006). Lifetime 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. Individuals are therefore assumed to be identical in all other respects, but they differ in their degree of quasi-hyperbolic discounting. 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 individuals derive utility from a composite good (z), which is taken as the numeraire, and 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

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

where $v' > 0, v'' < 0$ and the harm function[10] is characterised by $h' > 0$ and $h'' \geqslant 0$. We

[10] 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.

therefore assume that the harm function is either linear or convex, so that incremental consumption of goods such as alcohol is more harmful at high levels of consumption.

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 $u(x_t) = v(x_t) - \beta_i \delta h(x_t) + z_t$. 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, and $q = 1 + \tau$ 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[11]

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

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.[12] Therefore, when thinking about future decisions, the consumer would like to choose consumption levels that maximise $u^o(x)$. We take this long-run perspective as the one relevant for welfare evaluation - this has become a standard choice in the literature on sin taxes (see for example Gruber and Köszegi (2004), O'Donoghue and Rabin (2003; 2006)). There are clear reasons that justify this choice of welfare criterion: Firstly, we assume that taxes are implemented from the period after the policy decision is made. Therefore, consumers themselves agree that $u^o(x)$ is the relevant utility function from the point of view of tax policy, and voting decisions will be made based on maximising this function. We thus use the same criterion consistently when deriving both the optimum and the equilibrium level of taxes. Further, $u^o(x)$ 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.[13] This latter consideration applies irrespective of the timing of the model.

The optimal level of consumption therefore satisfies $v'(x^o) - \delta h'(x^o) = q$: because of quasi-hyperbolic discounting ($\beta < 1$), the equilibrium level of consumption of the

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

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

[13] See also Bernheim and Rangel (2007, 4) for a discussion on this point.

harmful good (x^*) is higher than the optimal level (x^o).

3 The second-best optimal sin tax

We argued above that long-run utility is the appropriate welfare criterion in our model. The social welfare function is then given by $W(q) \equiv \int_{\beta_l}^{\beta_H} G(V(q;\beta)) f(\beta) d\beta$, where $V(q;\beta) = u^o(x^*(q;\beta))$ is the long-run indirect utility function. Note again that maximising u^o is identical to maximising (1) from the next period onwards, given our specification for the periodic utility function (2). We assume that the function $G(.)$ is utilitarian, and the social welfare function therefore becomes[14]

$$\begin{aligned} W(q) &= \textstyle\int_{\beta_l}^{\beta_H} V(q;\beta) f(\beta) d\beta = E_\beta [V(q;\beta)] \\ &= E_\beta [v(x^*(q;\beta)) - \delta h(x^*(q;\beta)) - q x^*(q;\beta) + S(q,\beta)] + B, \end{aligned}$$

where x^* satisfies (3) and is therefore distorted whenever $\beta < 1$, as argued above. Taking into account the government's budget constraint $\tau E_\beta [x^*(q;\beta)] = E_\beta [S(q,\beta)]$, the social welfare function can be written as

$$W(q) = E_\beta [V(q;\beta)] = E_\beta [v(x^*(q;\beta)) - \delta h(x^*(q;\beta)) - x^*(q;\beta)] + B.$$

Given the distortion in consumption caused by quasi-hyperbolic discounting, the government may consider imposing a sin tax on harmful goods as a corrective measure. The social planner's first-order condition is

$$\begin{aligned} E_\beta \left[\tfrac{\partial V(q;\beta)}{\partial q}\right] &= E_\beta \left[[v'(x^*(q;\beta)) - \delta h'(x^*(q;\beta)) - 1] \tfrac{\partial x^*(q;\beta)}{\partial q} \right] \\ &= E_\beta \left[[\tau - (1-\beta) \delta h'(x^*(q;\beta))] \tfrac{\partial x^*(q;\beta)}{\partial q} \right] = 0, \end{aligned} \tag{4}$$

where the last step was obtained by using (3).

As we consider a case where a uniform tax is applied, choosing the optimal tax involves a trade-off between helping consumers with a severe self-control problem, whilst causing a distortion for those who are rational. From (4), the second-best optimal tax is given by

[14] Note that we use the expectations operator for notational convenience to refer to the average of the relevant variable.

$$\tau^o = \delta E_\beta \left[(1-\beta)h'\left(x^*\left(q;\beta\right)\right)\right] + \frac{\delta Cov_\beta \left[(1-\beta)h'\left(x^*\left(q;\beta\right)\right), \frac{\partial x^*(q;\beta)}{\partial q}\right]}{\frac{\partial E_\beta[x^*(q;\beta)]}{\partial q}}. \tag{5}$$

It should be noted that the socially optimal tax rate is independent of the way in which tax revenue is distributed back to consumers, that is, of the form of the function $S(\tau, \beta)$. Therefore, in both of the cases considered below - that is, regardless of whether sin taxes have redistributive effects or not - the socially optimal tax rate is given by (5).

The first term in the tax formula (5), $\delta E\left[(1-\beta)h'(x^*)\right]$, is the average distortion caused by self-control problems in the economy. The second term is basically the covariance between the extent of the mistake made by an individual, and the responsiveness of his demand to price changes. It reflects the fact that the weight the social planner assigns to a consumer depends on how much a price change affects the quantity of the sin good the consumer buys. Intuitively, if the consumer's choices are virtually unaffected by price changes, the sin tax can neither distort nor correct the consumer's choices. The larger the effect of a price change on the amount of sin goods consumed, the more sin taxes correct or distort the consumer's choices, and the higher the weight given to the consumer in the optimal tax calculus.

It is shown in the Appendix that the second term in (5) is positive (negative) if $\frac{\partial^2 x^*(q;\beta)}{\partial q \partial \beta} > (<) 0$. If $\frac{\partial^2 x^*(q;\beta)}{\partial q \partial \beta} > 0$, the impact of taxation on consumption is increasing in the level of self-control problems, and vice versa if $\frac{\partial^2 x^*(q;\beta)}{\partial q \partial \beta} < 0$. In the rest of the paper we assume that $\frac{\partial^2 x^*(q;\beta)}{\partial q \partial \beta} > 0$, which holds for commonly used functional forms and is also supported by empirical evidence (see below). 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, higher taxation 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.

In the current and the next section, we make the following assumptions about the functional forms of $v(x)$ and $h(x)$, which provide sufficient conditions for $\frac{\partial^2 x^*(q;\beta)}{\partial q \partial \beta} > 0$ to hold:

Assumption 1 (i) $v'''(x) \geq 0$ and (ii) $-2 \leq \frac{h'''(x)h'(x)}{[h''(x)]^2} \leq 1$.

Assumption 1 is satisfied for commonly used functional forms, for example when v is of the CRRA or CARA-variety[15] or quadratic, and when the harm function is linear[16], quadratic, exponential or $h(x) = x^s$ where $s \geq 4/3$. We can now state the following proposition:

Proposition 1 *The socially optimal sin tax is higher than the average distortion caused by self-control problems, that is,* $\tau^o > \delta E_\beta \left[(1-\beta)h'\left(x^*\left(q;\beta\right)\right)\right]$ *.*

Proof. See the appendix. ■

Proposition 1 therefore states that even though the social planner chooses the corrective tax to maximise the expectation of individual welfare, the socially optimal tax rate exceeds the average distortion caused by self-control problems in the economy. The proposition has a very intuitive explanation. As was explained above, Assumption 1 implies that taxation has a larger impact on irrational consumers with a high level of consumption than on rational consumers with a low or moderate level of consumption . The benefit of a high sin tax for consumers with a severe self-control problem thus exceeds the (negative) impact on the utility of (close to) rational individuals.

An important question of course is whether the condition $\frac{\partial^2 x^*(q;\beta)}{\partial q \partial \beta} > 0$ is likely to hold for the demand for sin goods. The evidence that we require to judge the appropriateness of this condition is hard to find, as most studies on the demand for goods such as alcohol and tobacco estimate iso-elastic demand functions, and therefore there is no information on how the price responsiveness of demand varies across consumers (or variation may be allowed according to dimensions such as age or gender) - see for example Cook and Moore (2000) and Chaloupka and Warner (2000) for reviews of demand studies on alcohol and tobacco. An important exception is Manning *et al.* (1995), where the price elasticity of alcohol demand is allowed to vary between heavy drinkers, moderate drinkers and light drinkers. More specifically, Manning *et al.* use individual-level data from the 1983 US National Health Interview Survey to estimate the price elasticity of demand for each decile of drinkers. The evidence is broadly consistent with assumption 1: even though the demand of both light and heavy drinkers is less elastic than the demand of moderate drinkers, the absolute changes in demand are uniformly increasing in the level of consumption for the vast majority of the population. This evidence is reported in Table 1.

[15] Kimball (1990) provides an economic interpretation of the condition $v''' > 0$, albeit from a context that is rather different from ours: $v''' > 0$ is associated with the concept of prudence, and implies that precautionary savings of risk averse individuals increase with increased uncertainty.

[16] Note that when the harm function is linear, part (i) of Assumption 1 has to hold as a strict inequality.

Table 1. Price responsiveness of demand for alcohol[1].

Percentile (among drinkers)[2]	Daily ethanol consumption (US fl oz)	Estimated price elasticity	Absolute change
0	0,01	-0,5550	-0,0055
5	0,03	-0,5561	-0,0167
10	0,04	-0,5312	-0,0212
25	0,09	-0,8269	-0,0744
50	0,23	-1,1916	-0,2741
75	0,64	-0,8470	-0,5421
90	1,44	-0,4940	-0,7114
95	2,25	0,1213[3]	0,2729

[1]Source: Manning *et al.* (1995), Tables 4 and A.1.

[2]Manning *et al.* (1995) estimate price elasticities for each decile as well as the 5th and 95th percentile of drinkers, whereas the information on daily ethanol consumption is given for the percentiles reported here. We have obtained the elasticity at the 25th percentile by averaging the elasticities at the 20th and 30th percentiles; similarly for the elasticity at the 75th percentile.

[3]The estimate is not statistically different from zero (t=0.40).

The only deviation from the pattern of increasing responsiveness to price changes occurs for the 95th percentile of drinkers, whose consumption is found to be completely inelastic (the elasticity estimate is not significantly different from zero). The problem that this might pose for our analysis is alleviated by a number of factors. Firstly, the 95th percentile of drinkers corresponds to 3% of the adult population (aged 17 or over), and therefore the price responsiveness of demand is indeed increasing in the quantity consumed for the vast majority of the population. Note also that what we need is simply a correlation between harm from consumption and $\frac{\partial x^*(q;\beta)}{\partial q}$ (see equation (5)), and therefore $\frac{\partial x^*(q;\beta)}{\partial q}$ does not necessarily have to increase monotonically. Further, even if we are mainly interested in problem drinking, it is important to note that the harmful effects of alcohol consumption become significant at consumption levels well below the 95th percentile of drinkers (see for example Farrell *et al.* 2003). Further, various undesirable outcomes associated with drinking (such as drunk driving or the occurrence of diseases such as liver cirrhosis) have been found to be responsive to price - see Cook and Moore (2000) for a review of the evidence.

4 Political equilibrium

From the consumer's point of view, the problem is that he would like to consume less in the future, but repeatedly fails to do so due to self-control problems. We assume throughout the analysis that consumers are sophisticated - that is, they are completely aware of their self-control problem.[17] However, market-based mechanisms for correcting the distortion caused by time-inconsistent preferences are likely to be ineffective (see Köszegi (2005)): even though both consumers and firms would have the incentive, ex ante, to sign contracts that implement the optimal level of consumption, in a competitive market consumers cannot be prevented from purchasing from other firms ex post. Consumption of harmful goods is therefore as if only a spot market was available (that is, suboptimally high). To the extent that laws on commodity taxation cannot be changed within a given period, sophisticated consumers might value sin taxes as a way of committing to a lower level of consumption in the future.

