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 individuals to take smoking decisions that are more self-controlled, 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 campaigns usefully complement taxation by specifically targeting smokers with above-average health harms and below-average degrees of self-control, while smoking bans target the external costs due to smoking.

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

JEL Codes: I18, H23.

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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 on youth access to tobacco products — have gained importance complementing taxation as tobacco control policies. Indeed, the empirical evidence reported in Section 2 shows that antismoking campaigns, as well as smoking restriction laws, are used jointly with taxation and play an important role in tobacco control. 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) antismoking campaigns that affect consumption by inducing individuals to be more self-controlled when taking smoking decisions, 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 Köszegi (2005) to examine the socially optimal level of taxation of a harmful good.\(^3\) We extend their setup by introducing the two regulatory instruments referred

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\(^1\)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.A., 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 theoretical model by Adda and Cornaglia (2010), which is used to derive testable predictions for an empirical analysis on the interplay among bans, taxes and passive smoking. There are instead several empirical and experimental papers investigating the impact of taxation and other control policies on tobacco consumption, as we review in Section 2.

\(^3\)Other models, in particular Gruber and Köszegi (2004), provide a more articulated characterization of tobacco consumption, focusing also on dynamic issues. Bernheim and Rangel (2004) develop a framework, based on evidence from neurosciences, in which the consumption of harmful goods is due to ‘mistakes’ that are triggered by environmental cues. Their model is particularly appropriate for the
to above, 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 responsiveness to antismoking mass media campaigns. 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 is applicable (like public sites), in the form of smoking bans aimed at curbing external costs, 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 that prevention programs and smoking restrictions are very useful in mitigating the inefficiencies that are left unaddressed by uniform taxation.

In particular, our results show that taxation and smoking bans are substitute instruments for correcting the externalities due to smoking in consumption locations where free-air legislation can be effectively enforced. While smoking bans correct for the external costs of smoking in the consumption locations under their coverage, taxation corrects for the average marginal internalities induced by smoking and for the marginal externalities caused by smoking in consumption locations that cannot be regr-
ulated, or that are not worth being regulated, by means of free-air measures. However, being tuned on the characteristics of the ‘average’ smoker, the optimal uniform tax does not properly account for individuals’ heterogeneity in terms of health harms and degree of self-control, and it is precisely for this reason that prevention programs can usefully complement taxation. The optimal tax rate — tailored on the internal costs of the average smoker — is second-best: a higher (lower) tax rate would be desirable for smokers suffering above-average (below-average) health harms or having below-average (above-average) degree of self-control. This is exactly what can be achieved through prevention policies, since, with respect to taxation, they impact relatively more on tobacco consumption by smokers with above-average health harms or below-average degree of self-control than on consumption by smokers with below-average health harms or above-average degree of self-control. Hence, provided that the degree of heterogeneity of the population of smokers is sufficiently high, prevention programs can usefully complement taxation in tobacco regulation.

The implications in terms of the optimal structure of regulation policy are also clearcut. If it is optimal to use all instruments, the second-best optimal tax rate — where taxation is joined by prevention programs and smoking bans to regulate tobacco consumption — is lower than the third-best optimal tax rate — where only taxation is used. That is, the non-price instruments are substitutes of the price instrument. Instead, the non-price instruments are complements of each other, since the introduction of smoking bans, by reducing the optimal tax rate, calls for an increase in the expenditure on prevention programs.

The rest of the paper is organized as follows. Section 2 presents a brief survey of the literature on tobacco regulation, as well as stylized facts on the relevance of the additional policy instruments on which we focus. Section 3 sets up the model, Section 4 defines the social objective function, and Section 5 examines the impact of policy instruments on smoking. The optimal structure of tobacco regulation policies is studied in general terms in Section 6 and through a numerical example in Section 7. Section 8 concludes.

2 Related literature and stylized facts

Most of the available theoretical 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, 2001, Gruber and Köszegi, 2008, and U.S. National Cancer Institute and World Health Organization, 2016, ch. 4, for comprehensive non-technical surveys). 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 Köszegi (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 Köszegi, 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 Köszegi (2004) and Kotakorpi (2008) provide another 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 rather than regressive. 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.

There is a large empirical literature on the impact of taxation on smoking habits. See Chaloupka et al. (2012), and U.S. National Cancer Institute and World Health Organization (2016, ch. 4), for throughout recent accounts. There is also a growing body of empirical studies on the impact of non-price instruments on tobacco consumption, and on their interaction with taxation. For instance, Chaloupka and Wechsler (1997) examine how taxation and smoking restrictions in public places affect tobacco consumption by young adults, while Evans et al. (1999) focus on workplace smoking bans. Rousu et al. (2014) estimate the value for smokers of the information conveyed through warning labels on cigarettes packages.

Of particular interest for our theoretical analysis is the assessment of how antismoking mass media campaigns and smoke-free measures affect smoking behavior. In a recent study, Xu et al. (2015) focus on Tips From Former Smokers (Tips), the first federally funded national mass media antismoking campaign launched in the U.S. in 2012, finding robust evidence that Tips has been cost-effective at successfully reducing morbidity and mortality associated to smoking. Also the recent survey in U.S. National Cancer Institute and World Health Organization (2016, ch. 8) brings evidence that, because of consumers’ limited awareness about the risks of smoking, information programs — including antismoking mass media campaigns — are necessary and effective tools in modern tobacco control policies. As for smoke-free policies, which are mainly based on smoking bans in public places, there is hard evidence that they are effective tools for limiting not only exposure to secondhand smoke, but also for reducing tobacco consumption (see the account in U.S. National Cancer Institute and World Health Organization, 2016, ch. 6).

There is abundant evidence about the diffusion of taxation, antismoking campaigns, and smokefree measures in tobacco control policies around the world. A comprehensive dataset is provided by the Global Health Observatory of the World Health Organization, covering 194 countries. In the following, we focus on the most recent available data (referring to 2014) that indicate, for each of the countries in the sample, how intensively a policy instrument is used by means of a categorical indicator, taking values $i \in \{1, 2, 3, 4, 5\}$ for tax rates and antismoking campaigns, and $i \in \{1, 2, 3, 4, 6\}$ for smoking...
Table 1: Tobacco control indicators in 194 countries (2014)

<table>
<thead>
<tr>
<th>indicator</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>taxation</td>
<td>9</td>
<td>35</td>
<td>54</td>
<td>64</td>
<td>32</td>
<td>–</td>
</tr>
<tr>
<td>antismoking mass media campaigns</td>
<td>20</td>
<td>101</td>
<td>4</td>
<td>30</td>
<td>39</td>
<td>–</td>
</tr>
<tr>
<td>coverage of smoking bans</td>
<td>7</td>
<td>70</td>
<td>47</td>
<td>22</td>
<td>–</td>
<td>48</td>
</tr>
</tbody>
</table>

Source: WHO, Global Health Observatory.

