The Design of Tobacco Control Policies: Taxation, Antismoking Campaigns, and Smoking Bans

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Abstract

We examine the optimal design of policies directed at regulating tobacco consumption through three types of instruments: (i) an excise tax hindering consumption by increasing the price of cigarettes, (ii) prevention programs helping smokers to make consumption choices that are more time consistent, and (iii) smoking bans directly restricting tobacco use. We find that taxation helps curbing the inefficiencies arising from the behavior of the 'average' smoker. Antismoking programs and smoking bans usefully complement taxation by specifically targeting smokers with above-average health harms and smoking externalities in different locations, respectively.

Keywords: Harmful consumption, Corrective taxation, Prevention programs, Smoking bans.

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1 Introduction

Tobacco consumption is exposed to various forms of regulation in many countries. Historically, taxation is the first instrument used by governments, initially mainly as a revenue-raising device, subsequently also as a mean to limit tobacco consumption.[1] While still widely employed, during the last decades an expanded array of instruments — such as smoke-free-air laws, information-campaign programs about smoke-related diseases, bans on advertising, restrictions of youth access to tobacco products — have gained importance complementing taxation as tobacco control policies. Indeed, the empirical evidence on the USA reported in Section 2 shows that prevention programs, as well as smoking restriction laws, are used jointly with taxation and play an important role, both quantitatively and qualitatively. However, while the theoretical underpinnings of tobacco taxation have a long history that we briefly review in Section 2, those of other types of control policies are still limited.[2] The main purpose of this paper is to investigate how non-price regulatory instruments add to and interact with taxation in the design of tobacco control policies.

We develop a framework in which a policy maker can use three types of regulatory instruments: (i) an *excise tax* that discourages tobacco consumption by increasing its price, (ii) *prevention programs* that affect consumption by inducing smokers to take decisions that are more time consistent when comparing the pleasure of current tobacco consumption with its future health harm, and (iii) *smoking bans,* such as free-air laws, that directly restrict consumption. Our theoretical model of smoking behavior is based on the framework developed by O'Donoghue and Rabin (2005, 2006) and Kőszegi (2005) to examine the socially optimal level of taxation of a harmful good.[3] We extend their

[1] For instance, in the UK, excise duty on tobacco was first introduced in 1660 (Report on tobacco taxation in the United Kingdom, WHO). In the U.S., the first federal excise tax on tobacco products was introduced in 1862, while the first state tax was introduced in Iowa in 1921 (Tax Foundation). The Australian government has imposed an excise tax on tobacco products since 1901 (Australian Government, The Department of Health).

[2] A notable exception is the model by Adda and Cornaglia (2010), who focus on the interplay among bans, taxes and passive smoking. Instead, several *empirical* and *experimental* papers have investigated the impact of taxation and other control policies on tobacco consumption (e.g., Chaloupka and Wechsler, 1997; Evans *et al.*, 1999, Adda and Cornaglia, 2006, Chaloupka *et al.*, 2010, Chaloupka *et al.*, 2012, Rousu *et al.*, 2014). A comprehensive discussion of the issues involved in tobacco regulation is in Gruber (2001).

[3] Other models, in particular Gruber and Kőszegi (2004), provide a more articulated characterization of tobacco consumption, focusing also on dynamic issues. Bernheim and Rangel (2004) develop a

setup by introducing the two regulatory instruments referred to above,[4] and study the optimal mix between the three types of instruments assuming that a benevolent policy maker maximizes the aggregate surplus of the economy.

We consider a population of consumers that is heterogeneous along several dimensions, such as the intensity of preferences for smoking, the size of future health harms caused by current tobacco consumption, the degree of self-control in smoking, and the sensibility to public awareness programs. We also distinguish between consumption locations where smoking causes external harms to other individuals (like indoor sites) and those where it does not (like outdoor sites). As for the former, we distinguish between locations in which regulation, in the form of smoking bans aimed at curbing external costs, is applicable (like public sites) and locations in which a ban is not applicable (like private homes).

Our normative analysis shows how prevention policies and smoking restrictions can usefully complement taxation in controlling tobacco consumption. Ideally, a set of individual- and location-specific taxes (i.e., taxes tailored to match the characteristics of individual smokers and the external costs of smoking in the various consumption locations) would allow to implement an allocation that is first-best efficient, hence making other instruments redundant. However, individual- and location-specific taxes are unfeasible in practice, because of lack of information and high administrative costs. Therefore, policy makers must rely on a second-best uniform tax on all smokers and applicable throughout all locations, which in turn calls for the introduction of additional policy instruments targeting specific inefficiencies. Our analysis shows how prevention programs and smoking restrictions, although unable to restore the first-best for the same reasons indicated above, prove very useful in mitigating the inefficiencies that are left unaddressed by uniform taxation.

In particular, our results show that the optimal excise tax is a sufficient instrument for correcting the inefficiencies arising from the behavior of the 'average' smoker.

framework, based on evidence from neuroscience, in which the consumption of harmful goods is due to 'mistakes' that are triggered by environmental cues. Their model is particularly appropriate for the analysis of consumption of highly addictive substances.

[4] O'Donoghue and Rabin (2006) refer primarily to junk food, while Kőszegi (2005) focuses also on beneficial goods (like exercise) and on the role of market solutions (two-part tariffs, non-linear pricing) besides public intervention. As for taxation and prevention programs, also our analysis can accommodate harmful goods different from tobacco, like alcoholic drinks, drugs, or unhealthy food. Regulation by means of smoke-free air laws is instead obviously specific to tobacco consumption.

However, by targeting the average smoker and the average external costs throughout locations, the optimal uniform tax does not properly account for individuals' heterogeneity in terms of health harms, degree of self-control, receptiveness to prevention programs. Furthermore, by simply correcting for the average external harm, it does not properly account for the fact that different acts of smoking exert different external harms in different locations.

As for antismoking programs, we show that their optimal level crucially depends on the variance of health harms for smokers. Intuitively, for the smokers suffering an health harm above the average level, it is socially beneficial to induce a further decrease in tobacco consumption, in addition to the one already achieved through taxation. The opposite holds for smokers with health harm below the average. This is exactly what can be achieved through prevention policies, the introduction of which, coupled with an appropriate reduction in taxation, is therefore useful for increasing the efficiency of tobacco control policies.

As for smoking restrictions, we show that they represent an additional useful instrument for curbing smoking externalities that are only partially corrected by uniform taxation, since the latter — by correcting for the average externality — is unable to account for the different external costs caused by smokers in different environments. Note that also smoking bans are second best policies, since they impose zero tobacco consumption while the latter should only be reduced to its efficient positive level in the first best allocation.

The rest of the paper is organized as follows. Section 2 presents a brief survey of the literature on tobacco taxation, as well as stylized facts supporting our interest on additional policy instruments. The model is introduced in Section 3 while the impact of policy instruments on smoking is examined in Section 4. The social objective function is defined in Section 5 and Section 6 studies the optimal structure of tobacco regulation policies. Section 7 concludes.

2 Related literature and stylized facts

Most of the available literature focuses exclusively on the role of taxation for regulating tobacco consumption. There are at least three 'traditional' arguments that are advocated in favor of tobacco taxation. First, it constitutes a good source of tax revenue (being a relatively simple levy to administer) both at the central and at the sub-central levels of government. Second, it represents a simple way to have smokers paying for the pecuniary externalities they impose on society, mainly due to the extra health care costs that are necessary to treat smoking related diseases. Third, taxation is often motivated by the paternalistic view building on the value of discouraging tobacco consumption, seen as a harmful good that would otherwise be consumed in excessive quantities by 'boundedly rational' consumers. This paternalistic view has been forcefully criticized by Becker and Murphy (1988) based on the idea of rational addiction. According to their view, as smoking habits are the result of optimizing choices by rational agents, there is no need to reduce demand by levying taxes on tobacco. Among the other arguments against tobacco taxation, a very popular one holds that its burden is regressive, since cigarettes consumption accounts for a larger share of the income of poor households. Such taxes are therefore also criticized on equity grounds.

The more recent literature has both refreshed and challenged the traditional view just outlined along several dimensions (see, e.g., Gruber and Kőszegi (2008) for a comprehensive non-technical survey). First, the premise that smokers may not behave in a fully rational way has been revived by building on the theory of intertemporal choices with hyperbolic discounting (on the latter, see, among others, Laibson, 1997). For instance, the models developed by Gruber and Kőszegi (2004), and by O'Donoghue and Rabin (2006), provide a rigorous underpinning of the role that taxation can play in correcting time inconsistent choices by the consumers of a harmful good. Second, some authors (e.g., Gruber and Kőszegi, 2008) reject the pecuniary externality argument in favor of tobacco taxation. In particular, they hold that the burden on health care systems to treat smoke-related diseases is approximately of the same magnitude as the savings on retirement expenditures, since smokers have a shorter life expectation than non-smokers (see also Crawford *et al.*, 2010, for a critical assessment of the empirical literature about the estimation of the net costs of smoking). Third, Gruber and Kőszegi (2004) and Kotakorpi (2008), provide another important challenge to the traditional view on tobacco taxation, by arguing that the taxation of cigarettes consumption may show a burden profile that is, in welfare terms, progressive. The intuition is simple. In a setting of time inconsistent behavior, tobacco taxation plays a corrective role by reducing over-consumption. However, since low income consumers are more sensitive to tax induced price changes than high income consumers, taxation may turn out to benefit more the low than the high income individuals, hence showing a progressive pattern in terms of welfare gains.