In this section we analyse the level of taxes that will emerge in a political equilibrium and compare the equilibrium tax rate with the social optimum. We assume that consumers vote over a sin tax to be implemented in all subsequent periods, starting from the period following the vote. Another interpretation that would yield identical results, would be that individuals vote each period on a tax rate that will apply in the next period only.[18]

As utility from all subsequent periods is discounted exponentially, the individual's policy preference function is given by his indirect long-run utility function, $V(q;\beta_i) = u^o(x^*(q;\beta_i)) = v(x^*(q;\beta_i)) - \delta h(x^*(q;\beta_i)) + z$: the individual's preferred tax rate is the one that maximises his long-run utility, taking into account the fact that actual consumption decisions will be distorted in the absence of a sin tax.

Finally, we assume that the outcome of the vote is determined by direct majority rule.[19]

[17] 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 recently 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. Since there are no intertemporal linkages in the marginal benefits and costs of consumption in our model, consumption decisions (in the absence of commitment) would be the same for naifs and sophisticates. However, voting decisions depend on whether the individual is aware of his self-control problem: (partially) naive individuals would vote for a lower tax than sophisticated individuals.

[18] If consumers were to vote on taxes only for *this* period, all consumers would vote for zero taxes; and if they were to vote on taxes to be implemented forever but *including* the current period, they would vote for a lower level of taxes than implied by the analysis below (the socially optimal level of taxes would also be lower; see Gruber and Köszegi (2004, 1967)) .

[19] The same results hold if there is a representative democracy with two-party electoral competition, the parties can fully commit to a tax policy and care only about their chances of being elected (and do not have preferences over the level of taxes themselves) - this would be a simple case of Downsian electoral competition (Downs (1957); see also Persson and Tabellini (2000)).

4.1 Benchmark: sin taxes have no redistributive effects

Even though the social optimum is unaffected by the way in which tax revenue is distributed back to consumers, consumers clearly will not be indifferent about the subsidies that they receive. The shape of the function $S(\tau, \beta)$ thus has an effect on the political equilibrium. Consider first the case where the tax has no redistributive effects,[20] namely $S(\tau, \beta) = \tau x^*(q; \beta)$.[21] The long-run indirect utility function of individual i and therefore his policy preference function is then given by

$$\begin{aligned} V(q; \beta_i) &= v(x^*(q; \beta_i)) - \delta h(x^*(q; \beta_i)) - (1+\tau) x^*(q; \beta_i) + \tau x^*(q; \beta_i) + B \quad (6) \\ &= v(x^*(q; \beta_i)) - \delta h(x^*(q; \beta_i)) - x^*(q; \beta_i) + B. \end{aligned}$$

where x^* again satisfies (3).

4.1.1 The case of moderately harmful consumption

In the case where sin taxes have no redistributive effects, the comparison between the equilibrium and the social optimum turns out to depend on the extent of harm from consumption. Let us first analyse the political equilibrium in the case where current consumption causes harm in the future, but the optimal (rational) level of consumption is nevertheless positive at zero taxes, that is $v'(0) - \delta h'(0) - 1 > 0$. Using similar steps as in the previous section, the first-order condition is given by

$$\frac{\partial V(q; \beta)}{\partial q} = [\tau - (1-\beta)\delta h'(x^*(q; \beta))] \frac{\partial x^*(q; \beta)}{\partial q} \quad (7)$$

and each individual's preferred tax rate is given by

$$\tau^*(\beta) = (1-\beta)\delta h'(x^*(q; \beta)). \quad (8)$$

We show in the appendix that the policy preference function (6) is single-peaked. A majority voting equilibrium therefore exists and the tax rate preferred by the voter with the median most preferred level of taxes is chosen in equilibrium. Further, policy preferences are clearly monotonic in β: in the absence of redistribution, each individual

[20] In the present setting, it would also be possible to set individual-specific taxes. However, this case would not be very interesting, as there would then be no interpersonal trade-offs to be settled. The case of individual-specific transfers is also rather unrealistic, but it is useful for illustrating some of the key mechanisms in this paper, and serves as a benchmark for the more realistic case where sin taxes have redistributive effects.

[21] It is important to note that $S(\tau, \beta)$ is a lump-sum payment, and the consumer cannot change the subsidy by deviating from x^*.

prefers the tax rate that fully corrects the distortion in consumption. Since the distortion term $(1-\beta)\,\delta h'\left(x^*\left(q;\beta\right)\right)$ is decreasing in β, the individually preferred tax rate is monotonically increasing in the level of self-control problems. Given this monotonicity, the tax rate chosen in a majority voting equilibrium is given by

$$\tau^* = \left(1-\beta_{med}\right)\delta h'\left(x^*\left(q;\beta_{med}\right)\right). \tag{9}$$

We can now compare the tax rate chosen in political equilibrium, τ^*, to the socially optimal tax rate τ^o. Let us first examine a simple case, where the harm function is linear, namely $h(x) = \gamma x$. In this case $\tau^* = \delta\gamma\left(1-\beta_{med}\right)$. On the other hand, equation (5) implies that $\tau^o = \delta\gamma\left(1-E\left[\beta\right]+\kappa\right)$, where $\kappa \equiv Cov\left[\left(1-\beta\right), \frac{\partial x^*(q;\beta)}{\partial q}\right]/E_\beta\left[\frac{\partial x^*(q;\beta)}{\partial q}\right] > 0$. Then clearly $\tau^* < \tau^o$, as long as $E\left[\beta\right] < \beta_{med} + \kappa$.

In the appendix, we show that the right hand side of (9) is lower than the right hand side of (5) also for more general harm functions. The reader may worry that since the tax formulas in (5) and (9) are given in implicit form, the result might be related to tax *rules*, and not to actual tax *levels.* Limitations of this type are very common in the optimal taxation literature, as noted by Boadway and Keen (1993) and discussed by Gaube (2005). Using a Taylor-approximation of (7), we have further shown in the appendix that $\frac{dW(q)}{dq} - \frac{\partial V(q;\beta_{med})}{\partial q} \geq 0$ for all q, and therefore the result that $\tau^o > \tau^*$ is robust to this objection, at least when the tax rates are low enough so that the approximation used in the proof can be considered to be valid[22]. Given that we are in the current subsection concerned with goods that are moderately harmful (and tax rates should therefore not be very high), the approximation is likely to be fairly innocuous. In cases where the approximation is not valid (but the good is still only moderately harmful in the sense that the optimal level of consumption at zero taxes is positive), the result concerning the tax rules is nevertheless guaranteed to hold[23].

Proposition 2 *Assume that sin taxes have no redistributive effects and the optimal level of consumption at zero taxes is positive. If the distribution of β is not too much*

[22] To show that $\frac{dW(q)}{dq} - \frac{\partial V(q;\beta_{med})}{\partial q} > 0$ implies $q^o > q^*$, denote $\Delta\left(q\right) \equiv \frac{dW(q)}{dq} - \frac{\partial V(q;\beta_{med})}{\partial q} > 0$ and $\widetilde{\Delta} \equiv W\left(1\right) - V\left(1, \beta_{med}\right)$. Now $W\left(q\right) = V\left(q, \beta_{med}\right) + \int_1^q \Delta\left(\widehat{q}\right) d\widehat{q} + \widetilde{\Delta}$. The price level chosen in the political equilibrium is $q^* = \arg\max_q V\left(q, \beta_{med}\right)$. Next we show that the socially optimal price level $q^o = \arg\max W\left(q\right) > q^*$. (i) Assume by contrast that $q^o = \widetilde{q} < q^*$. Now $W\left(\widetilde{q}\right) = W\left(q^*\right) - \left[V\left(q^*, \beta_{med}\right) - V\left(\widetilde{q}, \beta_{med}\right)\right] - \int_{\widetilde{q}}^{q^*} \Delta\left(\widehat{q}\right) d\widehat{q} < W\left(q^*\right)$. Thus $\widetilde{q}$ cannot be optimal, a contradiction. (ii) $W'\left(q^*\right) = \frac{\partial V(q^*, \beta_{med})}{\partial q} + \Delta\left(q^*\right) > 0$, where the inequality follows since $\frac{\partial V(q^*, \beta_{med})}{\partial q} = 0$ and $\Delta\left(q^*\right) > 0$. Thus we can conclude that $q^o > q^*$. Notice that this proof applies even if $W\left(q\right)$ and $V\left(q\right)$ are multi-peaked.

[23] Note that in the case of a linear harm function, even the comparison of the tax rules gives an unambiguous answer, as we then have an explicit expression for τ^*.

skewed to the right, the socially optimal tax rate is higher than the tax rate chosen in a majority voting equilibrium.

Proof. See the appendix. ∎

In particular the proposition holds for all left-skewed distributions.[24] Empirically, this is perhaps the most relevant case: most consumers are relatively rational, while a minority has more severe self-control problems, so that $E[\beta] < \beta_{med}$.[25] As the median voter has smaller-than-average self-control problems, it is easy to understand that his preferred tax rate is below the socially optimal rate. However, the proposition also holds, when the distribution of self-control problems is symmetric, so that $E[\beta] = \beta_{med}$, and the equilibrium tax rate may be lower than the socially optimal rate even when the distribution of β is right-skewed , so that the median voter has larger-than-average self-control problems, or $\beta_{med} < E[\beta]$. To understand these results, remember that given our assumptions, the self-control benefits that irrational heavy-users obtain from high sin taxes, exceed the welfare losses incurred by (nearly) rational consumers. As the median voter ignores these asymmetric effects at the opposite ends of the distribution, the equilibrium tax rate τ^* tends to be lower than the second-best optimal tax rate τ^o under quite general conditions. If the distribution of β were too much skewed to the right, the equilibrium tax can be higher than the optimal tax.

4.1.2 The case of very harmful consumption

Consider next the case where consumption of commodity x is so harmful that the optimal (rational) level of consumption is zero even at zero taxes, that is, $v'(0) - \delta h'(0) - 1 \leq 0$. It is then immediately clear that, in the social optimum, no one should consume x. The (minimum) tax rate (τ^o) needed to implement the social optimum is such that even the least rational consumer abstains, and it is given by

$$\tau^o = v'(0) - \beta_L \delta h'(0) - 1. \tag{10}$$

It is easy to see that the socially optimal sin tax is in this case also a majority voting equilibrium for any distribution of β and for all functional forms $v(x)$ and $h(x)$:

Proposition 3 *Assume that sin taxes have no redistributive effects and the optimal level of consumption at zero taxes is zero. The socially optimal tax is then a majority*

[24] Throughout the paper, we say that the distribution of β is left-skewed, if $E[\beta] < \beta_{med}$, and it is right-skewed, if $\beta_{med} < E[\beta]$. This definition is consistent with the Pearson measure of skewness.

[25] The distribution of β is not observable, but some information on it can be obtained from the distribution of x^* (see p. 21-2 for a discussion).

voting equilibrium.