Table 1 shows the distributions of the three indicators. But for the countries for which data are not reported or not categorized (to which it is assigned an index equal to 1), more than two thirds of the remaining countries make a significant use of tobacco taxes (with scores of 3 or 4). The remaining third either barely uses taxes (index 2) or set taxes exceeding 75% of tobacco retail price (index 5). Conversely, 58% and 37% of the countries make a very mild use of antismoking campaigns and smoking bans, respectively, with the remaining countries being much more concentrated around the maximal value of the index rather than the central values.

The distributions of each pairwise combination of the three indicators are represented in Figures 1a-c by means of a scatterplot, where the size of the circles are proportional to the total number of countries characterized by the corresponding pair of indicators (the number of countries is also reported in the circles). Only 32 countries do not report data or report data that cannot be classified (score 1) in at least one policy dimension. Hence, for 162 countries the dataset is complete and it provides a picture of the intensity of tobacco control programs along the three policy dimensions we are focusing on.

Figure 1a shows that countries exerting minimum effort (index 2) on antismoking mass media campaigns — the vast majority, as noted above — are roughly uniformly distributed along the tax index, with a slight prevalence of central (3 and 4) over extreme scores (2 and 5). There are only 39 countries that rely heavily both on taxation and antismoking campaigns, scoring 4 or 5 in both dimensions. As Figure 1a shows, there is no evident association between the two policy instruments.\(^5\)

\(^5\)The Pearson \(\chi^2\) test rejects the null hypothesis. The statistic is equal to 17.16 for the whole sample (16 degrees of freedom, \(P_r = 0.375\)) and to 7.47 (9 degrees of freedom, \(P_r = 0.588\)) excluding countries with index equal to one either for taxation or antismoking campaigns.
In Figure 1b, the scatterplot of the tax and the smoking bans indicators shows that while most countries that levy low taxes on tobacco (score 2) also do not enact smokefree measures (scores 2 or 3), countries applying medium or high taxes (scores 3 to 5) are approximately uniformly distributed along the smoking bans indicator.\(^6\)

Finally, Figure 1c shows that there is evidence of some association between the intensity of antismoking campaigns programs and the coverage of smoke-free measures, with a large group of countries relying on low levels of regulations along both dimensions, and a significant group of 35 countries that heavily rely on both instruments, having scores above 3 for both indicators.\(^7\)

Overall, these data show that, although there is a large heterogeneity among countries — 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 beyond a framework that only focuses on the role of taxes.

### 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 media campaigns and free-air legislation to the set of available policy tools. We also acknowledge that tobacco consumption takes place in different types of locations, and that it can be harmful not only for smokers, but also for other individuals.

\(^6\)Also in this case there is no significant association between the two policy indicators. The Pearson \(\chi^2\) test is equal to 24.6 for the whole sample (\(Pr = 0.077\)) and to 13.33 (\(Pr = 0.148\)) excluding countries with index equal to one either for taxation or smoking bans.

\(^7\)The Pearson \(\chi^2\) test — being equal to 35.55 for the whole sample (\(Pr = 0.003\)) and to 21.13 (\(Pr = 0.012\)) excluding countries with index equal to one either for antismoking campaigns or smoking bans — suggests the existence of a statistically significant correlation.
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 refer to a ‘consumption activity’ occurring in type \( l \) locations as 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. 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 \( v^l(\cdot) \) 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 \( \rho^l \), for given \( x \). To guarantee an interior solution in \( x \), we also assume that \( \lim_{x \to 0} v^l_x = +\infty \), \( \lim_{x \to +\infty} v^l_x = 0 \). Note also that while the preferences for the harmful good can 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.

\[8\text{Although in reality not everyone is a regular smoker, for ease of analytical tractability we consider a framework in which all individuals consume a positive amount of the harmful good. Non-smokers can be accommodated into the model by letting a group of individuals to be characterized by a very steep marginal utility } v_x(\cdot), \text{ so that their tobacco consumption, albeit positive, is negligible.} ]
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.\textsuperscript{9}

We formalize these ideas by assuming that the utility from smoking is equal to 
\( v^3(x^3; \rho^3) \) 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, \( \xi x^3 \), 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, the utility of tobacco consumption in type 3 locations can be written as \( v^3(x^3; \rho^3) - r\xi x^3 \).

### 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 parameter, which captures (in a reduced form) the degree of time inconsistency, or of lack of self-control, in consumer behavior;\textsuperscript{10} \( \beta < 1 \) implies overconsumption with

\textsuperscript{9}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.

\textsuperscript{10}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 \( \gamma \)) 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
respect to its efficient level, whereas $\beta = 1$ implies fully rational behavior (more on this in Section 4.1).

Differently from O’Donoghue and Rabin (2006) and Kőszegi (2005), who take it as exogenously given, we assume that the parameter $\beta$ 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 $\beta$ is linked to $z$ through the function

$$\beta(z; \mathbf{b}),$$

where $\beta_z \geq 0$, $\beta_{zz} \leq 0$, and $\mathbf{b}$ is a vector of taste parameters that allows for heterogeneous responses by individuals on antismoking campaigns.

Concavity of $\beta(.)$ in $z$ has 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 $\beta$ does not decrease with $z$. However, since the production of ‘effective’ information occurs under decreasing returns, the marginal impact of higher spending $z$ on $\beta$ is nonincreasing in $z$ (e.g., the marginal impact on smokers’ behavior of antismoking TV adverts is a decreasing function of their broadcasting frequency and length).

### 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

$$s^l(x^l, y^l) = v^l(x^l; \rho^l) - \beta \delta \gamma x^l + y^l, \quad l = 1, 2,$$

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

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

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 awareness about health risks. Our theoretical model encompasses also this view, if one interprets the parameter $\beta$ as expressing the 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).
extra utility term $\lambda^l(a^l; a^l)$ representing the individual’s preferences for type $l$ locations. That is:

$$u^l(x^l, y^l, a^l) = a^l s^l(x^l, y^l) + \lambda^l(a^l; a^l).$$  \hspace{1cm} (5)

We assume that $\lambda^l(.)$ is strictly concave in $a$, $\lambda_a^l \geq 0$, $\lambda_{aa}^l < 0$, with the taste parameter $a^l$ 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 $\lim_{a \to 0} \lambda_a^l = +\infty$, $\lim_{a \to 1} \lambda_a^l = -\infty$.