The available empirical evidence for the USA, summarized in Table 1, shows that non-price control policies are widely used in addition to taxes as instruments to regulate tobacco consumption.

<Insert Table 1 about here>

The table reports recent data on each excise state tax per pack of cigarettes, on the per capita amount of state tax revenue from cigarette sales, on the per capita funds allocated for tobacco control programs, on the so called total Alciati score (measuring the extensiveness of state tobacco control youth access laws), and on an index of smoke-free air laws (measuring the level of smoking restrictions by state law).[5] Although there is a large heterogeneity among states — both in the extent and in the mix of the adopted measures — it is evident that policy makers do not rely exclusively (or even primarily) on taxation to restrict tobacco consumption, but rather combine a variety of different instruments. It is therefore important, in a theoretical perspective, to properly account for these instruments, moving behind a framework that only focuses on the role of taxes.[6]

3 The model

Our theoretical framework extends those by O'Donoghue and Rabin (2005, 2006) and Kőszegi (2005), in which taxation is the only policy instrument for controlling tobacco consumption, by adding antismoking campaigns and free-air legislation to the set of

[5] Although the latest available data on state tax revenue (REV) are for fiscal year 2013, in Table 1 we report the 2011 data in order to make a consistent comparison with the latest available data on control programs (TCP). Note also that the table reports only empirical observations on tobacco control policies undertaken by the U.S. States, although similar policies are implemented also at the federal and at the local levels of government. For instance, in addition to state taxes, there is a Federal excise tax of $1.01 per pack (since April 1, 2009) and, in some states, also a tax levied at the county and/or city levels. Note that, as largely expected, tobacco-producers states have both lower taxation and a lower reliance on other control policies.

[6] Similar evidence is available for the European Union, where data on excise duties on tobacco are periodically released by the European Commission (http://ec.europa.eu/taxation_customs/taxation/excise_duties/index_en.htm). The evolution of the European legislation on smoking bans is illustrated by the European Public Health Alliance (EPHA, http://www.epha.org/a/1941).

available policy tools. We also acknowledge that tobacco consumption takes place in different types of locations, and that it can harmful not only for smokers, but also for other individuals.

3.1 Consumption locations, externalities, and smoking bans

We consider individuals that consume two types of goods: a harmful good (i.e., tobacco), denoted by x, and a 'standard' consumption good, denoted by y. Consumption takes place in three types of locations, indexed by l, $l \in \{1,2,3\}$, characterized by the following features. Tobacco consumption does not cause any external harm to other individuals in type 1 locations (e.g., outdoor sites), whereas it can be harmful (e.g., second hand smoke) in type 2 and type 3 locations. However, while smoking can be effectively banned in type 3 locations, which are denoted as 'regulable' (e.g., restaurants, museums, schools, and so on), it cannot in type 2 locations, which are denoted as 'non-regulable' (e.g., private homes).

We denote as a 'consumption activity' occurring in type l locations the consumption of the specific bundle (x^l, y^l), and we let $a^l \in [0,1]$, $\sum_{l=1}^{3} a^l = 1$, be the share of consumption activities taking place in type l locations, where we have normalized the overall number of consumption activities to be equal to one. Hence, the amount of consumption in type l locations is equal to $(a^l x^l, a^l y^l)$, and total consumption in all locations is equal to (x, y), $x = \sum_{l=1}^{3} a^l x^l$, $y = \sum_{l=1}^{3} a^l y^l$. This setup implies that a consumer faces a two-dimensional decision problem. First, she chooses how many consumption activities to undertake in each type of location, based on her preferences over locations and on the net surpluses derived from the specific bundles (x^l, y^l) consumed in each type of location. Second, she chooses the composition of the typical bundle consumed in each location l, based on her preferences over consumption goods.

In the absence of smoking restrictions, the utility of bundle (x^l, y^l) is equal to

$$v^l(x^l; \rho^l) + y^l, \tag{1}$$

where $v^l(.)$ is a strictly concave function of x, $v^l_x \geq 0$, $v^l_{xx} < 0$, and $\rho^l > 0$ is a taste parameter that expresses the intensity of preferences for tobacco consumption. In particular, the marginal utility v^l_x is assumed to be monotonic in ρ^l, for given x. To guarantee an interior solution in x, we also assume that $\lim_{x \to 0} v^l_x = +\infty$, $\lim_{x \to +\infty} v^l_x = 0$.[7] Note also that while the preferences for the harmful good can

[7] Although in reality not everyone is a regular smoker, for ease of analytical tractability we consider

be contingent on consumption locations (i.e., the pleasure derived from smoking can differ in different locations), those for the standard consumption good are the same in all locations, with constant marginal utility equal to one. Individuals have also preferences for consumption locations, which are defined in Section 3.3.

The introduction of a smoking ban in type 3 locations affects consumption conditions therein. To illustrate, consider a smoking ban in restaurants. With perfect enforcement of the norm, the customers can no longer smoke while having a meal and yet the ban is not equivalent to a quantity rationing of tobacco consumption, since smokers can react to it by taking a break during the meal and go smoking outside the restaurant. However, a smoke outdoor might not be as enjoyable as one by the restaurant table.[8]

We formalize these ideas by assuming that the utility from smoking is equal $v^3(x^3;\rho^3)$ in the absence of the ban, while it is equal to $v^3(x^3;\rho^3)-\xi x^3$ when the ban is perfectly enforced. The cost of complying with the ban, ξx^3, is proportional to x^3, the quantity of tobacco in type 3 locations consumption bundles, and to the taste parameter $\xi \geq 0$ that expresses how costly is to comply with the ban, i.e., to smoke under 'restricted' conditions (in the above example, outside the restaurant premises).

We also model the smoking ban in type 3 locations as a continuous policy instrument $r \in [0,1]$, representing the degree of enforcement of the norm. If $r=0$, then smoking is not banned; if $r=1$, then the ban is perfectly enforced; if $r \in (0,1)$, there is imperfect enforcement of the norm. Hence, utility of tobacco consumption in type 3 locations can be written as $v^3(x^3;\rho^3) - r\xi x^3$. The costs sustained by the government for the enforcement of the smoking ban are defined in Section 5.2.

3.2 Health costs, lack of self-control, and antismoking campaigns

Present tobacco consumption causes future harm for smoker's health, which is assumed to be proportional to the amount of current tobacco consumption. More precisely, the present value of future harm for each unit of current tobacco consumption is perceived by the consumer as being equal to $\beta\delta\gamma$, where the parameter $\gamma \geq 0$ is the value of health harm, $\delta \in (0,1]$ is the discount factor and $\beta \in [0,1]$ is the quasi-hyperbolic discounting

a framework in which all individuals consume a positive amount of the harmful good. As we argue in the concluding Section 7, this hypothesis is not too restrictive.

[8] Smokers can also react to the ban by changing location, i.e., by substituting a meal in a restaurant with one in an unregulated site, an option we examine in Section 3.3.

parameter, which captures (in a reduced form) the degree of time inconsistency, or of lack of self-control, in consumer behavior;[9] $\beta < 1$ implies overconsumption with respect to its efficient level, whereas $\beta = 1$ implies fully rational behavior (more on this in Section 5.1).

Differently from O'Donoghue and Rabin (2006) and Kőszegi (2005), who take it as exogenously given, we assume that the parameter β can be positively affected by the amount of public spending, denoted by $z \geq 0$, that finances mass media campaigns and prevention programs against smoking. As documented in Section 2, these are forms of regulation that are quite effective in curbing tobacco consumption. We formalize this effect by assuming that β is linked to z through the function:

$$\beta(z; \kappa, \theta, \zeta), \tag{2}$$

where $\beta_z \geq 0$, $\beta_{zz} \leq 0$, $\beta(0; \kappa, \theta, \zeta) = \kappa$, $\lim_{z\to\infty} \beta(.) = \kappa + \theta(1 - \kappa)$, $\beta_\zeta \geq 0$.

These assumptions have a natural interpretation. Since higher spending on antismoking campaigns means that consumers are exposed to more information about health risks, we assume that a consumer's degree of self-control β increases with z. However, since the production of 'effective' information occurs under decreasing returns, the marginal impact of higher spending z on β is decreasing in z (e.g., the marginal impact on smokers' behavior of antismoking TV adverts is a decreasing function of their broadcasting frequency and length). Moreover, the function $\beta(.)$ is shaped by three taste parameters. The first is $\kappa \in [0, 1]$, representing the baseline level of β; i.e. the consumer's degree of self-control in the absence of antismoking campaigns. The second parameter, $\theta \in [0, 1]$, determines jointly with κ the asymptotic value of β when z goes to infinity; i.e. the maximum degree of self-control that the individual can achieve under the influence of prevention programs.[10] Finally, the parameter $\zeta > 0$ represents

[9] The assumption that smokers may lack self control (i.e., $\beta < 1$) while they are correctly informed about the true risks due to tobacco use (i.e., the value of γ) is consistent with the evidence reported by Khwaya *et al.* (2009). On the contrary, the studies surveyed by the U.S. National Cancer Institute and World Health Organization (2016, chapter 8) bring evidence that cigarettes smokers have low levels of awarness about health risks. However, in our theoretical model it is possible to accomodate both views, by interpreting the parameter β as expressing smokers' degree of underestimation of health harms. Further issues about smokers' inter-temporal choices —risk preferences, time discounting, abilities to plan— are critically assessed in Khwaya *et al.* (2007a, 2007b) and Scott *et al.* (2014).