Proof. Individuals with $\beta_i = \beta_L$ strictly prefer τ^o to any tax rate below τ^o, and they are indifferent between τ^o and any tax rate $\tau > \tau^o$. All individuals with $\beta_i > \beta_L$ strictly prefer τ^o to any tax rate below $\hat{\tau}(\beta_i) = v'(0) - \beta_i \delta h'(0) - 1$ and are indifferent between τ^o and any tax rate $\tau \geq \hat{\tau}(\beta_i)$. ■

That is, when it is optimal to abstain from the consumption of good x even in the absence of any taxation, all consumers prefer a tax policy that will help them to achieve a zero level of consumption. The socially optimal tax achieves this outcome and will therefore be a majority voting equilibrium. However, we show in section 4.2.2 that this result changes when we take into account the redistributive effects of sin taxes.

4.2 Accounting for the redistributive effects of sin taxes

Let us next analyse the more realistic case where the government does not have information on individual consumption levels, so that the subsidy paid to each consumer cannot be conditioned on individual consumption. We therefore assume from now on that all consumers receive a lump-sum transfer of equal size, and this subsidy is given by $S(q;\beta) = S(q) = \tau E_\beta [x(q;\beta)]$. The consumers' policy preference function is then given by

$$\tilde{V}(q;\beta_i) = v(x^*(q;\beta_i)) - \delta h(x^*(q;\beta_i)) - qx^* + \tau E_\beta [x^*(q;\beta)] + B.$$

4.2.1 The case of moderately harmful consumption

Consider again first the case where current consumption causes harm in the future, but the optimal (rational) level of consumption is nevertheless positive at zero taxes, that is, $v'(0) - \delta h'(0) - 1 > 0$. The first-order condition that determines voting behaviour of individual i is now given by[26]

$$\begin{aligned} \frac{\partial \tilde{V}(q;\beta_i)}{\partial q} &= -(1-\beta_i)\delta h'(x^*(q;\beta_i)) \frac{\partial x^*(q;\beta_i)}{\partial q} \\ &\quad - x^*(q;\beta_i) + E_\beta [x^*(q;\beta)] + \tau \frac{\partial E_\beta [x^*(q;\beta)]}{\partial q}. \end{aligned} \tag{11}$$

In the case where taxation had no redistributive effects it was easy to see that the individual's preferred tax rate was monotonic in the level of self-control problems and

[26] We assume that consumers have information on the aggregate demand for the sin good and how it responds to price changes.

a majority voting equilibrium was therefore guaranteed to exists. However, as noted in the introduction, in the case where sin taxes have redistributive effects there are two forces at play: on the one hand, a person with a high level of self-control problems will prefer a high tax in order to alleviate the distortion in his consumption decision. The corrective effect of taxation is identical to the case where sin taxes have no redistributive effects, and is given by the first term in (11). On the other hand, however, a high tax will also imply a transfer of income towards individuals with a relatively low level of consumption: this redistributive effect of taxation is captured by the remaining terms in (11).

Because of these two opposite effects, policy preferences may not be well-behaved, and the existence of a majority voting equilibrium is therefore not self-evident in this case. In particular, it is possible that policy preferences are not single-peaked: The consumer chooses not to buy any of the sin good, once the price reaches a certain level $\widetilde{q}(\beta_i) = v'(0) - \beta_i \delta h'(0)$. If $\widetilde{q}(\beta_i)$ is lower than the tax rate that maximises tax proceeds, say $\widehat{q}$, utility may be hump-shaped for values of $q < \widetilde{q}(\beta_i)$, then increasing for $\widetilde{q}(\beta_i) < q < \widehat{q}$ (as the consumer now only cares about tax revenues) and decreasing for $q > \widehat{q}$.

Even if policy preferences are not single-peaked, a median voter equilibrium exists if policy preferences satisfy the Gans-Smart single crossing property (Gans and Smart 1996). Gans and Smart show that when underlying preferences are defined over a two-dimensional real choice variable but attention can be restricted to a one-dimensional choice due to production or budget constraints (in our case due to the government's budget constraint), then single-crossing in the Spence-Mirrlees sense implies single-crossing in the Gans-Smart sense.

We therefore use the Spence-Mirrlees single-crossing condition to analyse the existence of a median voter equilibrium. In our simple case of quasilinear preferences, the Spence-Mirrlees condition amounts to $\frac{\partial \tilde{V}(q;\beta_i)}{\partial q}$ being monotonic in β. In the appendix, we prove that $\frac{\partial \tilde{V}(q;\beta_i)}{\partial q \partial \beta} \leq 0$. We can therefore state the following proposition, which holds regardless of whether preferences are single-peaked:

Proposition 4 *Assume that revenue from sin taxes is distributed equally among consumers. A majority voting equilibrium exists and the equilibrium sin tax is given by the tax rate preferred by the consumer with the median level of self-control problems.*

Proof. See the appendix. ■

The result $\frac{\partial \tilde{V}(q;\beta_i)}{\partial q \partial \beta} \leq 0$ implies that an individuals' most preferred tax rate is again monotonically increasing in the level of self-control problems. To gain some intuition on why this holds also when the redistributive effects of sin taxes are taken into account, using equations (15) and (24) (see the appendix), the corrective term in (11) can be written as

$$-(1-\beta_i)\delta h'\left(x^*\left(q;\beta_i\right)\right)\frac{\partial x^*\left(q;\beta_i\right)}{\partial q} = x^*\left(q;\beta_i\right) - x^*(q;1) + \Phi\left(q,\beta_i\right), \tag{12}$$

where $\Phi\left(q,\beta_i\right) = \int_{\beta_i}^{\beta_H}(1-\hat{\beta})\frac{\partial^2 x\left(q;\hat{\beta}\right)}{\partial\widehat{\beta}^2}d\widehat{\beta} > 0$ and $\Phi\left(q,\beta_i\right)$ is increasing in the level of self-control problems (decreasing in β). As expected, the corrective effect of the tax is the larger, the more consumption $x^*\left(q;\beta_i\right)$ differs from the quantity chosen by the rational consumer, $x^*(q;1)$. Further, the magnitude of the corrective effect exceeds the difference $x^*\left(q;\beta_i\right) - x^*(q;1)$. Importantly, the difference between the corrective effect and the monetary cost of the tax is increasing in the level of self-control problems: therefore, relatively irrational individuals prefer a higher tax rate than those who are relatively rational.

To illustrate, consider an example where $v\left(x\right) = \frac{\varepsilon}{\varepsilon-1}x^{\frac{\varepsilon-1}{\varepsilon}}$ and $h\left(x\right) = gx$. With these functional forms and using (3) to express $\beta\delta$ in terms of x^*, the self-control benefit from taxation can be expressed as

$$-(1-\beta_i)\delta h'\left(x^*\left(q;\beta_i\right)\right)\frac{\partial x^*\left(q;\beta_i\right)}{\partial q} = \varepsilon\left(\delta g + q\right)\left(x^*\right)^{\frac{\varepsilon+1}{\varepsilon}} - \varepsilon x^*.$$

It is easy to see from this expression that the self-control benefit increases more than linearly with the quantity consumed, which in turn is an increasing and convex function of self-control problems. Hence the self-control benefits increase more rapidly than monetary costs (which depend linearly on consumption), and the individuals' preferred tax rate is increasing in the level of self-control problems.

The specific functional forms used in the previous example serve to illustrate the mechanism behind Proposition 4. However, the property that self-control benefits increase more rapidly than monetary costs is more general, as Proposition 4 holds for all functional forms that satisfy Assumption 1. The intuition is apparent when we examine the three components that affect the magnitude of self-control benefits: Firstly, the harm function has been assumed to be either linear or convex. Secondly, the sensitivity of demand to tax changes increases with self-control problems. Finally, these two effects are multiplied by the level of self-control problems, $(1-\beta_i)$. Hence, these three forces reinforce each other, causing the self-control benefits to quite generally increase more than linearly in the level of consumption.

It is interesting to note that even in the present case where the optimal level of consumption in the absence of taxes is positive, there may be circumstances under which the redistributive motive for taxation implies that the median voter prefers not to consume in equilibrium, and will vote for the tax rate that maximises revenue. We have shown in the proof of Proposition 4, however, that single-crossing holds regardless of whether the median voter consumes the good in equilibrium or not. Therefore there cannot be situations where a coalition of near-rational users and highly irrational heavy-users vote for highest taxes, and are pitted against voters with an intermediate degree of rationality.[27]

Let us next turn to the comparison between the equilibrium and the optimum. Proposition 4 implies that the equilibrium tax rate is now given by

$$\tau^{**} = \frac{(1-\beta_{med})\delta h'\left(x^*\left(q;\beta_{med}\right)\right)\left|\frac{\partial x^*(q;\beta_{med})}{\partial q}\right| - x^*\left(q;\beta_{med}\right) + E_\beta\left[x^*\left(q;\beta\right)\right]}{\left|\frac{\partial E_\beta[x^*(q;\beta)]}{\partial q}\right|}. \tag{13}$$

The term $E_\beta\left[x^*\left(q;\beta\right)\right] - x^*\left(q;\beta_{med}\right)$ in the above formula captures the fact that if $x^*\left(q;\beta_{med}\right) < E_\beta\left[x^*\left(q;\beta\right)\right]$, sin taxes imply a transfer of income towards the median voter. This will typically occur if the distribution of β is skewed to the left so that $\beta_{med} > E\left[\beta\right]$ (though it can also occur in other cases, depending on the exact functional form of x^*). In such circumstances, the median voter then tends to vote for a higher tax than he would in the absence of redistribution.

Also notice that, like the social planner, the median voter now cares about how much a price change affects his own consumption and the choices made by others (the terms $\left|\frac{\partial x^*(q;\beta_{med})}{\partial q}\right|$ and $\left|\frac{\partial E_\beta[x^*(q;\beta)]}{\partial q}\right|$). These mechanisms contribute to aligning the incentives of the median voter with the objectives of the utilitarian social planner.

When harmful health effects are mild, the mechanism based on transfers works remarkably well. To see this, let $h\left(x\right) = \gamma g\left(x\right)$, where $g' >,\ g'' \geq 0$ and γ is a parameter measuring the severity of harm from consumption. Using second-order Taylor approximations around $\gamma = 0,\ \tau = 0$, we show in the appendix that the following proposition holds:

[27] It appears that this property might be related to our assumption of quasilinear preferences, and the implied zero income elasticity of demand for good x. Whether more general assumptions about preferences can give rise to voting coalitions where highly irrational consumers and fully rational consumers vote for higher taxes than consumers with an intermediate level of rationality, is left as a question for further research. See Epple and Romano (1996) for an analysis - albeit in a very different context - where the preferred level of public expenditure and taxation is non-monotonic in consumer type (in their case income) when the income elasticity of demand exceeds the (absolute value of the) price elasticity.

Proposition 5 *Assume that revenue from sin taxes is distributed equally among consumers. Let* $h(x) = \gamma g(x)$, *where* $g' > 0$, $g'' \geq 0$, *and assume that* γ *is small. (i) The difference between the socially optimal tax and the tax chosen in the political equilibrium is of the second order (i.e. proportional to* γ^2*), whereas the tax rates themselves are of the first order (i.e. they depend on* γ*). (ii) When the distribution of* β *is not too much skewed to the right, the socially optimal tax rate is higher than the tax rate chosen in a majority voting equilibrium.The difference between the tax rates is increasing in* γ.