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

$$u(x, y, a) = \sum_{l=1}^{3} u^l(x^l, y^l, a^l),$$  \hspace{1cm} (6)

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

Both consumption goods are exchanged in perfectly competitive markets.\footnote{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 5).} Production costs are linear, with marginal costs equal to average costs, normalized to unity 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

$$\sum_{l=1}^{3} a^l \left( px^l + y^l \right) \leq I.$$  \hspace{1cm} (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 $x$ and locational choices $a$ only:

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

\footnote{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 8, we discuss the implications of allowing for producers’ market power.}
— and solve the problem by proceeding backward.\footnote{The analysis in two stages is without loss of generality. The same solution is obtained in the simultaneous choice of consumption bundles and locations.}

In the second stage, the consumer maximizes Eq. (8) with respect to tobacco consumption levels $x$, for given locational choices $a$. From the first order conditions
\begin{align}
 v_2^l(x') &= \beta \delta \gamma + p, \quad l = 1, 2, \\
v_2^3(x^3) &= \beta \delta \gamma + p + r \xi,
\end{align}
we obtain $\tilde{x}$, 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.\footnote{Throughout the paper we use ‘tilde’ to denote the optimal values of the consumer’s problem.} 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
\begin{align}
 \tilde{s}^l(t, z) &= u^l(\tilde{x}^l) - (\beta \delta \gamma + p)\tilde{x}^l, \quad l = 1, 2, \\
 \tilde{s}^3(t, z, r) &= u^3(\tilde{x}^3) - (\beta \delta \gamma + p + r \xi)\tilde{x}^3,
\end{align}
be the net surplus from smoking associated to the chosen consumption bundles in the three locations. By the envelope theorem, it is
\begin{align}
 \tilde{s}^l &= (\beta \delta \gamma)^{-1} \tilde{s}^l - \tilde{x}^l, \quad l = 1, 2, 3, \\
 \tilde{s}^3 &= -\xi \tilde{x}^3.
\end{align}
By inserting $\tilde{x}$ into Eq. (8), we obtain:
\begin{align}
 u(\tilde{x}, a) &= \sum_{l=1}^{3} \left[ a^l \tilde{s}^l + \lambda^l(a^l) \right] + I.
\end{align}

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

$$\tilde{x}(t, z, r) = \sum_{l=1}^{3} \tilde{a}^l \tilde{x}^l.$$  \hspace{1cm} (17)

We next define the welfare measures and the social objective function that we use in the normative analysis of Section 6.

### 4 Welfare

#### 4.1 Individual welfare

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

$$\tilde{u}(t, z, r) = \sum_{l=1}^{3} \left[ \tilde{a}^l \tilde{s}^l + \lambda^l(\tilde{a}^l) \right] + I,$$ \hspace{1cm} (18)

where, by the envelope theorem, it is

$$\tilde{u}_t = -\tilde{x}, \quad \tilde{u}_z = \beta \gamma \tilde{u}_t, \quad \tilde{u}_r = -\xi \tilde{a}^3 \tilde{x}^3.$$ \hspace{1cm} (19)

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

$$w(x, a) = \sum_{l=1}^{3} d^l \left[ v'(x^l) - \delta \gamma x^l - px^l \right] - r \xi a^3 x^3 + \sum_{l=1}^{3} \lambda^l(a^l) + I.$$ \hspace{1cm} (20)

What distinguishes the utility function in Eq. (8) from that in Eq. (20) is the presence, in the former, of the quasi-hyperbolic discounting parameter $\beta$ (Laibson, 1997, O’Donoghue and Rabin, 1999) in front of period III health costs. Quasihyperbolic 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 $\delta$, 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 $\delta$. 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 employ the 'self-II' utility function (8) to carry out the positive analysis of consumer's actual behavior allowing for imperfect self-control. 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), to define a measure of consumer’s welfare for the normative analysis, we use instead the 'self-I' utility function (20), representing the consumer’s true welfare, evaluated at the actual consumption choices $(\tilde{x}, \tilde{a})$.

Let $\tilde{w} = w(\tilde{x}, \tilde{a})$ be the welfare function (20) evaluated at the consumption choices $(\tilde{x}, \tilde{a})$ that maximize the utility function (8), giving indirect utility $\tilde{u} = u(\tilde{x}, \tilde{a})$. It is immediate to see that the welfare measure $\tilde{w}$ and the indirect utility $\tilde{u}$ are linked by the following equation:

$$\tilde{w}(t, z, r) = \tilde{u} - (1 - \beta) \delta \gamma \tilde{x}. \quad (21)$$

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.

---

15See 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.
4.2 Social welfare

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

To define aggregate welfare, we adopt the Utilitarian criterion by first adding up the individual welfare levels $\tilde{w}$, defined in Eq. (21), to obtain the aggregate measure $E[\tilde{w}]$, 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 $E[t\tilde{x}]$. 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.\(^{16}\) Aggregate net public revenues are therefore equal to

$$\tilde{T}(t, z, r) = E[t\tilde{x}(t, z, r)] - z - C(r), \quad (22)$$

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.,

$$\tilde{\Gamma}(t, z, r) = \tilde{\Gamma}^2 + \tilde{\Gamma}^3, \quad \tilde{\Gamma}^2 = \eta^2 E[\tilde{a}^2\tilde{x}^2], \quad \tilde{\Gamma}^3 = (1 - r)\eta^3 E[\tilde{a}^3\tilde{x}^3], \quad (23)$$

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

\(^{16}\)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.
stricter enforcement \( r \) of the smoking ban in type 3 locations increases the externality in type 2 locations, since \((\tilde{a}^2 \tilde{x}^2)_r > 0\).\(^{17}\) Instead, taxation and antismoking campaigns usually curb both types of external costs, as we note in Section 5.

Our comprehensive measure of social welfare is then given by:

\[
\hat{\Omega}(t, z, r) = \mathbb{E}[\tilde{w}] - \hat{\Gamma} + \hat{T}.
\]

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 \( \hat{T} \) and the external costs \( \hat{\Gamma} \) to aggregate consumers’ welfare \( \mathbb{E}[\tilde{w}] \) without loss of generality. In fact, social welfare as defined in Eq. (24) is invariant with respect to the actual distribution of net revenues among consumers through lump sum transfers,\(^{18}\) as well as to the specific incidence of the external costs of tobacco usage on consumers. In terms of our normative analysis, this implies that the social objective function (24) 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.