[10] Note that for all admissible parametrizations of the function $\beta(.)$ the asymptotic value of β for $z \to \infty$ never exceeds unity. This means that we are assuming that smokers never 'over-react' to the information transmitted by the antismoking campaign, by consuming an amount of tobacco that is

a direct measure of how sensitive the smoker is to the information conveyed by the campaign. If we consider two individuals with the same κ and θ, the assumption that $\beta_\zeta \geq 0$ implies that, for $\zeta'' \geq \zeta'$, it is $\beta(z;\kappa,\theta,\zeta'') \geq \beta(z;\kappa,\theta,\zeta')$ for all values of z.

3.3 Individual consumption decisions

Based on the assumptions in Sections 3.1 and 3.2, the utility of each bundle (x^l, y^l) consumed in type 1 and type 2 locations, net of the perceived health costs from smoking, is equal to

$$s^l(x^l, y^l) = v^l(x^l;\rho^l) - \beta\delta\gamma x^l + y^l, \qquad l = 1, 2, \tag{3}$$

while that of each bundle (x^3, y^3) consumed in type 3 locations is given by

$$s^3(x^3, y^3) = v^3(x^3;\rho^3) - r\xi x^3 - \beta\delta\gamma x^3 + y^3. \tag{4}$$

The utility of all consumption activities undertaken in type l locations is assumed to be equal to the utility of the a^l bundles (x^l, y^l) consumed therein, $a^l s^l(x^l, y^l)$, plus an extra utility term $\lambda^l(a^l;\alpha^l)$ representing the individual's preferences for type l locations. That is:[11]

$$u^l(x^l, y^l, a^l) = a^l s^l(x^l, y^l) + \lambda^l(a^l;\alpha^l). \tag{5}$$

We assume that $\lambda^l(.)$ is strictly concave in a, $\lambda^l_a \geq 0$, $\lambda^l_{aa} < 0$, with the taste parameter α^l expressing a measure of individual preferences for type l locations. To guarantee an interior solution in the choice of consumption locations, we also assume that $\lim_{a\to 0}\lambda^l_a = +\infty$, $\lim_{a\to 1}\lambda^l_a = -\infty$.

By aggregating Eq. (5) over locations, the consumer total utility is thus equal to

$$u(\mathbf{x}, \mathbf{y}, \mathbf{a}) = \sum\nolimits_{l=1}^{3} u^l(x^l, y^l, a^l), \tag{6}$$

where to shorten notation we let $\mathbf{x} = (x^1, x^2, x^3)$, $\mathbf{y} = (y^1, y^2, y^3)$ and $\mathbf{a} = (a^1, a^2, a^3)$.

Both consumption goods are exchanged in perfectly competitive markets.[12] Production costs are linear, with marginal costs equal to average costs, normalized to unity

lower than the efficient level of a fully rational agent.

[11] Separability of preferences for consumption bundles and for consumption locations is useful because it implies clearcut, albeit not trivial, comparative statics results about the impact of policy instruments on tobacco consumption (see Section 4).

[12] We consider perfectly competitive markets, though it is well known that cigarettes manufacturers do have market power, as our goal is to examine how the policy instruments can be used to correct for inefficient consumers' behavior. In the concluding Section 7, we discuss the implications of allowing for producers' market power.

for both goods. Good y is the *numeraire* good, with unit market price. The market price of good x is equal to $p = 1 + t$, where $t \geq 0$ is a specific (excise) tax on cigarettes consumption, levied on producers.

Each individual is endowed with an exogenously given income I. The consumer's budget constraint is thus equal to

$$\sum_{l=1}^{3} a^l \left(px^l + y^l\right) \leq I. \tag{7}$$

By substituting $\sum_{l=1}^{3} a^l y^l = I - \sum_{l=1}^{3} a^l px^l$ from Eq. (7) into Eq. (6), the utility function can be expressed as a function of tobacco consumption $\mathbf{x}$ and locational choices $\mathbf{a}$ only:

$$u(\mathbf{x}, \mathbf{a}) = \sum_{l=1}^{3} a^l \left[v^l(x^l) - \beta\delta\gamma x^l - px^l\right] - r\xi a^3 x^3 + \sum_{l=1}^{3} \lambda^l(a^l) + I. \tag{8}$$

For expositional purposes, it is useful to examine the consumer's choices as occurring sequentially — first those on consumption locations, then those on consumption bundles — and solve the problem by proceeding backward.[13]

In the second stage, the consumer maximizes Eq. (8) with respect to tobacco consumption levels $\mathbf{x}$, for given locational choices $\mathbf{a}$. From the first order conditions

$$v_x^l(x^l) = \beta\delta\gamma + p, \qquad l = 1, 2, \tag{9}$$

$$v_x^3(x^3) = \beta\delta\gamma + p + r\xi, \tag{10}$$

we obtain $\tilde{\mathbf{x}}$, with elements $\tilde{x}^1(t, z)$, $\tilde{x}^2(t, z)$ and $\tilde{x}^3(t, z, r)$ as a unique solution, all strictly positive.[14] Since the utility function is linear in the standard consumption good, with unit marginal utility in all locations, from the consumer's optimization problem we obtain only the total consumption of good y as residually determined from the budget constraint. The consumer is then indifferent about any allocation of this total amount in the three types of consumption bundles and locations.

Let

$$\tilde{s}^l(t, z) = v^l(\tilde{x}^l) - (\beta\delta\gamma + p)\tilde{x}^l, \qquad l = 1, 2, \tag{11}$$

$$\tilde{s}^3(t, z, r) = v^3(\tilde{x}^3) - (\beta\delta\gamma + p + r\xi)\tilde{x}^3, \tag{12}$$

[13] The analysis in two stages is without loss of generality. The same solution is obtained in the simultaneous choice of consumption bundles and locations.

[14] Throughout the paper we use 'tilde' to denote the optimal values of the consumer's problem.

be the net surplus from smoking associated to the chosen consumption bundles in the three locations. By the envelope theorem, it is

$$\tilde{s}^l_t = (\beta_z \delta \gamma)^{-1} \tilde{s}^l_z = -\tilde{x}^l, \qquad l = 1, 2, 3, \tag{13}$$

$$\tilde{s}^3_r = -\xi \tilde{x}^3. \tag{14}$$

By inserting $\tilde{\mathbf{x}}$ into Eq. (8), we obtain:

$$u(\tilde{\mathbf{x}}, \mathbf{a}) = \sum\nolimits_{l=1}^{3} \left[a^l \tilde{s}^l + \lambda^l (a^l) \right] + I. \tag{15}$$

In the first stage, the consumer chooses where to consume by maximizing Eq. (15) with respect to $\mathbf{a}$, subject to the constraint $\sum_{l=1}^{3} a^l = 1$. Letting μ be the Lagrange multiplier, the locational choices $\tilde{\mathbf{a}}$, with elements $\tilde{a}^l(t, z, r)$, $l = 1, 2, 3$, all strictly positive, are easily obtained from the first order conditions:

$$\tilde{s}^l + \lambda^l_a (a^l) = \mu, \qquad l = 1, 2, 3. \tag{16}$$

Tobacco consumption in type l locations is thus equal to $\tilde{a}^l \tilde{x}^l$, and total consumption in all locations is equal to:

$$\tilde{x}(t, z, r) = \sum\nolimits_{l=1}^{3} \tilde{a}^l \tilde{x}^l. \tag{17}$$

We next derive some comparative statics results concerning the impact of policy instruments on smoking.

4 The impact of policy instruments on smoking

A marginal change in a policy instrument π, $\pi \in \{t, z, r\}$, can impact on tobacco consumption in type l locations, $\tilde{a}^l \tilde{x}^l$, and on total consumption in all locations, $\tilde{x}$, by affecting both the quantity $\tilde{x}^l$ of tobacco in type l consumption bundles, and the quantity $\tilde{a}^l$ of bundles consumed:[15]

$$(\tilde{a}^l \tilde{x}^l)_\pi = \tilde{a}^l \tilde{x}^l_\pi + \tilde{a}^l_\pi \tilde{x}^l, \qquad \tilde{x}_\pi = \sum\nolimits_{l=1}^{3} (\tilde{a}^l \tilde{x}^l)_\pi, \qquad \pi \in \{t, z, r\}. \tag{18}$$

First, we focus on taxation. By applying the implicit function theorem to the first

[15] With a slight abuse of notation, to save space we denote with $(\tilde{a}^l \tilde{x}^l)_\pi$ the derivative of the product $\tilde{a}^l \tilde{x}^l$ with respect to π.

order conditions shown in Eqs. (9), (10) and (16), we find that:[16]

$$\tilde{x}_t^l = 1/\tilde{v}_{xx}^l < 0, \qquad l = 1, 2, 3, \tag{19}$$

$$\tilde{a}_t^1 = \left[\tilde{\lambda}_{aa}^2(\tilde{x}^1 - \tilde{x}^3) + \tilde{\lambda}_{aa}^3(\tilde{x}^1 - \tilde{x}^2)\right]\tilde{\Delta}, \tag{20}$$

$$\tilde{a}_t^2 = \left[\tilde{\lambda}_{aa}^1(\tilde{x}^2 - \tilde{x}^3) + \tilde{\lambda}_{aa}^3(\tilde{x}^2 - \tilde{x}^1)\right]\tilde{\Delta}, \tag{21}$$

$$\tilde{a}_t^3 = -\tilde{a}_t^1 - \tilde{a}_t^2, \tag{22}$$

where $\tilde{\Delta} = 1/(\tilde{\lambda}_{aa}^1\tilde{\lambda}_{aa}^2 + \tilde{\lambda}_{aa}^1\tilde{\lambda}_{aa}^3 + \tilde{\lambda}_{aa}^2\tilde{\lambda}_{aa}^3) > 0$ by strict concavity of the functions $\lambda^l(.)$ in a.