Proof. See the appendix. ■

The first lesson from the above proposition is that for small levels of harm, the difference between the equilibrium and the socially optimal tax rate ($\tau^{**} - \tau^o$) is small, both in absolute terms and compared to the level of taxes. Note that this result holds regardless of the distribution of self-control problems; in particular, it holds even when the median voter is fully rational, and any sin taxes distort his consumption choices[28]. In sum, when health effects are mild, the model predicts that actual sin taxes should largely correspond to optimal sin taxes. In the appendix, we also contrast this result to the benchmark case where sin taxes have no redistribute effects: in that case, the difference between the equilibrium and the social optimum ($\tau^* - \tau^o$) is of the first order as long as $E[\beta] \neq \beta_{med}$. In particular, if the median voter is nearly rational ($\beta_{med} \approx 1$), τ^* can be many times smaller than the socially optimal tax τ^o. These results are illustrated in Figures 1, 2 and 3.

Thus, under certain circumstances, a simple mechanism consisting of a linear sin tax and a uniform transfer, can do a good job in inducing the median voter to internalise both the self-control gains accruing to irrational heavy users, and the welfare losses incurred by rational consumers, whose choices are distorted. The key to this result lies in the fact that the level of consumption is correlated with the degree of self-control problems. Above in Section 3 we saw that this correlation affects the level of the socially optimal tax. Given this correlation, there is also a relation between a consumer's self-control gain from sin taxes, and the net transfer he receives, or pays. For example,

[28] Interestingly, at mild levels of harm, the equilibrium tax is close to the second-best optimal level, even when people are naive, and are not aware of their future self-control problems. Then the median voter - and indeed all voters - casts his vote believing that in the future he will not need sin taxes as a commitment device (i.e. $\beta = 1$ in all future periods). But at the same time he also thinks that he will be at the receiving end of net transfers - a reason to vote for higher taxes. These two mistakes made by the median voter cancel each other out. To get this result, we need to assume that the median voter's delusion only concerns his own future self-control: the voter does not think that other people will overcome their self-control problems, and thus he is aware of the true relation between tax rates and tax revenues.

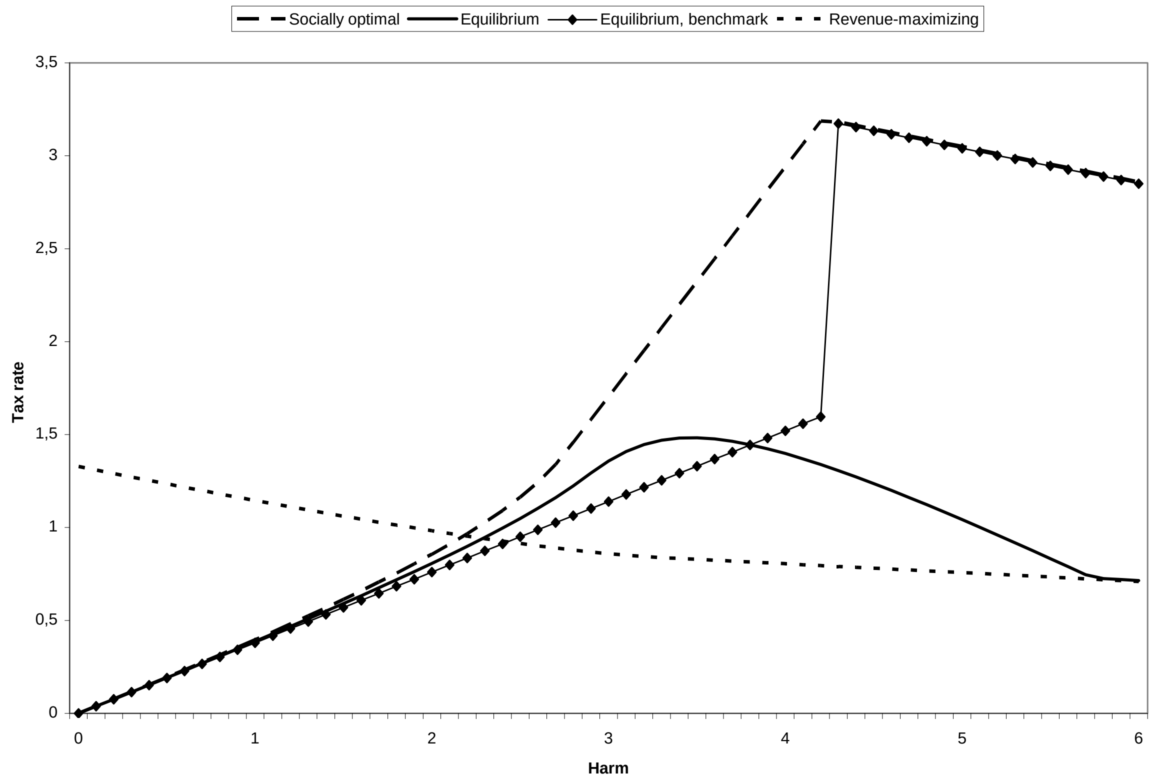

Figure 1: Sin taxes, when $v(x) = Lx - \frac{\sigma}{\sigma+1}x^{\frac{\sigma+1}{\sigma}}$, $h(x) = \gamma x$, and $x_i = x(q;\beta_i) = (\max\{0, (L - q - \gamma\delta\beta_i)\})^{\sigma}$. We adopt the parameter values $L = 5$, $\sigma = 2$, $\delta = 0.95$, while harm, γ, varies between 0 and 6 (horizontal axis). We assume that β is uniformly distributed over $[0.2, 1]$, so that $\beta_{med} = E[\beta]$. Notice that while $\left|\frac{\partial x}{\partial q}\right| = \sigma x_i^{\frac{\sigma-1}{\sigma}}$ is increasing in the level of consumption, the price elasticity $|\eta| = \left|\frac{\partial x}{\partial q}\right| \frac{q}{x} = \sigma q x_i^{-\frac{1}{\sigma}}$ is lower for heavy-users than for moderate consumers. Also notice that no-one should consume the sin good, if $\gamma > (L-1)/\delta = 4.22$.

assume that the median level of self-control problems β_{med} differs considerably from the average level $E[\beta]$. Then the median self-control gain tends to differ considerably from the average gain in the population, but also the net transfer received - or paid - by the median voter will be larger.

Nevertheless, the second part of the above proposition shows that the mechanism that helps to align the incentives of the median voter with the objectives of the utilitarian planner, is not perfect: as in the benchmark case studied in Section 4.1, the equilibrium tax tends to be lower than the socially optimal tax. While small at low levels of harm, we have shown in the appendix that this bias becomes more pronounced as the detrimental health effects grow. To understand this result, remember the discussion

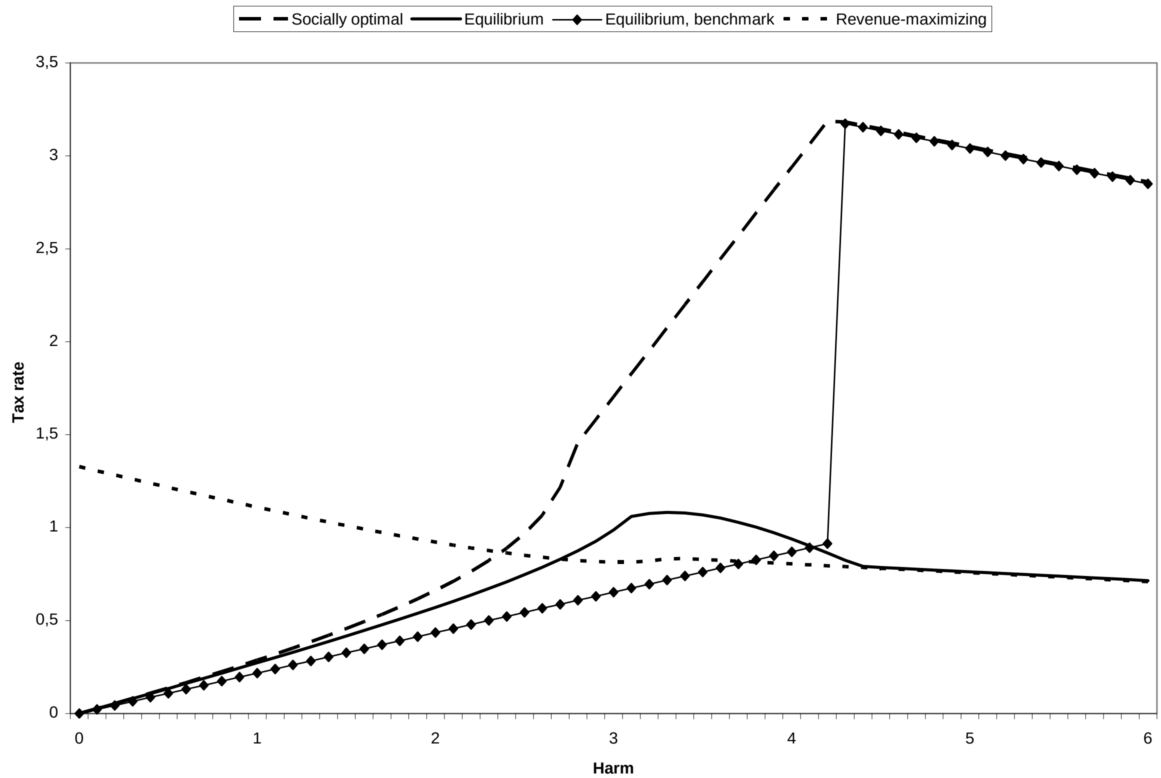

Figure 2: Sin taxes, when 30% of the consumers have no self-control problems ($\beta = 1$), while among the remaining consumers β is uniformly distributed over $[0.2, 1]$; the distribution is left-skewed, with $\beta_{med} > E[\beta]$. Other specifications as in Figure 1.

after Proposition 4 above, of how and why the self-control benefits typically increase more than linearly in consumption. Looking at equation (12), the transfers induce the median voter to internalise the part of self-control benefits that is linear in consumption $(x^*(q;\beta_i) - x^*(q;1))$; in contrast the non-linear part is not fully internalised.[29]

To put it slightly differently, we saw in Section 4.1 (see Proposition 2 and the discussion thereafter), that there are two factors that tend to make the equilibrium tax τ^* lower than the socially optimal tax τ^o. First, the equilibrium tax rate falls below the social optimum in particular if the median voter is relatively rational ($\beta_{med} > E[\beta]$). The discrepancy between the tax rates chosen by the median voter and the utilitarian social planner will be the larger, the more β_{med} differs from $E[\beta]$. Second, sin taxes have a larger effect on irrational heavy-users than on (nearly) rational consumers. Transfers

[29] Note that if we were to have a system whereby subsidies decrease more than linearly with consumption (i.e. increase with the degree of rationality), we would likely get closer to the social optimum. However, implementing such a scheme would require personalised subsidies and therefore each consumer's type would have to be observable to the authorities. See also the discussion in Section 5.