5 The impact of policy instruments on smoking

At the individual level, a marginal change in a policy instrument \( \pi, \pi \in \{t, z, r\} \), 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.\(^{19}\)

\[
\left(\tilde{a}^l \tilde{x}^l\right)_\pi = \tilde{a}^l \tilde{x}^l_{\pi} + \tilde{a}^l_{\pi} \tilde{x}^l, \quad \tilde{x}_\pi = \sum_{l=1}^{3} \left(\tilde{a}^l \tilde{x}^l\right)_\pi, \quad \pi \in \{t, z, r\}.
\]

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

\(^{17}\)This is the effect empirically assessed by Adda and Cornaglia (2010) in their study of the impact of smoking bans in public places on passive smoking by children in their private homes.

\(^{18}\)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.

\(^{19}\)With a slight abuse of notation, to save space we denote with \( (\tilde{a}^l \tilde{x}^l)_\pi \) the derivative of \( \tilde{a}^l \tilde{x}^l \) with respect to \( \pi \).
order conditions shown in Eqs. (9), (10) and (16), we find that:

\[ \tilde{x}_l^l = 1/\tilde{u}_{xx}^l < 0, \quad l = 1, 2, 3, \]  
\[ \tilde{a}_t^1 = \left[ \tilde{\lambda}_{aa}^2 (\tilde{x}_1^1 - \tilde{x}_3^1) + \tilde{\lambda}_{aa}^3 (\tilde{x}_1^1 - \tilde{x}_2^1) \right] \Delta, \]  
\[ \tilde{a}_t^2 = \left[ \tilde{\lambda}_{aa}^1 (\tilde{x}_2^2 - \tilde{x}_3^2) + \tilde{\lambda}_{aa}^3 (\tilde{x}_2^2 - \tilde{x}_1^2) \right] \Delta, \]  
\[ \tilde{a}_t^3 = -\tilde{a}_t^1 - \tilde{a}_t^2, \]  

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

Eq. (26) shows that an increase in the tax rate reduces \( \tilde{x}_l^l \) in all locations, while Eqs. (27)-(29) show that it reduces (increases) the amount \( \tilde{a}_l^l \) 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., \( \tilde{x}_1^1 > \tilde{x}_3^1 \) and \( \tilde{x}_1^1 > \tilde{x}_2^1 \)), then an increase in \( t \) results in a reduction in \( \tilde{a}_1^1 \). 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 \( \tilde{a}_l^l \tilde{x}_l^l \) in type \( l \) locations if \( \tilde{a}_l^l \) is decreasing in \( t \), whereas it can increase it if \( \tilde{a}_l^l \) is increasing in \( t \). However, although \( \langle \tilde{a}_l^l \tilde{x}_l^l \rangle_l \) is of ambiguous sign in at least one location \( l \), since \( \tilde{a}_l^l < 0 \) for at least one \( l \), the impact of taxation on overall consumption, \( \tilde{x} = \sum_{l=1}^{3} \tilde{a}_l^l \tilde{x}_l^l \), is always negative; i.e.,

\[ \tilde{x}_t = \sum_{l=1}^{3} \tilde{a}_l^l \tilde{x}_l^l + \sum_{l=1}^{3} \tilde{a}_t^l \tilde{x}_t^l < 0, \]  

since, by Eq. (26), it is \( \tilde{x}_t^l < 0, \quad l = 1, 2, 3, \) and, by Eqs. (27)-(29), it is:

\[ \sum_{l=1}^{3} \tilde{a}_l^l \tilde{x}_l^l = \left[ \tilde{\lambda}_{aa}^2 (\tilde{x}_1^1 - \tilde{x}_3^1)^2 + \tilde{\lambda}_{aa}^3 (\tilde{x}_1^1 - \tilde{x}_2^1)^2 + \tilde{\lambda}_{aa}^1 (\tilde{x}_2^2 - \tilde{x}_3^2)^2 \right] \Delta < 0. \]

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

\[ \tilde{x}_z^l = \beta_z \delta \gamma \tilde{x}_t^l, \quad \tilde{a}_z^l = \beta_z \delta \gamma \tilde{a}_t^l, \quad l = 1, 2, 3; \quad \tilde{x}_z = \beta_z \delta \gamma \tilde{x}_t. \]

---

\[ ^{20} \]Being standard, the proofs of all comparative statics results shown in this section are omitted.

\[ ^{21} \]Clearly, \( \tilde{x}_1^1 > \tilde{x}_3^1 \) and \( \tilde{x}_1^1 > \tilde{x}_2^1 \) is only a sufficient condition for \( \tilde{a}_1^1 \) to be decreasing in the tax rate. The same relation can hold also if \( \tilde{x}_1^1 > \tilde{x}_3^1 \) and \( \tilde{x}_1^1 < \tilde{x}_2^1 \), or if \( \tilde{x}_1^1 < \tilde{x}_3^1 \) and \( \tilde{x}_1^1 > \tilde{x}_2^1 \), provided that \( \tilde{\lambda}_{aa}^l (\tilde{x}_1^1 - \tilde{x}_3^1) + \tilde{\lambda}_{aa}^3 (\tilde{x}_1^1 - \tilde{x}_2^1) < 0. \]
Eqs. (26)-(29) and Eq. (31) 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 for tobacco consumption $\alpha$, for consumption locations $\lambda^l$, the impact of a marginal change in $z$ depends also on the intensity of future health costs $\gamma$, on the discount factor $\delta$, and on the vector $b$ of taste parameters affecting $\beta_z$, the marginal impact of $z$ on the smoker’s degree of self-control $\beta$.