Eq. (19) shows that an increase in the tax rate reduces $\tilde{x}^l$ in all locations, while Eqs. (20)-(22) show that it reduces (increases) the amount $\tilde{a}^l$ of bundles consumed in the locations characterized by intense (weak) tobacco usage. For instance, if tobacco is more intensively consumed in type 1 locations (i.e., $\tilde{x}^1 > \tilde{x}^3$ and $\tilde{x}^1 > \tilde{x}^2$), then an increase in t results in a reduction in $\tilde{a}^1$.[17] The intuition is that, from the point of view of the smoker, taxation causes greater welfare losses for consumption bundles that are more tobacco intensive. Hence, by relocating her consumption activities in favor of locations where tobacco consumption is less intensive, the smoker manages to mitigate the welfare loss of taxation. The conclusion is that taxation reduces total consumption $\tilde{a}^l\tilde{x}^l$ in type l locations if $\tilde{a}^l$ is decreasing in t, whereas it can increase it if $\tilde{a}^l$ is increasing in t. However, although $(\tilde{a}^l\tilde{x}^l)_t$ is of ambiguous sign in at least one location l, since $\tilde{a}_t^l < 0$ for at least one l, the impact of taxation on overall consumption, $\tilde{x} = \sum_{l=1}^3 \tilde{a}^l\tilde{x}^l$, is always negative; i.e.,

$$\tilde{x}_t = \sum_{l=1}^3 \tilde{a}^l\tilde{x}_t^l + \sum_{l=1}^3 \tilde{a}_t^l\tilde{x}^l < 0, \tag{23}$$

since, by Eq. (19), it is $\tilde{x}_t^l < 0$, $l = 1, 2, 3$, and, by Eqs. (20)-(22), it is:

$$\sum_{l=1}^3 \tilde{a}_t^l\tilde{x}^l = \left[\tilde{\lambda}_{aa}^2(\tilde{x}^1 - \tilde{x}^3)^2 + \tilde{\lambda}_{aa}^3(\tilde{x}^1 - \tilde{x}^2)^2 + \tilde{\lambda}_{aa}^1(\tilde{x}^2 - \tilde{x}^3)^2\right]\tilde{\Delta} < 0.$$

The impact of antismoking campaign programs on tobacco consumption is proportional, by the factor $\beta_z\delta\gamma$, to that of taxation:

$$\tilde{x}_z^l = \beta_z\delta\gamma\tilde{x}_t^l, \qquad \tilde{a}_z^l = \beta_z\delta\gamma\tilde{a}_t^l, \qquad l = 1, 2, 3; \qquad \tilde{x}_z = \beta_z\delta\gamma\tilde{x}_t. \tag{24}$$

[16] Being standard, the proofs of all comparative statics results shown in this section are omitted.

[17] Clearly, $\tilde{x}^1 > \tilde{x}^3$ and $\tilde{x}^1 > \tilde{x}^2$ is only a sufficient condition for $\tilde{a}^1$ to be decreasing in the tax rate. The same relation can hold also if $\tilde{x}^1 > \tilde{x}^3$ and $\tilde{x}^1 < \tilde{x}^2$, or if $\tilde{x}^1 < \tilde{x}^3$ and $\tilde{x}^1 > \tilde{x}^2$, provided that $\tilde{\lambda}_{aa}^2(\tilde{x}^1 - \tilde{x}^3) + \tilde{\lambda}_{aa}^3(\tilde{x}^1 - \tilde{x}^2) < 0$.

Eqs. (19)-(22) and Eq. (24) show that while the impact of a marginal change in t on smoker's decisions (which is equivalent to that of a change in the price of tobacco) depends on the taste parameters ρ^l for tobacco consumption and α^l for consumption locations, the impact of a marginal change in z depends also on the intensity of future health costs γ, on the discount factor δ, and on the triplet of taste parameters (κ, θ, ζ) shaping the size of the marginal impact of z on the smoker's degree of self-control β.

Turning, finally, to the smoking ban in type 3 locations, we find that an increase in r induces the smoker to reduce $\tilde{x}^3$ and to move her consumption activities from type 3 to type 1 and type 2 locations (provided that complying with the ban is costly for the smoker, i.e., $\xi > 0$):

$$\tilde{a}_r^1 = -\tilde{\lambda}_{aa}^2 \xi \tilde{x}^3 \tilde{\Delta} \geq 0, \qquad \tilde{a}_r^2 = -\tilde{\lambda}_{aa}^1 \xi \tilde{x}^3 \tilde{\Delta} \geq 0, \qquad \tilde{x}_r^1 = \tilde{x}_r^2 = 0, \tag{25}$$

$$\tilde{a}_r^3 = -\tilde{a}_r^1 - \tilde{a}_r^2 \leq 0, \qquad \tilde{x}_r^3 = \xi \tilde{x}_t^3 < 0. \tag{26}$$

Hence, while an increase in r reduces tobacco consumption $\tilde{a}^l \tilde{x}^l$ in type 3 locations, it increases it in type 1 and type 2 locations. The impact on total consumption, given by

$$\tilde{x}_r = \tilde{a}^3 \tilde{x}_r^3 + \sum\nolimits_{l=1}^{3} \tilde{a}_r^l \tilde{x}^l = \xi (\tilde{a}^3 \tilde{x}^3)_t, \tag{27}$$

is thus of ambiguous sign. Note however, as Eq. (27) shows, that the impact of r on $\tilde{x}$ is proportional (by the factor ξ) to that of t on $\tilde{a}^3 \tilde{x}^3$. The result follows immediately by combining Eqs. (25)-(26) with Eqs. (20)-(22), to obtain:

$$\sum\nolimits_{l=1}^{3} \tilde{a}_r^l \tilde{x}^l = \left[\tilde{\lambda}_{aa}^1 (\tilde{x}^3 - \tilde{x}^2) + \tilde{\lambda}_{aa}^2 (\tilde{x}^3 - \tilde{x}^1) \right] \xi \tilde{x}^3 \tilde{\Delta} = \xi \tilde{a}_t^3 \tilde{x}^3.$$

The results of the above comparative statics are summarized in the following proposition.

Proposition 1 *The impact of policy instruments on overall tobacco consumption is given by*

$$\tilde{x}_\pi < 0, \ \pi = t, z, \qquad \tilde{x}_r \leq 0 \ \textit{if} \ \tilde{a}_t^3 \leq 0, \quad \tilde{x}_r \lesseqgtr 0 \ \textit{if} \ \tilde{a}_t^3 > 0,$$

while the impact on total consumption in the different types of locations is:

$$(\tilde{a}^l \tilde{x}^l)_\pi \leq 0 \ \textit{if} \ \tilde{a}_\pi^l \leq 0, \quad (\tilde{a}^l \tilde{x}^l)_\pi \lesseqgtr 0 \ \textit{if} \ \tilde{a}_\pi^l > 0, \quad \pi = t, z, \quad l = 1, 2, 3,$$

$$(\tilde{a}^l \tilde{x}^l)_r \geq 0, \ l = 1, 2, \qquad (\tilde{a}^3 \tilde{x}^3)_r \leq 0.$$

That stricter enforcement of a smoking ban in type 3 locations can have a positive impact on overall tobacco consumption, or that taxation and prevention programs can increase total consumption in some locations (but never overall consumption) can be further confirmed through numerical simulations, by relying e.g. on a Constant Relative Risk Aversion (CRRA) specification of the utility function.[18]

5 Welfare

5.1 Individual welfare

By substituting the smoker's choices about consumption locations $\tilde{\mathbf{a}}$ into Eq. (15), we obtain the consumer's indirect utility function

$$\tilde{u}(t, z, r) = \sum\nolimits_{l=1}^{3} \left[\tilde{a}^l \tilde{s}^l + \lambda^l(\tilde{a}^l)\right] + I, \tag{28}$$

where, by the envelope theorem, it is

$$\tilde{u}_t = -\tilde{x}, \qquad \tilde{u}_z = \beta_z \delta\gamma \tilde{u}_t, \qquad \tilde{u}_r = -\xi \tilde{a}^3 \tilde{x}^3. \tag{29}$$

In order to define a measure of consumer's welfare to be used for the normative analysis of the optimal regulation of tobacco consumption, we follow Kőszegi (2005) by considering a three-period framework. In period I, the consumer evaluates and plans her period II consumption activities. In period II, actual decisions are taken and consumption takes place. Finally, in period III, the individual suffers the health harm, which is proportional to the amount of tobacco consumed in period II.