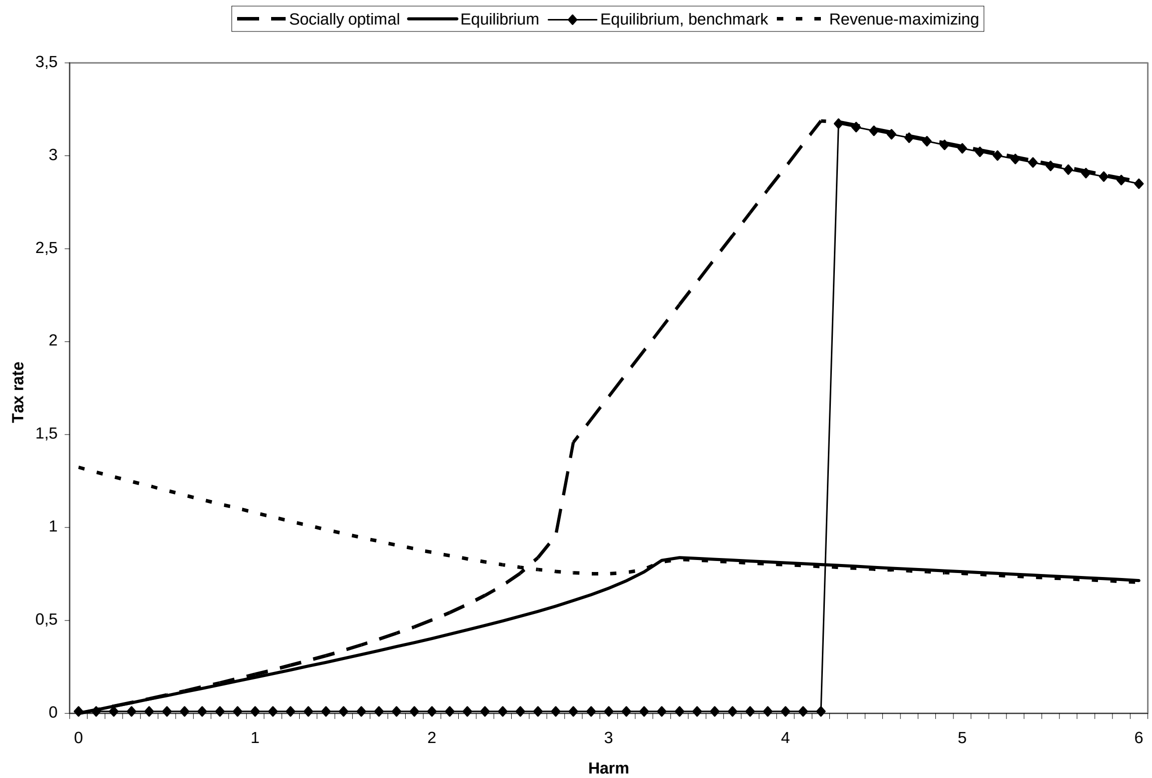

Figure 3: Sin taxes, when 50% of the consumers have no self-control problems ($\beta = 1$), while among the remaining consumers β is uniformly distributed over $[0.2, 1]$. Notice that $\beta_{med} = 1$, so that the median voter has no self-control problems. Other specifications as in Figure 1.

induce the median voter to internalise the first factor: if β_{med} differs considerably from $E[\beta]$, also the net transfer will be large. However, due to the asymmetric effects of taxes at the opposite ends of the distribution, the self-control benefit increases more than linearly in consumption. This part is not internalised by the median voter.

The second part of Proposition 5 again holds if the distribution of β is not too much skewed to the right. In order to gain a more concrete feel of the difference between optimal and equilibrium taxes, the tax formulas can be written in terms of the distribution of consumption - the relevant formulas are given in the appendix. This exercise is useful, since the distribution of consumption is observable, while the distribution of self-control problems is not. The formulas in the appendix could thus be used to take the model to real consumption data, and to examine the implications of the model empirically. In the appendix, we show how the difference between τ^{**} and τ^{o} depends on the distribution of x^{*} and on the elasticity of demand. For instance, it can be noted that the equilibrium tax τ^{**} is below the socially optimal level τ^o, if average consumption $\overline{x}^*$ exceeds median consumption x^*_{med}. Note that in the case of tobacco, the median consumer abstains from consumption. Also in the case of alcohol, the median level of consumption is typically much lower than the average - see for example the evidence reported in Manning *et al.* (1995), where the mean consumption of alcohol is six times the median. Also, the larger the variance in consumption, the more the equilibrium rate will fall short of the socially optimal rate.

Even when the second-order Taylor approximations used in deriving the previous proposition are not valid, we can show that the equilibrium tax rate is below the socially optimal level, when certain conditions are met:

Proposition 6 *Assume that revenue from sin taxes is distributed equally among consumers. If (i)* $(1-\beta)\frac{\partial^2 x(q;\beta)}{\partial \beta^2}$ *is non-increasing in* β*, (ii)* $\frac{\partial x}{\partial q} \to 0$*, when* $x \to 0$*, and (iii) the distribution of* β *is not too much skewed to the right, the socially optimal tax rate is higher than the tax rate chosen in a majority voting equilibrium.*

Proof. See the appendix. ■

In the appendix, we show that if $(1-\beta)\frac{\partial^2 x(q;\beta)}{\partial \beta^2}$ is non-increasing in β, the derivative (11) is not only increasing, but also a convex function of the level of self-control problems. The result therefore again has a very intuitive explanation: the convexity of (11) implies that the marginal welfare benefit of high taxation for relatively irrational individuals is higher than the corresponding welfare loss for close to rational individuals. The condition that $(1-\beta)\frac{\partial^2 x(q;\beta)}{\partial \beta^2}$ should be non-increasing in β again holds for many commonly used functional forms, for example when v is of the CRRA or CARA-variety or quadratic, and when the harm function is linear or $h(x) = x^s$ where $s \geq 2$.

Further, in order to interpret the condition that $(1-\beta)\frac{\partial^2 x(q;\beta)}{\partial \beta^2}$ should be non-increasing in β, we show in the appendix that this holds (approximately) if a price change affects the health of irrational consumers (heavy users) more than the health of rational consumers. This holds given Assumption 1.

Condition (ii) in the proposition is needed if some individuals abstain from consumption. The condition stipulates that, despite the possibility of abstention, the derivative (11) is continuous, both in terms of the price q, and in terms of self-control problems β.

Propositions 5 and 6 show that despite the fact that high sin taxes result in a transfer of income towards the median voter, the equilibrium tax rate is typically lower than the socially optimal tax. Even though we argued above that the transfer mechanism works well when harm from consumption is low, the income transfer is in general not sufficient for the median voter to fully internalise the benefit that would accrue to highly irrational individuals, if the tax rate was increased. It seems particularly noteworthy that the difference becomes more pronounced when harm from consumption increases. See again Figures 1, 2 and 3 for an illustration.

One force that tends to make the equilibrium tax fall below the optimum at high levels of harm is the fact that when consumption is highly harmful, the median voter consumes very little of the good and therefore is mainly interested in maximising tax revenue in order to maximise redistribution from more irrational individuals towards himself. The socially optimal tax on the other hand will be high, and will likely exceed the revenue maximising tax: At high levels of harm, the sin tax tends to have only a very small effect on the consumption choices made by (nearly) rational individuals - the lower bound for consumption is zero - and the social planner's objective essentially boils down to correcting mistakes made by consumers with severe self-control problems. A polar case is the one where consumption is so harmful that no-one should consume the good in equilibrium, and the socially optimal tax is therefore so high that tax revenue will be zero. Below, we show that in this case the equilibrium tax rate is too low under very mild conditions.

4.2.2 The case of very harmful consumption

Consider again the case where consumption is so harmful that at zero taxes, the optimal choice is to abstain from consuming the commodity x. The (minimum) tax rate (τ^o) needed to implement the social optimum is then given by (10).

The condition for the result $\tau^{**} < \tau^o$ to hold in this case is especially mild, namely that β_{med} does not coincide with the lowest level of β. Further it is important to note that this result does not depend on Assumption 1, but holds for any functional forms of $v(x)$ and $h(x)$, such that $v', h' > 0$, $v'' < 0$ and $h'' \geq 0$:

Proposition 7 *Assume that revenue from sin taxes is distributed equally among consumers and consumption is so harmful that the optimal level of consumption at zero taxes is zero. Then, for any distribution of self-control problems where $\beta_{med} > \beta_L$, the socially optimal tax rate is higher than the tax rate chosen in a majority voting equilibrium.*

Proof. Since no-one consumes at $\tau = \tau^o$, no tax revenues are collected in the social optimum. Suppose that, starting from $\tau = \tau^o$, the tax rate is lowered by a small amount $d\tau$. Then the least rational individuals (β_L), who were just indifferent between consuming and not consuming, are triggered to consume a small amount

$$x(\beta_L; \tau^o - d\tau) = -\frac{d\tau}{v''(0) + \beta_L \delta h''(0)} > 0.$$

Also, tax revenues increase from zero to $-\frac{\tau^o d\tau}{v''(0)+\beta_L \delta h''(0)} dF(\beta_L) > 0$. Consumers other than type β_L still consume no x, and the welfare of this majority group increases, due to transfers from type β_L. The redistributive motive for taxation then implies that the level of taxes that eliminates all consumption cannot arise as a political equilibrium. ■

5 Discussion

The current paper has analysed how linear sin taxes and transfers can be used to address distortions in the consumption of goods with delayed negative effects when consumers have time-inconsistent preferences. Concentrating on linear taxation and lump-sum transfers is in line with most of the previous literature on sin taxes. One simple reason for this focus is that linear taxes and lump-sum transfers are easily implementable. Further, as our focus is on political economy and therefore on understanding existing tax systems, concentrating on linear taxation seems particularly warranted (as tobacco and alcohol taxes that we observe in reality are linear).

When the consumption decisions of different individuals are subject to different distortions, the first-best could in principle be achieved through personalised taxation. This would however require that personal consumption levels are observable to the authorities. As the assumption of observable individual consumption levels is in most situations untenable, not only the literature on sin taxes but also the previous literature on optimal taxation more generally has been restricted to the case where commodity taxation is assumed to be linear (see for example Cremer *et al.* 2001).

Assume, for instance, that we wished to implement a system where consumers with a high level of self-control problems face higher taxes than consumers with low self-control problems. This scheme is however subject to a similar objection as systems involving first degree price discrimination more generally: ex post there would be incentives to create a secondary market, where individuals with serious self-control problems buy the sin good from individuals with mild self-control problems. Further, in this situation it is not clear whether individuals have the right incentives even ex ante: it may be profitable to understate one's level of self-control problem in order to obtain a low tax, and then make a profit by re-selling some of the sin good in the future. Also social networks can undo the effects of personalised sin taxes: Ex post there are incentives to ask a friend or a family member with a lower tax rate to do the shopping.

Recently, Cowell (2009) has discussed the possibility of using smart cards to circumvent the information constraints in the implementation of non-linear commodity taxation. Considering the particular case of sin goods, O'Donoghue and Rabin (2005) discuss the possibility of using sin licenses that individuals can purchase in order to commit themselves to a given level of consumption in the future. However, for this mechanism to work, re-selling the sin licences as well as the sin good itself would again have to somehow be prohibited. The design and implementation of optimal screening mechanisms to alleviate the distortions caused by time-inconsistent preferences is an interesting issue for further research.

Another very interesting question for future research would be to analyse whether quantity restrictions can do better than taxation in regulating the consumption of harmful goods. Our analysis appears to provide an argument for quantity restrictions on the consumption of certain highly harmful substances (such as illicit drugs), as the discrepancy between the optimum and equilibrium taxes is particularly stark in this case and consumption will be suboptimally high. However, if re-selling the sin good is possible, it seems that optimal quantity restrictions may not be implementable through the political process either: relatively rational individuals may then have an incentive to vote for a quantity restriction that is too loose from the social point of view, as they can later make a profit on re-selling the good to individuals with self-control problems. A full analysis of quantity vs. price regulation of the consumption of harmful goods, as well as other possible regulatory mechanisms such as advertising bans, is left as an issue for further research.