Turning, finally, to the smoking ban in type 3 locations, we find that an increase in $r$ induces the smoker to reduce $\tilde{z}^3$ 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., $\xi > 0$):

$$\tilde{a}_r^1 = -\tilde{\lambda}_{aa}^1 \xi \tilde{z}^3 \Delta \geq 0, \quad \tilde{a}_r^2 = -\tilde{\lambda}_{aa}^2 \xi \tilde{z}^3 \Delta \geq 0, \quad \tilde{x}_r^1 = \tilde{x}_r^2 = 0, \quad (32)$$

$$\tilde{a}_r^3 = -\tilde{a}_r^1 - \tilde{a}_r^2 \leq 0, \quad \tilde{x}_r^3 = \xi \tilde{z}_r^3 < 0. \quad (33)$$

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

$$\tilde{z}_r = \tilde{a}_r^3 \tilde{x}_r^3 + \sum_{l=1}^{3} \tilde{a}_r^l \tilde{x}_r^l = \xi (\tilde{a}_r^3 \tilde{x}_r^3)_t, \quad (34)$$

is thus of ambiguous sign. Note however, as Eq. (34) shows, that the impact of $r$ on $\tilde{x}$ is proportional (by the factor $\xi$) to that of $t$ on $\tilde{a}_r^3 \tilde{x}_r^3$. The result follows immediately by combining Eqs. (32)-(33) with Eqs. (27)-(29), to obtain:

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

Summarizing the results about the individual responses to changes in the regulatory instruments: (i) higher taxation and larger prevention programs reduce overall tobacco consumption, (ii) stricter enforcement of a smoking ban in type 3 locations reduces tobacco consumption therein while it increases it in type 1 and type 2 locations, (iii) taxation and prevention programs can increase total consumption in one, at most two, locations, (iv) stricter enforcement of a smoking ban in type 3 locations can have a positive impact on overall tobacco consumption.

The peculiar nature of results (iii) and (iv) is easily explained by looking at Eqs. (27)-(29), which show that taxation can have a strong impact on smoking locational choices whenever the individual preferences are highly heterogenous either within consumption locations (implying large differences between $\tilde{x}_r^1$, $\tilde{x}_r^2$ and $\tilde{x}_r^3$) or among consumption locations (implying large differences between $\tilde{\lambda}_{aa}^1$, $\tilde{\lambda}_{aa}^2$ and $\tilde{\lambda}_{aa}^3$). Hence, only
individuals with highly heterogenous preferences across smoking locations may react to an increase in $t$ or $z$ by increasing smoking in some locations, or may respond to an increase in $r$ by augmenting overall smoking.

These last remarks lead us to conclude that, while at the individual level it is possible that $(\alpha_l \tilde{x}_l^t) > 0$, $(\alpha_l \tilde{x}_l^z) > 0$ for some location $l$, or that $\tilde{x}_r > 0$, at the aggregate level these are unlikely occurrences, since they require that a large fraction of smokers have similar preferences which are highly heterogenous across consumption locations. Instead we expect, as a normal case, that the population of smokers is composed of individuals with highly heterogeneous preferences, some (the majority) with relatively homogeneous preferences for consumption locations (for whom $(\alpha_l \tilde{x}_l^t) < 0$, $(\alpha_l \tilde{x}_l^z) < 0$, $\tilde{x}_r < 0$), others (the minority) with highly differentiated preferences for consumption locations (for whom it is possible that $(\alpha_l \tilde{x}_l^t) > 0$, $(\alpha_l \tilde{x}_l^z) > 0$, $\tilde{x}_r > 0$). In this situation, it is likely that, in the aggregate, the impact of the policy instruments is of the expected sign: $E[(\alpha_l \tilde{x}_l^t)] < 0$, $E[(\alpha_l \tilde{x}_l^z)] < 0$ in all locations $l$; $E[\tilde{x}_r] < 0$. We assume this to be the case throughout the rest of the paper.

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. (24).

By differentiating Eq. (24) with respect to the policy instruments, we obtain

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

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

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

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:

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

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

$$\tilde{\Omega}_r = -E[(1 - \beta)\delta \gamma \tilde{x}_r] - \tilde{\Gamma}_r + t E[\tilde{x}_r] - C_r - E[\xi \tilde{a}_3 \tilde{x}_3], \quad (40)$$

We have tested the validity of these claims by means of numerical simulations using a CRRA specification of the utility function $v^l(.)$ defined in Eq. (1) and a log specification of the utility function $\lambda(.)$ defined in Eq. (5).
where, by differentiation of Eq. (23), it is

\[ \hat{\Gamma}_\pi = \eta^2 E \left[ (\tilde{a}_2 \tilde{x}_2)_\pi \right] + (1 - r) \eta^3 E \left[ (\tilde{a}_3 \tilde{x}_3)_\pi \right], \quad \pi = t, z; \quad (41) \]

\[ \hat{\Gamma}_r = \eta^2 E \left[ \tilde{a}_2^2 \tilde{x}_2^2 \right] + (1 - r) \eta^3 E \left[ (\tilde{a}_3 \tilde{x}_3)_r \right] - \eta^3 E \left[ \tilde{a}_3^3 \tilde{x}_3^3 \right]. \quad (42) \]

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 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 to 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), using Eq. (41) for \( \pi = t \), setting \( \Omega_t = 0 \) and rearranging, the first order condition for the optimal tax rate can
be expressed as follows:\textsuperscript{23}

\[ t = E\left[ (1 - \beta)\delta \gamma \right] + \frac{\text{cov}\left[ (1 - \beta)\delta \gamma, \tilde{x}_t \right]}{E[\tilde{x}_t]} + \eta^2 E\left[ (\tilde{a}^2 \tilde{x}^2)_t \right] E[\tilde{x}_t] + (1 - r)\eta^3 E\left[ (\tilde{a}^3 \tilde{x}^3)_t \right] E[\tilde{x}_t]. \] (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 to 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, 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. Indeed, in this case, the second term in Eq. (43) is positive (recall that \( E[\tilde{x}_t] \) appearing at the denominator is negative), and therefore it adds up to the first term. Similar, but reversed, arguments hold if the covariance term is positive.

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 \( \eta^2 \), the externality produced by each unit of tobacco consumption in type 2 locations, multiplied by \( E\left[ (\tilde{a}^2 \tilde{x}^2)_t \right] /E[\tilde{x}_t] \), 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 \( E\left[ (\tilde{a}^3 \tilde{x}^3)_t \right] /E[\tilde{x}_t] \). 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 \( \eta^2 \) and \( (1 - r)\eta^3 \) are not weighted by the respective absolute consumption share in the location, \( E\left[ \tilde{a}^l \tilde{x}^L \right] /E[\tilde{x}] \), but by the relative behavioral response to taxation, measured by \( E\left[ (\tilde{a}^l \tilde{x}^l)_t \right] /E[\tilde{x}_t] \). 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.