In this setup, the distinction between period I and period II consumer's preferences is crucial. In particular, the utility function defined in Eq. (8) is the consumer's period II 'decision' function; i.e., the objective function that dictates her choices when consumption actually takes place. The consumer's period I utility function is instead defined as equal to

$$w(\mathbf{x}, \mathbf{a}) = \sum\nolimits_{l=1}^{3} a^l \left[v^l(x^l) - \delta\gamma x^l - px^l\right] - r\xi a^3 x^3 + \sum\nolimits_{l=1}^{3} \lambda^l(a^l) + I. \tag{30}$$

[18] Preliminar numerical results not reported here show that if the consumer's preferences in (and among) consumption locations are not too heterogeneous, then $(\tilde{a}^l \tilde{x}^l)_\pi \leq 0$, $\pi = t, z$, $l = 1, 2, 3$, so that taxation and antismoking campaigns have a negative impact on total tobacco consumption in all types of locations. Moreover, we find that $\tilde{x}_r \leq 0$, suggesting that a smoking ban in type 3 locations has a negative impact on overall tobacco consumption. Only highly heterogeneous preferences among consumption locations can yield effects of the opposite sign.

What distinguishes the utility function in Eq. (8) from that in Eq. (30) is the presence, in the former, of the quasi-hyperbolic discounting parameter β (Laibson, 1997, O'Donoghue and Rabin, 1999) in front of period III health costs. Quasi-hyperbolic discounting means that while the marginal rate of substitution between two temporally subsequent welfare outcomes, both occurring in the future, is equal to the discount factor δ, that between a current and an immediately subsequent outcome is equal to $\beta\delta$. Hence, when $\beta < 1$, the individual assigns a relatively greater weight to current than to future outcomes. Following the pertinent literature, we can speak of different 'selves' of the same individual in different time periods. At time I, 'self-I', when considering the optimal consumption of harmful goods she would like to undertake at time II, trades-off future (time II) hedonic pleasure and future (time III) health costs at the discount factor δ. However, when the actual choice is made at time II, 'self-II' trades-off current pleasure with future health damages at the quasi-hyperbolic discount factor $\beta\delta$. This implies, for $\beta < 1$, that the actual consumption of harmful goods made by 'self-II' is greater than that planned by 'self-I', because the former has preferences that are biased in favor of immediate gratification and she behaves in an impatient, time inconsistent, manner (from the point of view of 'self-I').

In Section 3.3, we employed the 'self-II' utility function (8) to carry out the positive analysis of consumer's actual behavior. In line with a consolidated literature on the optimal taxation of sin goods (e.g., Gruber and Kőszegi, 2004, Kőszegi, 2005, O'Donoghue and Rabin, 2006), we use instead the 'self-I' utility function (30), evaluated at the actual consumption choices $(\tilde{\mathbf{x}}, \tilde{\mathbf{a}})$, to define a measure of consumer's welfare for the normative analysis. In short, the premise underlying the welfare criterion is that 'self-II', although lacking of self-control and behaving impulsively, aspires to behave rationally in line with the preferences of her 'self-I', which are those representing her true welfare.[19]

Let $\tilde{w} = w(\tilde{\mathbf{x}}, \tilde{\mathbf{a}})$ be the welfare function (30) evaluated at the consumption choices $(\tilde{\mathbf{x}}, \tilde{\mathbf{a}})$ that maximize the utility function (8), giving indirect utility $\tilde{u} = u(\tilde{\mathbf{x}}, \tilde{\mathbf{a}})$. It is immediate to see that the welfare measure $\tilde{w}$ and the indirect utility $\tilde{u}$ are linked by the following equation:

$$\tilde{w}(t, z, r) = \tilde{u} - (1 - \beta)\delta\gamma\tilde{x}. \tag{31}$$

[19] See Gruber and Kőszegi (2004), Kőszegi (2005), and O'Donoghue and Rabin (2006), for more articulated justifications of the normative criterion defined above. See instead Bernheim and Rangel (2008) for a critical view and for alternative characterizations of welfare measures.

That is, the welfare measure is obtained by subtracting from the indirect utility the so-called 'internality', which is the component of health harm, $(1-\beta)\delta\gamma\tilde{x}$, that the smoker does not internalize in her consumption decisions because of lack of self- control.

5.2 Social welfare

We consider a population of consumers that is composed of a continuum of heterogeneous individuals, each one characterized by the vector $\Upsilon = (\boldsymbol{\rho}, \xi, \boldsymbol{\alpha}, \gamma, \delta, \kappa, \theta, \zeta)$, $\boldsymbol{\rho} = (\rho^1, \rho^2, \rho^3)$, $\boldsymbol{\alpha} = (\alpha^1, \alpha^2, \alpha^3)$, of individual attributes. A specific vector Υ thus denotes a type of consumer. Let $F(\Upsilon)$ be the cumulative distribution of types on the support set of the parameters. The expected value of the parameter υ, $\mathrm{E}[\upsilon]$, with υ element of Υ, denotes the aggregate, or per capita, value for the entire population, and similarly for the expected value, $\mathrm{E}[\chi(.)]$, of the variable $\chi(.)$, function of one or more parameters $\upsilon \in \Upsilon$.

To define aggregate welfare, we adopt the Utilitarian criterion by first adding up the individual welfare levels $\tilde{w}$, defined in Eq. (31), to obtain the aggregate measure $\mathrm{E}[\tilde{w}]$, and then by considering revenues from tobacco taxation, expenditures for policy intervention, and the external costs of smoking.

Revenues from tobacco taxation are equal to $\mathrm{E}[t\tilde{x}]$. Public spending on antismoking campaign programs is z (see Section 3.2). The costs of enforcing a smoking ban in type 3 consumption locations are $C(r) \geq 0$, $C_r \geq 0$, $C_{rr} \geq 0$. We assume, instead, that there are no costs for tax administration as it is standard in the literature on optimal taxation.[20] Aggregate net public revenues are therefore equal to

$$\tilde{T}(t, z, r) = \mathrm{E}[t\tilde{x}(t, z, r)] - z - C(r), \tag{32}$$

which are assumed to be distributed, by means of lump sum transfers, to consumers.

As for the external costs of smoking, recalling that they occur only in non-regulable (type 2) and in regulable (type 3) locations, we assume that they are proportional to aggregate tobacco consumption; i.e.,

$$\tilde{\Gamma}(t, z, r) = \eta^2 \mathrm{E}\left[\tilde{a}^2 \tilde{x}^2\right] + (1-r)\eta^3 \mathrm{E}\left[\tilde{a}^3 \tilde{x}^3\right], \tag{33}$$

[20] Of course, we are not denying that the taxation of tobacco products needs careful design and administration, especially for contrasting tax avoidance and evasion. In fact, two chapters in the recent report by the U.S. National Cancer Institute and World Health Organization (2016, chapters 5 and 14) are dedicated to these issues.

where $\eta^2 > 0$ and $\eta^3 > 0$ are the exogenously given per-unit-of-consumption external costs in type 2 and type 3 locations, respectively. Note that in type 3 locations the externality is proportional to the degree of effectiveness, $1 - r$, of the smoking ban. In particular, with perfect enforcement (i.e., $r = 1$), there is no externality. Note also that stricter enforcement r of the smoking ban in type 3 locations increases the externality in type 2 locations, since $(\tilde{a}^2 \tilde{x}^2)_r > 0$.[21] Instead, taxation and antismoking campaigns usually curb both types of external costs, as we remarked in Section 4.

Our comprehensive measure of social welfare is then given by:

$$\tilde{\Omega}(t, z, r) = \mathrm{E}[\tilde{w}] - \tilde{\Gamma} + \tilde{T}. \tag{34}$$

Note that the quasi-linearity of individual utility functions implies that the marginal utility of income is constant and equal to one for all consumers, and that there are no income effects on the demand for tobacco. This, combined with the Utilitarian criterion, entails that we can sum the net public revenues $\tilde{T}$ and the external costs $\tilde{\Gamma}$ to aggregate consumers' welfare $\mathrm{E}[\tilde{w}]$ without loss of generality. In fact, social welfare as defined in Eq. (34) is invariant with respect to the actual distribution of net revenues among consumers through lump sum transfers,[22] as well as to the specific incidence of the external costs of tobacco usage on consumers. In terms of our normative analysis, all this implies is that the social objective function (34) accounts only for the benefits and costs of policy intervention in terms of efficiency. Indeed, any distributional issues among heterogeneous individuals are not accounted for.

6 Efficient policies

In this section, we characterize the efficient structure of tobacco regulation, by considering a policy maker that sets the policy instruments (t, z, r) with the aim of maximizing the social welfare function defined above in Eq. (34). We assume throughout that $\mathrm{E}\left[(\tilde{a}^l \tilde{x}^l)_\pi\right] \leq 0$, $\pi = t, z$, $l = 1, 2, 3$, and $\mathrm{E}[\tilde{x}_r] \leq 0$.[23]

[21] This is the effect empirically assessed by Cornaglia and D'Adda (2010) in their study of the impact of smoking bans in public places on passive smoking by children in their private homes.

[22] For the same reasons, in Section 3.3 it was possible to ignore the lump sum transfer paid by the government in the consumer's budget constraint.