Finally, a central issue in previous literature on corrective taxation has been the question of how optimal taxes are affected when taxation not only has a corrective role, but taxes are also used to finance public expenditure - see e.g. Bovenberg and de Mooij (1994) on taxation in the presence of externalities and O'Donoghue and Rabin (2006) for a short comment on this issue in the context of sin taxes. In an earlier version of the paper (Haavio and Kotakorpi 2007) we have shown that our analysis generalises to the case where sin taxes are also used for revenue raising purposes: it can be shown that a result similar to proposition 6 holds also in this case, and equilibrium taxes therefore tend to be lower than optimal taxes. Perhaps surprisingly, the result regarding the comparison between τ^* and τ^o holds both when tax revenue is used to finance public expenditure, as well as in the case where a part of tax revenue is wasted (for example due to administrative costs).

6 Conclusions

We have shown that optimal sin taxes will typically exceed the average distortion caused by self-control problems in the economy: this result arises due to the asymmetric effects of sin taxes on the welfare of those with severe self-control problems on the one hand, and on (close to) rational individuals on the other hand. We have argued that under reasonable assumptions, the demand of irrational large-scale consumers is (in absolute terms) more responsive to taxation than the demand of rational individuals with a low level of consumption. Therefore, the positive welfare effect of taxation on irrational consumers typically exceeds the negative impact on rational consumers. The median voter, however, does not take such asymmetries into account. There is therefore a bias in voting behaviour, which implies that the sin tax chosen in a majority voting equilibrium tends to be below the socially optimal level.

When harmful health effects are mild, the redistributive effects of sin taxes work rather well in aligning the median voters' preferences with those of the utilitarian social planner, and the difference between the equilibrium and the social optimum tends to be small. However, this mechanism works well only at low levels of harm, and the difference between the equilibrium and the optimum becomes more pronounced when consumption is more harmful. In cases where consumption is extremely harmful, the redistributive effects of sin taxes in fact contribute towards a more severe divergence between the equilibrium and the optimum: The median voter then consumes very little (or none) of the good in question, and is therefore mainly interested in maximising tax revenue in order to maximise redistribution from more irrational individuals towards himself. The socially optimal tax on the other hand will be very high, and will be likely to exceed the revenue maximising tax in such circumstances.

The view that emerges from previous empirical literature seems to be that for example excise duties on cigarettes are in most countries very high compared to the external costs of smoking. However, the present analysis provides a theoretical argument suggesting that such taxes may nevertheless be too low from a social point of view.

Finally, it should be noted that throughout the analysis, we have assumed that individuals are sophisticated - that is, they are fully aware of their self-control problem. Individuals thus value sin taxes as a self-control device, and vote for positive taxes.

However, if some individuals are partially naive, their preferred tax rate will be lower than the level indicated by our results. In the case where some individuals are either partially or fully naive, therefore, the problem of sub-optimally low equilibrium taxes would be exacerbated.

Appendix

Preliminaries

The following derivatives are used a number of times in the analysis:

$$\frac{\partial x^*(q,\beta)}{\partial q} = \frac{1}{v''(x^*) - \beta\delta h''(x^*)} < 0.$$

$$\frac{\partial x^*(q,\beta)}{\partial \beta} = \frac{\delta h'(x^*)}{v''(x^*) - \beta\delta h''(x^*)} < 0 \tag{14}$$

Given these results, the corrective effect of taxation can be written as

$$-(1-\beta_i)\delta h'(x^*(q;\beta_i))\frac{\partial x^*(q;\beta_i)}{\partial q} = -(1-\beta_i)\frac{\partial x^*(q;\beta_i)}{\partial \beta}. \tag{15}$$

Proof of Proposition 1

Since $E_\beta\left[\frac{\partial x^*}{\partial q}\right] < 0$, $\tau^o > \delta E_\beta\left[(1-\beta)h'(x^*(q;\beta))\right]$ if $Cov_\beta\left[(1-\beta)h'(x^*), \frac{\partial x^*}{\partial q}\right] < 0$. When $h''(x) \geq 0$, $(1-\beta)h'(x^*(q;\beta))$ is decreasing in β. Therefore, $Cov_\beta\left[(1-\beta)h'(x^*), \frac{dx^*}{dq}\right] < 0$ if $\frac{\partial^2 x^*(q;\beta)}{\partial q\partial\beta} > 0$. This derivative is given by

$$\frac{\partial^2 x^*(q;\beta)}{\partial q\partial\beta} = \frac{-\left[v'''(x^*) - \beta\delta h'''(x^*)\right]\frac{\partial x^*}{\partial\beta} + \delta h''(x^*)}{\left[v''(x^*) - \beta\delta h''(x^*)\right]^2}.$$

It can be shown that $\frac{\partial^2 x^*(q;\beta)}{\partial q\partial\beta} > 0$ if (sufficient conditions) $v'''(x) \geq 0$ and

$$\frac{h'''(x)h'(x)}{\left[h''(x)\right]^2} < \frac{\beta\delta h''(x) - v''(x)}{\beta\delta h''(x)}.$$

Clearly $\frac{\beta\delta h''(x) - v''(x)}{\beta\delta h''(x)} > 1$. Thus the above condition is less demanding than

$$\frac{h'''(x)h'(x)}{\left[h''(x)\right]^2} \leq 1.$$

Proof of Proposition 2

In this proof, we first show that the policy preference function (6) is single-peaked. Secondly, we show that the right hand side of (5) is larger than the right hand side of (9). Thirdly, we derive a condition that guarantees $\frac{dW(q)}{dq} - \frac{\partial V(q;\beta_{med})}{\partial q} \geq 0$. Finally, we interpret this condition, and use an approximation to show that it holds in our model.

(i) To prove that (6) is single-peaked, we have to show that $\frac{\partial^2 V(q;\beta)}{\partial q^2} < 0$, whenever $\frac{\partial V(q;\beta)}{\partial q} = 0$: the non-existence of interior minima implies single-peakedness. To show that $\frac{\partial^2 V(q;\beta)}{\partial q^2} < 0$ when $\frac{\partial V(q;\beta)}{\partial q}$, first remember that

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

Then clearly

$$\begin{aligned} \frac{\partial^2 V(q;\beta)}{\partial q^2} &= \left[v''\left(x^*(q;\beta)\right) - \delta h''\left(x^*(q;\beta)\right)\right] \left(\frac{\partial x^*(q;\beta)}{\partial q}\right)^2 \\ &\quad + \left[v'\left(x^*(q;\beta)\right) - \delta h'\left(x^*(q;\beta)\right) - 1\right] \frac{\partial^2 x^*(q;\beta)}{\partial q^2}. \end{aligned} \tag{16}$$

But when $\frac{\partial^2 V(q;\beta)}{\partial q^2} = 0$, $\quad v'\left(x^*(q;\beta)\right) - \delta h'\left(x^*(q;\beta)\right) - 1 = 0$, and the second term in (16) vanishes. Thus

$$\frac{\partial^2 V(q;\beta)}{\partial q^2} = \left[v''\left(x^*(q;\beta)\right) - \delta h''\left(x^*(q;\beta)\right)\right] \left(\frac{\partial x^*(q;\beta)}{\partial q}\right)^2 < 0,$$

when $\frac{\partial V(q;\beta)}{\partial q} = 0$.

(ii) In the text we show that the proposition holds for a linear $h(x)$. If $h(x)$ is not linear, then

$$E_\beta\left[(1-\beta)\,h'\left(x^*(q;\beta)\right)\right] \neq (1-\beta_{med})\,h'\left(x^*(q;\beta_{med})\right)$$

even if $\beta_{med} = E[\beta]$. In particular, if $\xi(\beta) = (1-\beta)\,h'\left(x^*(q;\beta)\right)$ is a convex function of β, then the Jensen inequality implies that

$$E_\beta\left[(1-\beta)\,h'\left(x^*(q;\beta)\right)\right] > (1-E[\beta])\,h'\left(x^*(q;E[\beta])\right).$$

We therefore need to show that $\frac{d^2\xi(\beta)}{d\beta^2} > 0$. Now

$$\frac{d^2\xi(\beta)}{d\beta^2} = \left[(1-\beta)\frac{\partial^2 x^*}{\partial\beta^2} - 2\frac{\partial x^*}{\partial\beta}\right] h''(x^*) + (1-\beta)h'''(x^*)\left(\frac{\partial x^*}{\partial\beta}\right)^2.$$

It can be shown that $\frac{d^2\xi(\beta)}{d\beta^2} > 0$ if $v'''(x) \geq 0$ and

$$\frac{h'''(x)\, h'(x)}{\left[h''(x)\right]^2} > -2\frac{v''(x^*) - \beta\delta h''(x^*)}{v''(x^*)}\frac{\delta h''(x^*) - v''(x^*)}{\delta h''(x^*)}. \tag{17}$$

Clearly, $\frac{v''(x^*)-\beta\delta h''(x^*)}{v''(x^*)}\frac{\delta h''(x^*)-v''(x^*)}{\delta h''(x^*)} > 1$, and thus the condition (17) is less demanding than

$$\frac{h'''(x)\, h'(x)}{\left[h''(x)\right]^2} \geq -2. \tag{18}$$

.

Therefore $\xi(\beta) = (1-\beta)\, h'(x^*)$ is a convex function of β if $v'''(x) \geq 0$ and (18) holds (sufficient conditions). The condition (18) essentially states that $h'''(x)$ should not be too small, or equivalently, $h'(x)$ should not be too concave: harm and therefore also self-control benefits from consumption depend on $h'(x)$. Excessive concavity of $h'(x)$ might thus offset the effect of increasing sensitivity to taxation as self-control problems get worse.

(iii) Next, we show that $\frac{dW(q)}{dq} - \frac{\partial V(q;\beta_{med})}{\partial q} \geq 0$ for all $q \leq 1+\tau^*$. For the remaining proofs, we find if useful to adopt the notation

$$\rho \equiv 1-\beta,$$

where ρ measures the degree of self-control problems directly: for fully rational consumers $\rho = 0$, and for fully myopic consumers $\rho = 1$.

Using (15), $\frac{\partial V(q;\rho)}{\partial q}$ can therefore be written as

$$\begin{aligned}\frac{\partial V(q;\rho)}{\partial q} &= \left[\tau - \rho\delta h'(x^*(q;\rho))\right]\frac{\partial x^*(q;\rho)}{\partial q} = \tau\frac{\partial x^*(q;\rho)}{\partial q} + \rho\frac{\partial x^*(q;\rho)}{\partial \rho} \\ &= \frac{\partial V(q;\rho_L)}{\partial q} + \int_{\rho_L}^{\rho}\left[\tau\frac{\partial^2 x^*(q;\widehat{\rho})}{\partial q\partial\widehat{\rho}} + \widehat{\rho}\frac{\partial^2 x^*(q;\widehat{\rho})}{\partial\widehat{\rho}^2} + \frac{\partial x^*(q;\widehat{\rho})}{\partial\widehat{\rho}}\right] d\widehat{\rho}.\end{aligned}$$

Adopting the notation

$$\Psi(q,\rho) = \tau\frac{\partial^2 x^*(q;\rho)}{\partial q\partial\rho} + \rho\frac{\partial^2 x^*(q;\rho)}{\partial\rho^2} + \frac{\partial x^*(q;\rho)}{\partial\rho}, \tag{19}$$

we know that $\frac{\partial V(q;\rho)}{\partial q}$ is a convex function of ρ if

$$\frac{\partial \Psi\left(q,\rho\right)}{\partial \rho} \geq 0. \tag{20}$$

Given this convexity, $E_\rho\left[\frac{\partial V(q;\rho)}{\partial q}\right] > \frac{\partial V(q;E[\rho])}{\partial q}$ for all q. Also, since $\frac{\partial^2 V(q;\rho)}{\partial q \partial \rho} > 0$, we can conclude that $\frac{dW(q)}{dq} = E_\rho\left[\frac{\partial V(q;\rho)}{\partial q}\right] > \frac{\partial V(q;\rho_{med})}{\partial q}$,if

$$\rho_{med} \leq E\left[\rho\right]. \tag{21}$$

Therefore the equilibrium tax is lower than the socially optimal tax if (20) and (21) hold (sufficient conditions).