\textsuperscript{23}we examine only the first order conditions for maximizing social welfare, assuming, as it is typically done in the optimal taxation literature, that second order conditions hold true. Our numerical simulations in Section 7 confirm that this is indeed the case for specifications of the utility function and parameter constellations that are consistent with the available empirical evidence.
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 $\beta$, 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.\footnote{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.}

### 6.2 Antismoking campaigns

We now examine 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 focus first on antismoking campaigns.

Let all variables that are function of $t^*(z, r)$, defined by Eq. (43), be identified through the superscript *. Standard algebra (see Appendix A.2) shows that Eq. (39) can be rewritten, for $t = t^*(z, r)$, as

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

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 implicitly 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 \(\bar{x}_t^*\) 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), if the covariance terms are negative, then 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 \(\bar{x}_t^*\) exceeds that with \(\bar{x}_t^*\). Otherwise, given that an optimal tax is already in place, it is useless to introduce costly prevention programs. If, instead, the covariance terms are positive, then antismoking campaigns are useful only if the degree of correlation of \((1 - \beta)\delta \gamma\) with \(\bar{x}_t^*\) is weaker than that with \(\bar{x}_t^*\).

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

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

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

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. Taxation targets the ‘average’ smoker, by increasing the price of tobacco by an amount equal to the average internal cost, \(E[(1 - \beta)\delta \gamma]\). With no correlation between \((1 - \beta)\delta \gamma\) and \(\bar{x}_t^*\), this is the only role taxation can play, since the second term in Eq. (43) is nil. Note also that the optimal tax rate, tailored on the internal costs of the average smoker, is second-best: a higher (lower) tax rate would be desirable for smokers with above-average (below-average) internal costs. However, since personalized first-best taxes are unfeasible, a uniform tax is applied. The role of antismoking campaigns stems from the fact that they determine behavioral responses that are more diversified than those produced by taxation. Since \(\bar{x}_z^* = \beta_z \delta \gamma \bar{x}_t^*\), 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 \(\beta_z\) is negatively correlated with \(\beta\)). As Eq. (45) shows, a
A dollar increase in antismoking spending produces a welfare gain if \( \text{var} [\delta \gamma] > 0 \) and/or \( \text{cov} [(1 - \beta), \beta_z] > 0 \). The first condition is self evident: smokers do have different discount factors \( \delta \) and do suffer different health damages \( \gamma \) 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 \( \beta_z \) 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 — as our numerical simulations in Section 7 confirm — even in the presence of some degree of correlation among \( (\delta, \gamma), (\beta, \beta_z) \) and \( \tilde{z}_l^* \).

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 optimal tax only if the former instrument determines additional behavioral responses on smokers characterized by high health costs and/or low degree of 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:

\[
\frac{\mathbb{E} [(\tilde{a}_l^l \tilde{x}_l^*)^*]}{\mathbb{E} [\tilde{x}_l^*]} - \frac{\mathbb{E} [((\tilde{a}_l^l \tilde{x}_l^*)^*)]}{\mathbb{E} [(\tilde{a}_l^l \tilde{x}_l^*)^*]} = \frac{\text{cov} [\beta_z \delta \gamma, (\tilde{a}_l^l \tilde{x}_l^*)^*]}{\mathbb{E} [(\tilde{a}_l^l \tilde{x}_l^*)^*]} - \frac{\text{cov} [\beta_z \delta \gamma, \tilde{z}_l^*]}{\mathbb{E} [\tilde{x}_l^*]}, \quad l = 2, 3. \tag{46}
\]

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 \( l \), \( (\tilde{a}_l^l \tilde{x}_l^*)^* \), is significantly different from that with overall demand, \( \tilde{z}_l^* \). 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 by reducing the internal costs of smoking due to their lack of self-control; the only requirement is that the welfare benefits exceed the marginal costs. Instead, 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), for $t = t^*(z, r)$, we obtain (see Appendix A.2)

$$
\hat{\Omega}_r = \mathbb{E} \left[ (\eta^3 - \xi)(\bar{a}^3 \bar{x}^3)^* \right] - \mathbb{E} [\bar{x}_r^*] (1 - r) \eta^3 \left\{ \frac{\mathbb{E} \left[ (\bar{a}^3 \bar{x}^3)^* \right]}{\mathbb{E} [\bar{x}_r^*]} - \frac{\mathbb{E} \left[ (\bar{a}^3 \bar{x}^3)^* \right]}{\mathbb{E} [\bar{x}_r^*]} \right\} + 

-C_r - \mathbb{E} [\bar{x}_r^*] \eta^2 \left\{ \frac{\mathbb{E} \left[ (\bar{a}^2 \bar{x}^2)^* \right]}{\mathbb{E} [\bar{x}_r^*]} - \frac{\mathbb{E} \left[ (\bar{a}^2 \bar{x}^2)^* \right]}{\mathbb{E} [\bar{x}_r^*]} \right\} + 

-\mathbb{E} [\bar{x}_r^*] \left\{ \frac{\text{cov} \left[ (1 - \beta)\delta \gamma, \bar{x}_r^* \right]}{\mathbb{E} [\bar{x}_r^*]} - \frac{\text{cov} \left[ (1 - \beta)\delta \gamma, \bar{x}_r^* \right]}{\mathbb{E} [\bar{x}_r^*]} \right\} \right) \tag{47}
$$

The first row on the right hand side of Eq. (47) contains the marginal benefits of stricter enforcement of the smoking ban. The first term represents the direct marginal benefits in terms of external costs abatement in type 3 locations, net of the compliance costs sustained by smokers; these benefits are positive as long as $\eta^3$, the externality per unit of tobacco consumption, exceeds $\mathbb{E} [\xi]$, the average compliance costs per unit of tobacco consumption.\(^{25}\)

The second term shows the marginal benefits ensuing from the behavioral responses of smokers to increased enforcement of the ban. Like in the case of antismoking programs, stricter enforcement of the smoking ban adds benefits beyond those already achieved through taxation only if the aggregate behavioral response to the ban, $\mathbb{E} \left[ (\bar{a}^3 \bar{x}^3)^* \right] / \mathbb{E} [\bar{x}_r^*]$, is greater than that caused by taxation, $\mathbb{E} \left[ (\bar{a}^3 \bar{x}^3)^* \right] / \mathbb{E} [\bar{x}_r^*]$, which is already embedded in the fourth term of the optimal tax rate defined in Eq. (43). While the similar term in the first order condition (44) for antismoking programs is, as we have argued, of negligible size, in this case it is significant, since the instrument $r$, which is specific to type 3 smoking locations, causes a stronger impact on tobacco consumption in type 3 locations than the instrument $t$ that applies uniformly to all locations; that is, $\mathbb{E} \left[ (\bar{a}^3 \bar{x}^3)^* \right] / \mathbb{E} [\bar{x}_r^*] > \mathbb{E} \left[ (\bar{a}^3 \bar{x}^3)^* \right] / \mathbb{E} [\bar{x}_r^*]$. Note also that the term $(1 - r)$ makes these marginal benefits to be a decreasing function of $r$, driven to zero with full enforcement $r = 1$.