[23] Recall that at the individual level the impact of the policy instruments can go in the opposite direction, but only for individuals with preferences for consumption locations that are highly heterogeneous (see Section 4). Hence, if the latter type of individuals represents, as it is likely the case, a

In order to study the benefits and costs of policy intervention, we differentiate Eq. (34) with respect to the policy instruments, obtaining

$$\tilde{\Omega}_t = \mathrm{E}\left[\tilde{u}_t - (1-\beta)\delta\gamma\tilde{x}_t\right] - \tilde{\Gamma}_t + t\,\mathrm{E}\left[\tilde{x}_t\right] + \mathrm{E}\left[\tilde{x}\right], \tag{35}$$

$$\tilde{\Omega}_z = \mathrm{E}\left[\tilde{u}_z - (1-\beta)\delta\gamma\tilde{x}_z + \beta_z\delta\gamma\tilde{x}\right] - \tilde{\Gamma}_z + t\,\mathrm{E}\left[\tilde{x}_z\right] - 1, \tag{36}$$

$$\tilde{\Omega}_r = \mathrm{E}\left[\tilde{u}_r - (1-\beta)\delta\gamma\tilde{x}_r\right] - \tilde{\Gamma}_r + t\,\mathrm{E}\left[\tilde{x}_r\right] - C_r. \tag{37}$$

Substituting $\tilde{u}_t = -\tilde{x}$, $\tilde{u}_z = -\beta_z\delta\gamma\tilde{x}$, and $\tilde{u}_r = -\xi\tilde{a}^3\tilde{x}^3$, in Eqs. (35), (36) and (37), respectively, we can express the partial derivatives as follows:

$$\tilde{\Omega}_t = -\mathrm{E}\left[(1-\beta)\delta\gamma\tilde{x}_t\right] - \tilde{\Gamma}_t + t\,\mathrm{E}\left[\tilde{x}_t\right], \tag{38}$$

$$\tilde{\Omega}_z = -\mathrm{E}\left[(1-\beta)\delta\gamma\tilde{x}_z\right] - \tilde{\Gamma}_z + t\,\mathrm{E}\left[\tilde{x}_z\right] - 1, \tag{39}$$

$$\tilde{\Omega}_r = -\mathrm{E}\left[(1-\beta)\delta\gamma\tilde{x}_r\right] - \tilde{\Gamma}_r + t\,\mathrm{E}\left[\tilde{x}_r\right] - C_r - \mathrm{E}\left[\xi\tilde{a}^3\tilde{x}^3\right], \tag{40}$$

where, by differentiation of Eq. (33), it is

$$\tilde{\Gamma}_\pi = \eta^2\mathrm{E}\left[(\tilde{a}^2\tilde{x}^2)_\pi\right] + (1-r)\eta^3\mathrm{E}\left[(\tilde{a}^3\tilde{x}^3)_\pi\right], \qquad \pi = t, z, \tag{41}$$

$$\tilde{\Gamma}_r = \eta^2\mathrm{E}\left[\tilde{a}_r^2\tilde{x}^2\right] + (1-r)\eta^3\mathrm{E}\left[(\tilde{a}^3\tilde{x}^3)_r\right] - \eta^3\mathrm{E}\left[\tilde{a}^3\tilde{x}^3\right]. \tag{42}$$

Derivatives (38)-(40) highlight the marginal benefits and the marginal costs, in terms of social welfare, stemming from a marginal increase in the respective policy instrument. In each equation, the first two terms on the right hand side represent the marginal benefits ensuing from reductions in the internal and the external costs of smoking, respectively. As for the latter, Eq. (41) shows that both taxation and antismoking campaigns reduce tobacco consumption in the locations in which smoking causes external costs. Eq. (42) shows instead that stricter enforcement of the smoking ban, by making consumers to shift part of their consumption activities from smoke-free (type 3) to non-smoke-free (type 2) locations, produces an increase in the external costs in type 2 locations, and a reduction in type 3. Moreover, the last term in Eq. 42) shows that stricter enforcement in itself bears a negative impact on the external costs in type 3 locations.

Turning to marginal costs, the third term on the right hand side of Eqs. (38)-(40) represents the marginal excess burden caused by the corresponding policy instrument, expressed as the part of consumers' surplus reduction that is not returned back to

minority of the entire population, it is reasonable to assume that, in the aggregate, the impact of policy instruments on tobacco consumption is of the expected, negative, sign.

individuals through the distribution of tax revenues. The marginal costs of government spending for antismoking campaigns and for the enforcement of a smoking ban in type 3 locations are shown as the fourth term in Eqs. (39)-(40), respectively; this kind of term is absent in Eq. (38), since we have assumed that taxation is costless to administer. Finally, there is a specific term —the last one— in Eq. (40), representing the marginal welfare costs sustained by smokers to comply with stricter enforcement of the smoking ban.

6.1 Optimal tobacco taxation

The derivatives in Eqs. (38)-(40) are now used characterize the optimal structure of tobacco control policy, starting with taxation. By using the covariance formula to expand the first term on the right hand side of Eq. (38), Eq. (41) for $\pi = t$, and by setting $\Omega_t = 0$ and rearranging, the first order condition for the optimal tax rate can be expressed as follows:[24]

$$t = \mathrm{E}\left[(1-\beta)\delta\gamma\right] + \frac{\mathrm{cov}\left[(1-\beta)\delta\gamma,\, \tilde{x}_t\right]}{\mathrm{E}\left[\tilde{x}_t\right]} + \eta^2 \frac{\mathrm{E}\left[(\tilde{a}^2\tilde{x}^2)_t\right]}{\mathrm{E}\left[\tilde{x}_t\right]} + (1-r)\eta^3 \frac{\mathrm{E}\left[(\tilde{a}^3\tilde{x}^3)_t\right]}{\mathrm{E}\left[\tilde{x}_t\right]}. \quad (43)$$

Eq. (43) is not an explicit solution for the optimal tax rate, since t appears on both sides of the equation. However, it highlights that the optimal tax rate is made up of four terms, the first two referred to the internal costs, the other two to the external costs, of smoking.

The first term in Eq. (43) equals the population-average marginal-internality, i.e., the average value of future health costs, per unit of tobacco consumption, that smokers fail internalize into their consumption decisions because of lack of self control. The second term depends on how the individual internal costs are linked to the sensitivity to taxation of the individual demands for tobacco. In particular, if the covariance between $(1-\beta)\delta\gamma$ and $\tilde{x}_t$ is negative, then this second component of the tax rate is positive, since $\mathrm{E}\left[\tilde{x}_t\right]$ appearing at the denominator is negative. The economic interpretation is simple. A negative correlation means that taxation is more effective at discouraging smoking consumption among individuals characterized by high internal costs, while it is less effective with those characterized by low internal costs. In this case, it is optimal to set a tax rate that exceeds the population-average marginal-externality —the first term of Eq. (43), since taxation is relatively more effective at discouraging smoking among

[24] In this section, and in Sections 6.2 and 6.3, we examine only the first order conditions for maximizing social welfare, assuming that second order conditions hold true.

individuals with high internal costs and elastic demand for tobacco products than among individuals with low costs and rigid demand. Similar, but reversed, arguments hold if the covariance term is positive. We further investigate on the sign of this covariance term at the end of this section, where we consider a numerical simulation of optimal policies.

The third and the fourth components of the tax rate shown in Eq. (43) correct for the external costs of smoking in type 2 and type 3 locations, respectively. The third term is equal to η^2, the externality produced by each unit of tobacco consumption in type 2 locations, multiplied by $\mathrm{E}\left[(\tilde{a}^2\tilde{x}^2)_t\right]/\mathrm{E}\left[\tilde{x}_t\right]$, the ratio between the slope of tobacco demand in type 2 locations and the slope of overall demand. Similarly, the fourth term is equal to the product between $(1-r)\eta^3$ and $\mathrm{E}\left[(\tilde{a}^3\tilde{x}^3)_t\right]/\mathrm{E}\left[\tilde{x}_t\right]$. Both ratios are positive and less than unity, since $\tilde{x}_t = \sum_{l=1}^{3}(\tilde{a}^l\tilde{x}^l)_t$. Note also that the unit external costs η^2 and $(1-r)\eta^3$ are not weighted by the respective absolute consumption share in the location, $\mathrm{E}\left[\tilde{a}^l\tilde{x}^l\right]/\mathrm{E}\left[\tilde{x}\right]$, but by the relative behavioral response to taxation, $\mathrm{E}\left[(\tilde{a}^l\tilde{x}^l)_t\right]/\mathrm{E}\left[\tilde{x}_t\right]$. This means that, for instance, if smoking is mostly concentrated in a given location, but it is barely discouraged by taxation in that location, then there is no point in trying to use the tax instrument to curb the external costs occurring therein.

Let $t^*(z,r)$ be the optimal tax rate that solves Eq. (43). It is then immediate to see from Eq. (43) that an increase in spending z on antismoking campaigns, by lowering β, lowers the optimal tax rate. The same effect follows from stricter enforcement r of the smoking ban, which lowers the unit externality, $(1-r)\eta^3$, in type 3 locations.[25]

6.2 Antismoking campaigns

An interesting question to ask is whether, in the presence of an optimal tobacco tax, other policy instruments, such as antismoking campaigns and direct regulation, can play a role in complementing taxation. We address this question by first focusing on antismoking campaigns.