Next, we proceed to interpreting condition (20). First note that (15) implies that

$$\frac{\partial x^*\left(q;\rho\right)}{\partial \rho} = -\delta \frac{\partial h\left(x^*\left(q;\rho\right)\right)}{\partial q}. \tag{22}$$

This is the effect of a price change on health. First-order Taylor series approximation with respect to ρ and q yields

$$\frac{\partial x^*\left(q;\rho\right)}{\partial \rho} \simeq \frac{\partial x^*\left(1;0\right)}{\partial \rho} + \rho \frac{\partial^2 x^*\left(q;\rho\right)}{\partial \rho^2} + \tau \frac{\partial^2 x^*\left(q;\rho\right)}{\partial \rho \partial q}$$

(note that the derivatives are evaluated at (q,ρ)). Solving the above expression for $\tau \frac{\partial x^*(q;\rho)}{\partial \rho \partial q}$ and substituting into (19) yields

$$\Psi\left(q,\rho\right) \simeq 2\frac{\partial x^*\left(q;\rho\right)}{\partial \rho} - \frac{\partial x^*\left(1;0\right)}{\partial \rho}.$$

The second term in this expression is a constant. Therefore, $\Psi\left(q,\rho\right)$ is increasing in ρ, if $\frac{\partial x^*(q;\rho)}{\partial \rho}$ is increasing in ρ. Condition (20) therefore states that a price change affects the health of irrational consumers (heavy users) more than the health of rational consumers. Finally, we can check that this holds in our model:

$$\frac{\partial\left(-\delta \frac{dh(x(q;\rho))}{dq}\right)}{\partial \rho} = -\delta\left[h''\left(x\left(q;\rho\right)\right)\frac{\partial x\left(q;\rho\right)}{\partial q}\frac{\partial x\left(q;\rho\right)}{\partial \rho} + h'\left(x\left(q;\rho\right)\right)\frac{\partial^2 x\left(q;\rho\right)}{\partial q \partial \rho}\right] > 0.$$

The inequality follows from Assumption 1, which implies that $\frac{\partial^2 x(q;\rho)}{\partial q \partial \rho} < 0$.

Even when the rational level of consumption at zero taxes x^o is positive, some people may abstain when a positive sin tax is set. Next we show that, if condition (20) is satisfied, $W(q) > \frac{\partial V(q;\rho_{med})}{\partial q}$ even in this case. Assume that at price level q consumers with $\rho \leq \widetilde{\rho}(q)$ abstain, where the critical level of self-control problems $\widetilde{\rho}(q)$ is given by $v'(0) - q - (1 - \widetilde{\rho}(q))\,\delta h'(0) = 0$. Clearly $\widetilde{\rho}(q) < \rho_{med}$ at tax rates $\tau \leq \tau^*$. Then

$$\frac{\partial V(q;\rho)}{\partial q} = \begin{cases} [\tau - \rho\delta h'(x^*(q;\rho))] \frac{\partial x^*(q;\rho)}{\partial q} & \text{for } \rho > \widetilde{\rho}(q) \\ 0 & \text{for } \rho \leq \widetilde{\rho}(q) \end{cases}.$$

Next, clearly $\tau - \widetilde{\rho}(q)\,\delta h'(x^*(q;\rho)) > 0$: since type $\widetilde{\rho}(q)$ abstains, the actual tax rate is evidently higher than his preferred tax rate. As a consequence there may be a discontinuity at $\rho = \widetilde{\rho}(q)$:

$$0 = \lim_{\rho \to \widetilde{\rho}(q)^-} \frac{\partial V(q;\rho)}{\partial q} \geq \lim_{\rho \to \widetilde{\rho}(q)^+} \frac{\partial V(q;\rho)}{\partial q} = \lim_{\rho \to \widetilde{\rho}(q)^+} [\tau - \rho\delta h'(x^*(q;\rho))] \frac{\partial x^*(q;\rho)}{\partial q},$$

where strict inequality holds if $\lim_{\rho \to \widetilde{\rho}(q)^+} \frac{\partial x^*(q;\rho)}{\partial q} < 0$. Next, define the function

$$\frac{\partial \widehat{V}(q;\rho)}{\partial q} = \begin{cases} \frac{\partial V(q;\rho)}{\partial q} & \text{for } \rho > \widetilde{\rho}(q) \\ \lim_{\rho \to \widetilde{\rho}(q)^+} [\tau - \rho\delta h'(x^*(q;\rho))] \frac{\partial x^*(q;\rho)}{\partial q} & \text{for } \rho \leq \widetilde{\rho}(q) \end{cases}$$

Clearly, $\frac{\partial \widehat{V}(q;\rho)}{\partial q}$ is continuous in ρ; moreover $\frac{\partial \widehat{V}(q;\rho)}{\partial q}$ is constant over the range $\rho \in [\rho_L, \widetilde{\rho}(q)]$, and it is increasing and convex (if the condition (20) applies) in ρ, when $\rho > \widetilde{\rho}(q)$. Given these properties, $E_\rho\left[\frac{\partial \widehat{V}(q;\rho)}{\partial q}\right] > \frac{\partial \widehat{V}(q;E[\rho])}{\partial q}$. Thus $E_\rho\left[\frac{\partial \widehat{V}(q;\rho)}{\partial q}\right] > \frac{\partial \widehat{V}(q;\rho_{med})}{\partial q} = \frac{\partial V(q;\rho_{med})}{\partial q}$, if $\rho_{med} \leq E[\rho]$. Finally since $\frac{\partial V(q;\rho_{med})}{\partial q} \geq \frac{\partial \widehat{V}(q;\rho_{med})}{\partial q}$ for all ρ,

$$W(q) = E_\rho\left[\frac{\partial V(q;\rho_{med})}{\partial q}\right] > \frac{\partial V(q;\rho_{med})}{\partial q} \tag{23}$$

for all $\tau \leq \tau^*$ if condition (20) is satisfied and $\rho_{med} \leq E[\rho]$. The inequality (23) may hold even when $\rho_{med} > E[\rho]$.

Proof of Proposition 4

To prove the existence of a majority voting equilibrium, we have to show that the Spence-Mirrlees single-crossing condition is satisfied. Since we assume quasi-linear preferences this reduces to showing that $\frac{\partial \tilde{V}(q;\rho)}{\partial q}$ is monotonic in ρ.

The effect of a marginal tax change on the welfare of type ρ is now given by (11).

Note that

$$x(q;\rho) = x(q;\rho_L) + \int_{\rho_L}^{\rho} \frac{\partial x(q;\widehat{\rho})}{\partial \widehat{\rho}} d\widehat{\rho} = x(q;\rho_L) + \rho \frac{\partial x(q;\rho)}{\partial \rho} - \rho_L \frac{\partial x(q;\rho_L)}{\partial \rho} - \int_{\rho_L}^{\rho} \widehat{\rho} \frac{\partial^2 x(q;\widehat{\rho})}{\partial \widehat{\rho}^2} d\widehat{\rho}. \tag{24}$$

Substituting (15) and (24) into (11) shows that

$$\frac{\partial \tilde{V}(q;\rho)}{\partial q} = \frac{\partial \tilde{V}(q;\rho_L)}{\partial q} + \int_{\rho_L}^{\rho} \widehat{\rho} \frac{\partial^2 x(q;\widehat{\rho})}{\partial \widehat{\rho}^2} d\widehat{\rho}. \tag{25}$$

Differentiating with respect to ρ yields

$$\frac{\partial^2 \tilde{V}(q;\rho)}{\partial q \partial \rho} = \rho \frac{\partial^2 x(q;\rho)}{\partial \rho^2} \geq 0. \tag{26}$$

Notice that these results hold even when some individuals do not consume in equilibrium, that is, $x(q;\rho) = 0$ for $\rho \in [\rho_L, \widetilde{\rho}(q)]$, where $\widetilde{\rho}(q)$ is given by $v'(0) - (1-\widetilde{\rho}(q))\delta h'(0) - q = 0$. Then

$$\frac{\partial \tilde{V}(q;\rho)}{\partial q} = \frac{\partial \tilde{V}(q;\rho_L)}{\partial q} = E_\rho[x(q;\rho)] + \tau E_\rho\left[\frac{\partial x(q;\rho)}{\partial q}\right] \text{ for } \rho \in [\rho_L, \widetilde{\rho}(q)] \tag{27}$$

$$\frac{\partial \tilde{V}(q;\rho)}{\partial q} = \frac{\partial \tilde{V}(q;\rho_L)}{\partial q} + \widetilde{\rho}(q)\frac{\partial x(q;\widetilde{\rho}(q))}{\partial \rho} + \int_{\widetilde{\rho}(q)}^{\rho} \widehat{\rho} \frac{\partial^2 x(q;\widehat{\rho})}{\partial \widehat{\rho}^2} d\widehat{\rho} \text{ for } \rho > \widetilde{\rho}(q) \tag{28}$$

and it is easy to see that $\frac{\partial^2 \tilde{V}(q;\rho)}{\partial q \partial \rho} = 0$ for $\rho \in [\rho_L, \widetilde{\rho}(q))$, and $\frac{\partial^2 \tilde{V}(q;\rho)}{\partial q \partial \rho} = \rho \frac{\partial^2 x(q;\rho)}{\partial \rho^2} \geq 0$ for $\rho > \widetilde{\rho}(q)$. There may be a discontinuity at $\rho = \widetilde{\rho}(q)$, but since $\widetilde{\rho}(q)\frac{\partial x(q;\widetilde{\rho}(q))}{\partial \rho} \geq 0$ it follows that $lim_{\rho \to \widetilde{\rho}(q)^-} \frac{\partial \tilde{V}(q;\rho)}{\partial q} \leq lim_{\rho \to \widetilde{\rho}(q)^+} \frac{\partial \tilde{V}(q;\rho)}{\partial q}$, so that $\frac{\partial \tilde{V}(q;\rho)}{\partial q}$ is non-decreasing in ρ even at this point.