\(^{25}\)In fact, since $\mathbb{E} \left[ (\eta^3 - \xi)(\bar{a}^3 \bar{x}^3)^* \right] = \mathbb{E} [\eta^3 - \xi] \mathbb{E} \left[ (\bar{a}^3 \bar{x}^3)^* \right] - \text{cov} \left[ \xi, (\bar{a}^3 \bar{x}^3)^* \right]$, and since the covariance is negative (individuals with high compliance costs smoke, ceteris paribus, less than those with low compliance costs), $\eta^3 > \mathbb{E} [\xi]$ is only a sufficient condition for $\mathbb{E} \left[ (\eta^3 - \xi)(\bar{a}^3 \bar{x}^3)^* \right] > 0$. 25
The second row of Eq. (47) contains the marginal costs due to stricter enforcement of the smoking ban. The first term, $C_r$, is the direct marginal cost for administering stricter free-air legislation. The second term represents the increase in the external costs in the non-regulable type 2 locations, since stricter enforcement induces smokers to shift part of their consumption activities from regulated to unregulated locations. This term is positive, since $E \left( (\tilde{a}^2 \tilde{x}^2)^*_r \right) > 0$, $E [\tilde{x}^*_r] < 0$, $E \left( (\tilde{a}^2 \tilde{x}^2)^*_t \right) < 0$, $E [\tilde{x}^*_t] < 0$, and it can be of considerable size if $\eta^2$, the externality per unit of tobacco consumption in type 2 locations, is sizeable.

The last term, in the third row of Eq. (47), is of ambiguous sign, since it depends on the non-internalized health costs of smoking, $(1 - \beta) \delta \gamma$, having a significantly different degree of correlation with $\tilde{x}^*_r$ and $\tilde{x}^*_t$. Since it is not obvious to see why the behavioral response of overall tobacco consumption to the smoking ban and to taxation should have significantly different degrees of correlation with non-internalized costs, we conclude that this term is a residual one, at most of negligible size (a claim that is confirmed by our numerical simulations in Section 7).

Overall, Eq. (47) shows that, even in the presence of an optimal tobacco tax, a smoking ban can be useful to further improve the efficiency of policy intervention. As the third and the fourth term on the right hand side of Eq. (43) show, taxation, by applying uniformly to all consumption locations, corrects for the average marginal external costs of smoking, weighted by the behavioral response to taxation. As such, the optimal tax rate does not correct for the full amount of the marginal external costs in type 2 and type 3 locations. Ideally, location-specific taxes would be first-best, but they are clearly unfeasible. Hence, under a second-best uniform tax, smoking bans can usefully complement taxation by specifically targeting external costs in regulable locations.

7 A numerical example

To improve our understanding of the optimal structure of policy intervention, in this section we present a numerical example based on the following specification of our model. As in O’Donoghue and Rabin (2006), we consider a Constant Relative Risk Aversion (CRRA) specification of the utility of tobacco consumption in type $l$ locations, defined in Eq. (1); i.e.

$$v^l(x^l; \rho^l, \sigma^l) = \frac{\rho^l}{1 - \sigma^l} x^l(1 - \sigma^l),$$

(48)
where \( \rho' > 0, \sigma' \in (0,1) \) are taste parameters.

The demand function \( \tilde{x}^l \) stemming from Eq. (48) is increasing in \( \rho' \) and shows a price elasticity that is decreasing in \( \sigma' \). The demand and its elasticity are decreasing in \( \beta \gamma \) in all locations and in \( r \xi \) in type 3 locations. Taxation reduces tobacco consumption but it increases its price elasticity in all locations.\(^{26}\)

The demand function is

\[
\tilde{x}(a'; a, \alpha') = \alpha' \left( 1 - \frac{\alpha'}{2\alpha} \right) a,
\]

where the parameter \( \alpha' > 0 \) expresses the intensity of preferences for type \( l \) locations, and \( \alpha' \in (0,1) \) is the bliss point of \( \lambda^l(\cdot) \) in \( a' \).\(^{27}\)

Finally, the function \( \beta(\cdot) \), defined in Eq. (2), linking the expenditure \( z \) on prevention programs to the individual degree of self control \( \beta \), takes the following form:

\[
\beta(z; b) = \kappa + \theta(1 - \kappa) \frac{\zeta z}{1 + \mu \zeta z}, \quad b = (\kappa, \theta, \mu \zeta).
\]

This function, increasing and concave in \( z \), is shaped by three taste parameters. \( \kappa \in [0,1] \) represents the baseline level of \( \beta \); i.e. the consumer’s degree of self-control in the absence of prevention programs. \( \theta \in [0,1] \) determines, jointly with \( \kappa \), the asymptotic value of \( \beta \) when \( z \) goes to infinity, equal to \( \kappa + \theta(1 - \kappa) \), representing the maximum degree of self-control that the individual can achieve under the influence of antismoking campaigns.\(^{28}\) \( \mu \geq 0 \) determines how sensitive the smoker is to the information conveyed by the campaign, since the function \( \beta(\cdot) \) is such that \( \beta^A \geq \beta^B \) for all \( z > 0 \), whenever one considers two individuals \( A \) and \( B \) with the same \( \kappa \) and \( \theta \), but \( \mu^A \geq \mu^B \). Finally, the scalar \( \zeta \geq 0 \) scales-up/down the taste parameter \( \mu \) by a common factor for all smokers.

---

\(^{26}\)The demand function is \( \tilde{x}^l = [\rho'/(1 + t + \beta \gamma)]^{1/\sigma'} \) for \( l = 1, 2 \), and \( \tilde{x}^3 = [\rho^3/(1 + t + \beta \gamma + r \xi)]^{1/\sigma^3} \) for \( l = 3 \).

\(^{27}\)We employ a quadratic specification since it greatly simplifies the computation of the optimal policy, by giving closed form solutions for the locational choices \( \alpha' \). However, since corner solutions are possible, care is taken in calibrating the model so as to obtain interior solutions \( \alpha' \in (0,1) \) in all locations for all individual types.