[25] These are only the direct effects of instruments z and r on the efficient tax rate. There are, of course, also indirect effects running through their impact on the demand functions.

Standard algebra shows that Eq. (39) can be rewritten, for $t = t^*(z, r)$, as[26]

$$\tilde{\Omega}_z^* = -1 - \mathrm{E}\left[\tilde{x}_z^*\right]\left\{\frac{\mathrm{cov}\left[(1-\beta)\delta\gamma,\, \tilde{x}_z^*\right]}{\mathrm{E}\left[\tilde{x}_z^*\right]} - \frac{\mathrm{cov}\left[(1-\beta)\delta\gamma,\, \tilde{x}_t^*\right]}{\mathrm{E}\left[\tilde{x}_t^*\right]}\right\} +$$
$$-\mathrm{E}\left[\tilde{x}_z^*\right]\eta^2\left\{\frac{\mathrm{E}\left[(\tilde{a}^2\tilde{x}^2)_z^*\right]}{\mathrm{E}\left[\tilde{x}_z^*\right]} - \frac{\mathrm{E}\left[(\tilde{a}^2\tilde{x}^2)_t^*\right]}{\mathrm{E}\left[\tilde{x}_t^*\right]}\right\} +$$
$$-\mathrm{E}\left[\tilde{x}_z^*\right](1-r)\eta^3\left\{\frac{\mathrm{E}\left[(\tilde{a}^3\tilde{x}^3)_z^*\right]}{\mathrm{E}\left[\tilde{x}_z^*\right]} - \frac{\mathrm{E}\left[(\tilde{a}^3\tilde{x}^3)_t^*\right]}{\mathrm{E}\left[\tilde{x}_t^*\right]}\right\}. \quad (44)$$

The first term on the right hand side of Eq. (44), equal to minus one, is the direct welfare cost of an additional dollar of public spending z directed to antismoking campaigns programs. An additional dollar of spending is thus socially worth if it brings about welfare benefits of at least the same value, which are represented by the other three terms in the equation. Regarding the latter, notice that they are all made up by the difference of two terms, the second one of which is equal to one of the last three components of the optimal tax rate defined in Eq. (43).

Consider, to start with, the second term in the first line of Eq. (44). The two fractions in braces have the same structure: the first one reflects the behavioral response, $\tilde{x}_z^*$, of tobacco consumption to an increase in antismoking programs, while the second one reflects the behavioral response, $\tilde{x}_t^*$, to an increase in taxation. Moreover, the latter fraction is equal to the second component of the optimal tax rate defined in Eq. (43). The term in the first line of Eq. (44) can therefore be easily interpreted as follows. Recall that if the individual internal costs of smoking $(1-\beta)\delta\gamma$ are negatively (positively) correlated with the behavioral response $\tilde{x}_t^*$ to taxation then, based on Eq. (43), the optimal tax rate exceeds (falls short of) the average value of internal costs, for the reasons explained above. Hence, according to the first line of Eq. (44), antismoking campaigns bring about additional welfare benefits, on top of those already reaped through taxation, only insofar as the degree of correlation of $(1-\beta)\delta\gamma$ with $\tilde{x}_z^*$ exceeds that with $\tilde{x}_t^*$. Otherwise, given that an optimal tax is already in place, it is useless to introduce costly prevention programs.

The next step is to show that, under fairly general conditions, the term in braces in the first line of Eq. (44) is positive, implying that antismoking campaigns are indeed a useful instrument to regulate tobacco consumption even if an optimal tax is already employed. To see this, it is useful to consider a special case in which some of the taste parameters that characterize smokers' behavior are uncorrelated to each other.

[26] Note that all variables that are functions of t^* are identified through the superscript $*$.

In particular, assume that (δ, γ) are uncorrelated with both (β, β_z) and $\tilde{x}_t^*$, and that also the latter are not correlated. In this case, using the fact that $\tilde{x}_z^* = \beta_z \delta\gamma \tilde{x}_t^*$, it is immediate to see that

$$\frac{\text{cov}\left[(1-\beta)\delta\gamma,\, \tilde{x}_t^*\right]}{\text{E}\left[\tilde{x}_t^*\right]} = 0,$$

$$\frac{\text{cov}\left[(1-\beta)\delta\gamma,\, \tilde{x}_z^*\right]}{\text{E}\left[\tilde{x}_z^*\right]} = \frac{\text{E}\left[(1-\beta)\beta_z\right] \text{var}\left[\delta\gamma\right]}{\text{E}\left[\beta_z\right] \text{E}\left[\delta\gamma\right]} + \frac{\text{cov}\left[(1-\beta),\, \beta_z\right] \text{E}\left[\delta\gamma\right]}{\text{E}\left[\beta_z\right]} > 0. \quad (45)$$

In this special case, it is apparent that the two policy instruments have distinct roles in correcting for excessive tobacco consumption due to lack of self-control by smokers. On the one hand, taxation targets the 'average' smoker, by increasing the price of tobacco by an amount equal to the average internal cost, $\text{E}\left[(1-\beta)\delta\gamma\right]$. With no correlation between $(1-\beta)\delta\gamma$ and $\tilde{x}_t^*$, this is the only role taxation can play, since the second term in Eq. (43) is nil. On the other hand, antismoking campaigns determine behavioral responses that are more diversified than those produced by taxation. Since $\tilde{x}_z^* = \beta_z \delta\gamma \tilde{x}_t^*$, it means that prevention programs are more effective at discouraging smoking by individuals with large health costs and with low levels of self-control (if β_z is negatively correlated with β). As Eq. (45) shows, a dollar increase in antismoking spending produces a welfare gain if $\text{var}\left[\delta\gamma\right] > 0$ and/or $\text{cov}\left[(1-\beta),\, \beta_z\right] > 0$. The first condition is self evident: smokers do have different discount factors δ and do suffer different health damages γ from tobacco use. Also the second condition is empirically plausible: the more self-controlled an individual is, i.e., the lower is $1-\beta$, the smaller should be the impact β_z of prevention programs on her degree of self control.

Going back to the general case, it is clear that the role of prevention programs outlined above continues to hold — although perhaps attenuated— even in the presence of some degree of correlation among (δ, γ), (β, β_z) and $\tilde{x}_t^*$.

We finally turn to the second and the third line of Eq. (44), which refer to the external costs of smoking. As already highlighted when discussing the term in the first line of the equation, also the second and the third lines contain the difference between a term specific to prevention programs and a term specific to taxation, with the latter equal to a corresponding element of the optimal tax rate defined in Eq. (43). This shows that antismoking programs can yield additional welfare gains on externalities abatement with respect to those already achieved through an optimally set tax only if the former determines additional behavioral responses on smokers characterized by high health costs and/or low self-control. By simple algebraic manipulation of these terms, we can show that in this case prevention programs do not provide sizeable additional benefits. In fact, observe that:

$$\frac{\mathrm{E}\left[(\tilde{a}^l\tilde{x}^l)^*_z\right]}{\mathrm{E}\left[\tilde{x}^*_z\right]}-\frac{\mathrm{E}\left[(\tilde{a}^l\tilde{x}^l)^*_t\right]}{\mathrm{E}\left[\tilde{x}^*_t\right]}=\frac{\mathrm{cov}\left[\beta_z\delta\gamma,\,(\tilde{a}^l\tilde{x}^l)^*_t\right]}{\mathrm{E}\left[(\tilde{a}^l\tilde{x}^l)^*_t\right]}-\frac{\mathrm{cov}\left[\beta_z\delta\gamma,\,\tilde{x}^*_t\right]}{\mathrm{E}\left[\tilde{x}^*_t\right]},\qquad l=2,3. \tag{46}$$

This expression can be significantly different from zero only if the correlation between $\beta_z\delta\gamma$ and the slope of tobacco demand in location l, $(\tilde{a}^l\tilde{x}^l)^*_t$, is significantly different from that with overall demand, $\tilde{x}^*_t$. In this respect, we hold that, save for very peculiar cases, the correlation between $\beta_z\delta\gamma$ and the slope of tobacco demand is quite similar across locations, implying that the expression in Eq. (46) is approximately equal to zero, which means that also the terms in the second and third lines of Eq. (44) are at most of negligible size.

To summarize the findings of this section, the analysis of Eq. (44) —expressing the impact on social welfare of a marginal increase in spending on antismoking programs— shows that antismoking programs can usefully complement taxation for reducing the internal costs of smoking due to their lack of self-control; the requirement is that the welfare benefits exceed marginal costs. There is no significant role that antismoking campaigns can play to complement taxation with respect to reducing the external costs produced by tobacco consumption.