Proof of Proposition 5

Let let $h(x) = \gamma g(x)$, where $g' >,\ g'' > 0$. Then

$$\begin{aligned}\frac{\partial \tilde{V}(q;\rho,\gamma)}{\partial q} &= -\rho\delta\gamma g'(x^*(q;\rho,\gamma))\frac{\partial x^*(q;\rho,\gamma)}{\partial q} \\ &\quad - x^*(q;\rho,\gamma) + E_\rho[x^*(q;\rho,\gamma)] + \tau\frac{\partial E_\rho[x^*(q;\rho,\gamma)]}{\partial q}.\end{aligned}$$

Taking a second-order Taylor approximation around $\gamma = 0,\ \tau = 0$ yields

$$\begin{aligned}\frac{\partial\tilde{V}\left(q;\rho,\gamma\right)}{\partial q} &= \left\{\tau-E\left[\rho\right]\delta g'\left(\widehat{x}\right)\gamma-\frac{v'''\left(\widehat{x}\right)}{\left[v''\left(\widehat{x}\right)\right]^{2}}\left(\tau-E\left[\rho\right]\delta g'\left(\widehat{x}\right)\gamma\right)\tau\right.\\ &\quad -\frac{g''\left(\widehat{x}\right)}{v''\left(\widehat{x}\right)}\delta\tau\gamma-\left(1-\delta E\left[\rho\right]\right)\Omega\left(\widehat{x}\right)\tau\gamma \\ &\quad \left.+\left(E\left[\rho\right]-\frac{1}{2}E\left[\rho^{2}\right]-\frac{1}{2}\rho^{2}\right)\delta^{2}g'\left(\widehat{x}\right)\Omega\left(\widehat{x}\right)\gamma^{2}\right\}\frac{1}{v''\left(\widehat{x}\right)}\end{aligned} \tag{29}$$

where $\widehat{x}$, the level of consumption at zero harm and zero sin taxes, is implicitly given by $v'\left(\widehat{x}\right)=1$, and $\Omega\left(\widehat{x}\right)\equiv\frac{g'\left(\widehat{x}\right)v'''\left(\widehat{x}\right)}{\left[v''\left(\widehat{x}\right)\right]^{2}}-2\frac{g''\left(\widehat{x}\right)}{v''\left(\widehat{x}\right)}>0$. To derive sin tax formulas, when γ is small, we stipulate that

$$\tau=a\gamma+b\gamma^{2} \tag{30}$$

where a and b are unknown coefficients to be determined. The socially optimal tax τ^{o} and the equilibrium tax τ^{**} are given by the equations $E_{\rho}\left[\frac{\partial\tilde{V}\left(q^{o};\rho_{i},\gamma\right)}{\partial q}\right]=0$ and $\frac{\partial\tilde{V}\left(q^{**};\rho_{med},\gamma\right)}{\partial q}=0$, respectively. To determine the coefficients a and b, we plug in (29) and (30) , and require that the sum of first order terms (which are proportional to γ) is zero. Similarly, the sum of second order terms (which are proportional to γ^{2}) must be zero. In the computations, we ignore higher order terms, which are proportional to γ^{3} or γ^{4}. We get

$$\tau^{o}=E\left[\rho\right]g'\left(\widehat{x}\right)\delta\gamma+E\left[\rho\right]\frac{g''\left(\widehat{x}\right)}{v''\left(\widehat{x}\right)}g'\left(\widehat{x}\right)\delta^{2}\gamma^{2}+var\left(\rho\right)\Omega\left(\widehat{x}\right)g'\left(\widehat{x}\right)\delta^{2}\gamma^{2} \tag{31}$$

and

$$\tau^{**}=E\left[\rho\right]g'\left(\widehat{x}\right)\delta\gamma+E\left[\rho\right]\frac{g''\left(\widehat{x}\right)}{v''\left(\widehat{x}\right)}g'\left(\widehat{x}\right)\delta^{2}\gamma^{2}+\frac{1}{2}\left[\rho_{med}^{2}-\left(E\left[\rho\right]\right)^{2}+var\left(\rho\right)\right]\Omega\left(\widehat{x}\right)g'\left(\widehat{x}\right)\delta^{2}\gamma^{2} \tag{32}$$

With any distribution of self-control problems (ρ) the first-order term in the tax

formulas is identical, $E\left[\rho\right]g'\left(\widehat{x}\right)\delta\gamma$, and the difference between the socially optimal tax and the tax chosen in the political equilibrium is of the second order, i.e. proportional to γ^{2}. This can be contrasted with the benchmark case with no redistribute effects: when the harm function is of the form $\gamma g\left(x\right)$, the equilibrium tax τ^{*} can be approximated by

$$\tau^{*}=\rho_{med}g'\left(\widehat{x}\right)\delta\gamma+\left(1-\rho_{med}\right)\rho_{med}\frac{g''\left(\widehat{x}\right)}{v''\left(\widehat{x}\right)}g'\left(\widehat{x}\right)\left(\delta\gamma\right)^{2}$$

and the difference $\tau^* - \tau^o$ is of the first order, i.e. proportional to γ, as long as $\rho_{med} \neq E[\rho]$.

To examine the difference between τ^{**} and τ^o, subtracting (31) from (32) yields

$$\tau^{**} - \tau^o = \frac{1}{2}\left[\rho_{med}^2 - (E[\rho])^2 - var(\rho)\right]\Omega(\widehat{x})\, g'(\widehat{x})\,(\delta\gamma)^2. \tag{33}$$

Clearly, $\tau^{**} < \tau^o$, whenever $\rho_{med} \leq E[\rho] + \lambda$, where $\lambda > 0$ depends positively on $var(\rho)$: the more dispersed the distribution of self-control problems is, the more likely it is that the equilibrium tax rate is lower than the optimal tax rate. Notice also that $\tau^{**} - \tau^o < 0$ iff $\chi(\rho) \equiv \frac{\rho_{med}^2 - (E[\rho])^2}{var(\rho)} < 1$. Here $\chi(\rho)$ essentially measures the skewness of the distribution (it is similar to the Pearson skewness measure $\frac{3(\rho_{med} - E[\rho])}{sd(\rho)}$).

Next, using a first order Taylor approximation around $\gamma = 0,\ \tau = 0$ yields

$$x(q;\rho) = \widehat{x} + (1-\rho)\delta\frac{g'(\widehat{x})}{v''(\widehat{x})}\delta\gamma + \frac{1}{v''(\widehat{x})}\tau. \tag{34}$$

This equation allows us to express $\rho_{med},\ E[\rho]$ and $var(\rho)$ in terms of the distribution of consumption. Then we can rewrite the tax formulas (31) and (32) as follows

$$\tau^o = \frac{1}{|\eta|}\frac{\overline{x} - x_{\min}}{\widehat{x}} - \frac{\varphi}{|\eta|}\frac{(\overline{x} - x_{\min})(x_{\max} - x_{\min})}{\widehat{x}^2} + \frac{\zeta}{|\eta|}\frac{var(x)}{\widehat{x}^2}, \tag{35}$$

$$\begin{aligned}\tau^{**} = {} & \frac{1}{|\eta|}\frac{\overline{x} - x_{\min}}{\widehat{x}} - \frac{\varphi}{|\eta|}\frac{(\overline{x} - x_{\min})(x_{\max} - x_{\min})}{\widehat{x}^2} \\ & + \frac{1}{2}\frac{\zeta}{|\eta|}\frac{(x_{med} - x_{\min})^2 - (\overline{x} - x_{\min})^2 + var(x)}{\widehat{x}^2}\end{aligned} \tag{36}$$

and

$$\tau^{**} - \tau^o = \frac{1}{2}\frac{\zeta}{|\eta|}\frac{(x_{med} - x_{\min})^2 - (\overline{x} - x_{\min})^2 - var(x)}{\widehat{x}^2}, \tag{37}$$

where $x_{\min} = x(q,1),\ x_{\max} = x(q,0),\ x_{med} = x(q,\beta_{med})$ and $\overline{x} = E_\beta[x(q,\beta)]$ are the minimum, maximum, median and average level of consumption in the economy. Since the difference between the tax rates τ^o and τ^{**} is of the second order (i.e. proportional to γ^2), these consumption levels are identical, up to a first order approximation, under tax rates τ^o and τ^{**}. Thus when γ is small, the right-hand sides of the tax formulas (35) and (36) are comparable. Also notice that it is sufficient to use a first order Taylor approximation of $x(q;\rho)$ (eq (34)) to derive the formulas (35) and (36), since $var(x) = \left[\frac{g'(\widehat{x})}{v''(\widehat{x})}\right]^2 \delta^2 var(\rho)\gamma^2$ is of the second order, and the terms $(\overline{x} - x_{\min})(x_{\max} - x_{\min})$, $(x_{med} - x_{\min})^2$ and $(\overline{x} - x_{\min})^2$ are proportional to γ^2, as well.

Interpreting the remaining terms in formulas (35) and (36) , $|\eta|$ is (the absolute value of) the price elasticity of demand (evaluated at $\gamma = 0,\ \tau = 0$), and $\varphi = \frac{g''(\widehat{x})}{g'(\widehat{x})}\widehat{x}$ measures the curvature of the harm function. Finally, the term $\zeta = \frac{d\left|\ln\left(\frac{dh}{dq}\right)\right|}{d\ln(x)}$ tells how the effect of a price change on health $\left(\left|\frac{dh}{dq}\right|\right)$ depends on the level of consumption. Given our assumptions, tax changes entail larger health effects for heavy-users than for moderate consumers, and thus $\zeta > 0$. In particular, equation (37) indicates that the equilibrium tax τ^{**} is below the socially optimal level τ^{o}, if average consumption $\overline{x}$ exceeds median consumption x_{med}. Also, the larger the variance in consumption, the more the equilibrium rate will fall short of the socially optimal rate.

Proof of Proposition 6

From (25), (27) and (28) $\frac{\partial\tilde{V}(q;\rho)}{\partial q}$ is a quasi-convex function of ρ, if (i) $\rho\frac{\partial^2 x(q;\rho)}{\partial\rho^2}$ is increasing in ρ and (ii) $\frac{\partial x}{\partial q} \to 0$, when $x \to 0$. In particular, due to assumption (ii), $\frac{\partial x(q;\widetilde{\rho}(q))}{\partial\rho} = \delta h'\left(x\left(q;\widetilde{\rho}\left(q\right)\right)\right)\frac{\partial x(q;\widetilde{\rho}(q))}{\partial q} = 0$, and (28) simplifies to

$$\frac{\partial\tilde{V}\left(q;\rho\right)}{\partial q} = E_{\rho}\left[x\left(q;\rho\right)\right] + \tau E_{\rho}\left[\frac{\partial x\left(q;\rho\right)}{\partial q}\right] + \int_{\widetilde{\rho}(q)}^{\rho}\widehat{\rho}\frac{\partial^2 x\left(q;\widehat{\rho}\right)}{\partial\widehat{\rho}^2}d\widehat{\rho} \ \text{ for } \rho > \widetilde{\rho}\left(q\right)$$

so that there is no discontinuity at $\rho = \widetilde{\rho}\left(q\right)$. Then, since $\frac{\partial\tilde{V}(q;\rho)}{\partial q}$ is constant when $\rho \in \left[\rho_{L,}\widetilde{\rho}\left(q\right)\right]$, and quasi-convex in ρ for $\rho > \widetilde{\rho}\left(q\right)$, we can conclude that $\frac{\partial\tilde{V}(q;\rho)}{\partial q}$ is a quasi-convex function of ρ over the whole support $\left[\rho_L, \rho_H\right]$. Given the quasi-convexity of $\frac{\partial\tilde{V}(q;\rho)}{\partial q}$, the same argument as in the Proof of Proposition 2 shows that $\frac{dW(q)}{dq} > \frac{\partial\tilde{V}(q;\rho_{med})}{\partial q}$.

To interpret the condition that $\rho\frac{\partial^2 x(q;\rho)}{\partial\rho^2}$ should be increasing in ρ, a first-order Taylor approximation shows that the health effect of taxation can be written as

$$-\delta\frac{\partial h\left(x\left(q;\rho\right)\right)}{\partial q} = \frac{\partial x^*\left(q;\rho\right)}{\partial\rho} \simeq \frac{\partial x\left(q;0\right)}{\partial\rho} + \rho\frac{\partial^2 x\left(q;\rho\right)}{\partial\rho^2}.$$

Again, we therefore require that a price change affects the health of irrational consumers (heavy users) more than the health of rational consumers.

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