6.3 Smoking bans

We finally turn to smoking bans in type 3 locations. By manipulating the terms in Eq. (40), we obtain

$$\begin{aligned}\tilde{\Omega}^*_r \;=\;& \mathrm{E}\left[(\eta^3-\xi)(\tilde{a}^3\tilde{x}^3)^*\right]-C_r-\mathrm{E}\left[\tilde{x}^*_r\right](1-r)\eta^3\left\{\frac{\mathrm{E}\left[(\tilde{a}^3\tilde{x}^3)^*_r\right]}{\mathrm{E}\left[\tilde{x}^*_r\right]}-\frac{\mathrm{E}\left[(\tilde{a}^3\tilde{x}^3)^*_t\right]}{\mathrm{E}\left[\tilde{x}^*_t\right]}\right\}+\\ &-\mathrm{E}\left[\tilde{x}^*_r\right]\eta^2\left\{\frac{\mathrm{E}\left[(\tilde{a}^2\tilde{x}^2)^*_r\right]}{\mathrm{E}\left[\tilde{x}^*_r\right]}-\frac{\mathrm{E}\left[(\tilde{a}^2\tilde{x}^2)^*_t\right]}{\mathrm{E}\left[\tilde{x}^*_t\right]}\right\}+\\ &-\mathrm{E}\left[\tilde{x}^*_r\right]\left\{\frac{\mathrm{cov}\left[(1-\beta)\delta\gamma,\,\tilde{x}^*_r\right]}{\mathrm{E}\left[\tilde{x}^*_r\right]}-\frac{\mathrm{cov}\left[(1-\beta)\delta\gamma,\,\tilde{x}^*_t\right]}{\mathrm{E}\left[\tilde{x}^*_t\right]}\right\}.\end{aligned} \tag{47}$$

The first term on the right hand side of Eq. (47) represents the marginal benefits of stricter enforcement of the smoking ban in terms of external costs abatement, net of the compliance costs sustained by smokers. The second term represents the marginal costs of enforcement, while the third term is the analogous of the corresponding terms in the second and third lines of Eq. (44), and it is therefore at most of negligible size. As for the fourth term in Eq. (47), it captures the higher external costs generated by increased tobacco use in non-regulable type 2 locations. Finally, the fifth term highlights the marginal benefits stemming from the fact that stricter regulation is particularly effective in discouraging tobacco use by smokers with high compliance costs.

Overall, Eq. (47) shows that, also in the presence of an optimal tobacco tax and antismoking programs, smoking bans are useful to further improve the efficiency of policy intervention, at least to the extent that the benefits achieved through the ban in regulable locations overweight the costs imposed in terms of increased consumption in non-regulable locations.

7 Concluding remarks

This paper investigates the optimal design of policies controlling the consumption of tobacco based on the joint use of three instruments: excise taxes, antismoking programs and smoking bans.

We find that antismoking programs and smoking restrictions can usefully complement taxation in controlling tobacco consumption. While taxes can correct the average externalities and internalities induced by smoking, the other two policy instruments address smokers' heterogeneity. Furthermore, smoking restrictions also help curbing externalities that are only partially corrected by uniform taxation, as the latter can not properly account for the externalities imposed by smokers in different environments.

The paper can be extended along several dimensions. While our analysis combines three major policy instruments for controlling tobacco consumption, additional more specific measures have been neglected, such as restrictions and bans on advertising of tobacco products, or regulatory policies that target specific groups of individuals, like youth access laws. Furthermore, firms may combine lobbying of the policy maker with activities aimed at directly affecting consumers' choices, such as information campaigns aimed at counteracting public prevention programs. The introduction of these additional features into the analysis is a line of research to be pursued in the future.

Cremer *et al.* (2012) examine how the optimal structure of sin taxes is affected by the possibility that some individuals — realizing that their past sin-good consumption was a mistake — decide to buy health care coverage to insure against future health harms. This type of setting could be usefully combined with ours, by allowing our policy instruments — namely prevention programs — to influence or trigger the choice of investing in health care.

Additionally, our setting could be extended in future work to explicitly deal with the social aspects of smoking — i.e. the fact that smoking habits may ensue from imitation and social interactions, or cultural factors(see e.g. Nyborg and Rege (2003), Cutler and Glaeser (2010), Sari (2013) and Christopoulou and Lillard (2015).

Finally, in our model, tobacco taxation is of the *specific* type. This notwithstanding, in many countries also an *ad valorem* tax is used (in the EU, for instance, both VAT and excises are levied on tobacco and alcoholic products). Since ad valorem and specific taxation are not equivalent in oligopolistic markets (see, e.g. Myles, 1995), it might be interesting to examine the optimal mix between the two types of taxes in a setup characterized by imperfect competition.

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Table 1: U.S. States Cigarette tax rates, Tax revenue, Tobacco control programs, Total Alciati score, Smoke free air laws index

STATE	CTR (¢ p.p.) 2014	REV ($ p.c.) 2011	TCP ($ p.c.) 2011	ALC (index 0-39) 2006	SFAL (index 0-46) 2008
Alabama	42,5 (1)	29,01	1,52	15	14
Alaska	200,0	85,05	15,73	14	13
Arizona	200,0	50,66	3,43	9	45
Arkansas	115,0	68,18	4,78	16	38
California	87,0	22,42	2,41	25	31
Colorado	84,0	33,56	1,91	14	46
Connecticut	340,0	109,32	0,60	22	28
Delaware	160,0	138,56	10,94	21	41
Florida	133,9 (2)	65,63	3,64	13	38
Georgia	37,0	19,82	0,62	15	30
Hawaii	320,0	98,67	7,81	13	44
Idaho	57,0	25,59	2,00	26	35
Illinois	198,0 (1)	44,35	1,43	9	41
Indiana	99,5	68,75	1,73	17	4
Iowa	136,0	66,63	3,73	18	46
Kansas	79,0	33,31	1,13	14	17
Kentucky	60,0 (3)	61,75	1,05	19	2
Louisiana	36,0	28,14	2,38	17	42
Maine	200,0	102,25	8,98	24	34
Maryland	200,0	68,47	1,11	7	41
Massachusetts	351,0	85,51	1,68	9	41
Michigan	200,0	92,94	0,64	13	15
Minnesota	283,0 (4)	80,60	4,05	16	17
Mississippi	68,0	45,99	4,70	18	8
Missouri	17,0 (1)	15,46	1,05	16	20
Montana	170,0	76,54	9,75	22	38
Nebraska	64,0	33,87	2,52	10	16
Nevada	80,0	36,27	3,23	15	43
New Hampshire	178,0	165,30	1,15	20	19
New Jersey	270,0	88,83	0,34	20	46
New Mexico	166,0	44,80	4,17	22	38
New York	435,0 (1)	79,32	3,61	26	39
North Carolina	45,0	27,08	2,21	11	3
North Dakota	44,0	29,88	13,94	12	31
Ohio	125,0	70,68	0,76	12	41
Oklahoma	103,0	63,10	6,41	25	32
Oregon	131,0	54,89	2,70	16	26
Pennsylvania	160,0	90,02	1,82	15	38
Rhode Island	350,0	125,96	3,78	18	41
South	57,0	29,56	2,16	14	13
South Dakota	153,0	66,28	6,00	13	34
Tennessee	62,0 3)	44,60	0,42	27	16
Texas	141,0	52,86	0,76	29	5
Utah	170,0	37,12	3,15	16	39
Vermont	262,0	108,41	9,65	28	33
Virginia	30,0 (1)	19,89	1,41	16	11
Washington	302,5	63,56	3,07	28	42
West Virginia	55,0	59,27	4,01	12	4
Wisconsin	252,0	106,60	1,66	17	14
Wyoming	60,0	42,03	12,14	25	n.a.
Dist. of Columbia	250,0 (5)	58,85	6,51	12	42
U.S. Median	**136,0**	**61,75**	**2,52**	**16**	**34**

CTR: Excise tax rate in USD cents per pack of 20 cigarettes. Source: Federation of Tax Administrators, January 1, 2014. Available at http://www.taxadmin.org/fta/rate/cigarette.pdf
(1) Counties and cities may impose an additional tax on a pack of cigarettes in AL, 1¢ to 6¢; IL, 10¢ to 15¢; MO, 4¢ to 7¢; NYC $1.50; TN, 1¢; and VA, 2¢ to 15¢. **(2)** Florida's rate includes a surcharge of $1 per pack. **(3)** Dealers pay an additional enforcement and administrative fee of 0.1¢ per pack in KY and 0.05¢ in TN. **(4)** In addition, Minnesota imposes an in lieu cigarette sales tax determined annually by the Department. The current rate is 36.2¢ through December 31, 2013. **(5)** In addition, DC imposes an in lieu cigarette sales tax calculated every March 31. The current rate is 36¢.

REV: Annual gross tax revenue from cigarette sales in USD, per capita. Data are based on fiscal years ending June 30. Source: CDC-STATE System: Trend Report.

TCP: Total funds allocated for tobacco control programs, in USD, per capita, summed from state, federal, ALF, and RWJF funding sources. Source: CDC-STATE System: Trend Report.

ALC: Total Alciati score (min: 0, max: 39). Source: ImpactTeen. The index measures the extensiveness of state tobacco control youth access laws as, for instance, the level of restrictions for minimum age provision, the degree of provisions for photo identification requirements to buy tobacco products, the level of restrictions on selling tobacco products through a vending machine, the degree of graduated penalties to retailers for violation of youth access laws, and so on. Source: ImpacTEEN.

SFAL: Smoke Free Air Laws index (min: 0, max: 46). Source: ImpactTeen. The index is an aggregate measure of the level of SFA restrictions by state laws in 12 classified sites: government worksites, private worksites, child care centers, health care facilities, restaurants, recreational and cultural facilities, public transit, shopping malls, public and private schools, free standing bars. This aggregate measure is our own computation from the disaggregated data computed by ImpacTEEN.

REV and TCP data: http://apps.nccd.cdc.gov/statesystem/TrendReport/TrendReports.aspx; ALC and SFAL data: http://www.impacteen.org/tobaccodata.htm