\(^{28}\)In the given specification \( \lim_{z \to \infty} \beta(\cdot) \) never exceeds unity. That is, we assume that smokers never ‘over-react’ to the information transmitted by the antismoking campaign consuming an amount of tobacco that is lower than the efficient level for a fully rational agent. Our main qualitative results carry through even if we allow for over-reaction to antismoking campaigns.
7.1 Taxation and antismoking campaigns

We first examine the optimal mix of taxation and expenditure on antismoking campaigns in a world in which there are no externalities due to tobacco consumption, so that smoking bans are useless and the analysis can be carried out in a simplified single-consumption-location setting. Our model, except for the expenditure on prevention programs impacting on $\beta$, reduces to O’Donoghue and Rabin (2006). Indeed, we replicate one of their numerical examples to start with.

The population is composed of identical individuals but for the baseline self-control parameter, which takes values $\kappa = \{0.9, 0.95, 0.99, 1\}$ that identify four uniformly distributed types of smokers. All other parameters are single valued. In particular, $\gamma = 10$, $\rho = 17.7$, and $\sigma = 0.19$. The value of $\sigma$ is such that, for $\gamma = 10$, the elasticity of the aggregate demand for tobacco is equal to 0.5 for $t = 0$, while the value of $\rho$ is such that the aggregate demand is equal to 15 for $t = 0$. The calibration of the health cost of smoking at 10 times the producer cost of tobacco is taken from Gruber and Köszegi (2004). The value of 0.5 for the elasticity of tobacco demand is the value around which many empirical estimates are clustered; see the recent survey in U.S. National Cancer Institute and World Health Organization (2016, ch. 4). As for the parameters specific to our model, we set $\theta = 0.75$, implying that individuals with $\kappa = \{0.9, 0.95, 0.99, 1\}$ have asymptotic values $\beta = \{0.975, 0.9875, 0.9975, 1\}$, respectively. Throughout the numerical analysis, we also fix the discount factor $\delta$ to unity. Finally, since, to our knowledge, there is no available empirical evidence that can help us calibrating the impact of prevention programs on the smokers’ degree of self-control defined in Eq. (50), we compute the optimal policy for various values of $\mu \zeta$, by setting $\mu = 1$ and then letting the scale parameter $\zeta$ change.

The results are in Table 2. The first row shows that, for $\zeta \leq 1.416$, it is optimal to employ only the tax instrument, since prevention programs are not worth the cost;
Table 2: Effectiveness of antismoking campaigns and the optimal policy mix

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\(t^*\) With respect to no policy intervention \((t = z = 0)\).

...}

in formal terms, for \(\tilde{\zeta} \leq 1.416\), it is \(\hat{\Omega}_z^* \leq 0\) for all \(z \geq 0\), with \(\hat{\Omega}_z^*\) defined in Eq. (44). As in O’Donoghue and Rabin (2006, Table 1, fourth row), the optimal tax rate is \(t^* = 49.2\%\). Using Eq. (43), it is possible to split the value of the optimal tax rate into two components (not shown in Table 2). A first term equal to 40%, reflecting the average internal costs of smoking \(E[(1 - \beta^*)\delta\gamma]\). A second term, equal to the remaining 9.2%, reflecting the fact that taxation is relatively more effective at discouraging smoking among the less, than among the more, self-controlled individuals; in fact, the term \(\text{cov}[(1 - \beta^*)\delta\gamma, \bar{x}_t^*]/E[\bar{x}_t^*]\) in Eq. (43) is positive since both the numerator and the denominator are negative.

For \(\tilde{\zeta} > 1.416\), we depart from O’Donoghue and Rabin (2006), showing that it is optimal to employ both instruments. In particular, in Table 2 we consider eight values of \(\tilde{\zeta}\) that are multiples of the 1.416 threshold. Column 2 gives a measure of how changing the scalar \(\tilde{\zeta}\) affects the sensitivity of smokers to prevention programs, by means of the average value of the derivative \(\beta_z\) evaluated at \(z = 0\), denoted by \(E[\beta_0^0]\). Columns 3-4, reporting the optimal policy \((t^*, z^*)\), show that antismoking campaigns crowd out taxation: as \(\tilde{\zeta}\) increases from its lowest value of 1.416 to its maximum value of 1416, \(t^*\) falls from 49.2% to 12.5%, an effect almost entirely due to the positive

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(14) Recall that, although the tax is of the specific type, its monetary value expresses also the tax in \textit{ad valorem} terms, since the producer price of tobacco is equal to one.
impact of $z^*$ on the average degree of self-control $E[\beta^*]$, shown in column 6, which raises from 0.96 to 0.988. As a function of $\hat{z}$, the optimal expenditure on prevention programs follows an inverse U-shape pattern, both in absolute terms ($z^*$, column 4) and as a share of tax revenues ($z^*/T^*$, column 5). Note that, for the central values of $\hat{z}$ considered in the table, the ratio $z^*/T^*$ is quite stable around 2-3 percentage points.33

Columns 7-11 of Table 2 show how the optimal policy affects tobacco consumption of individuals with different degrees of self-control. There are two factors at work. On the one hand, taxation has a *slightly* larger impact on those smokers that have lower degrees of self-control, since $\bar{x}_t$ is weakly increasing in $t$. On the other hand, antismoking campaigns have a *significantly* larger impact on less self-controlled smokers, since $\bar{x}_z = \beta_z \delta \gamma \bar{x}_t$, with $\beta_z$ decreasing in $\kappa$. Hence, if only taxation is used to regulate tobacco because antismoking campaigns are not effective (as in the first row of Table 2), then the percentage reduction in smoking is about the same across types (from 22.3% for $\kappa = 0.9$ to 20.5% for $\kappa = 1$). If, instead, it is efficient to use both instruments, then the combination of a lower tax and a positive expenditure on prevention programs exerts a significantly different impact on the consumption of smokers with different degrees of self-control (for instance, focusing on the last row of Table 2, the percentage reduction in smoking is 34.3% for types $\kappa = 0.9$ and 5.8% for types $\kappa = 1$).

The last five columns of Table 2 show how tobacco regulation affects the welfare of different types of smokers.34 Taxation affects smokers’ welfare both by the induced reduction of tobacco consumption and by the uniform distribution of tax revenues in the form of a lump sum subsidy. The two effects, however, are different for different types of smokers. On the one hand, more self-controlled smokers suffer a welfare loss, since taxation distorts their otherwise efficient consumption choices. On the other hand, they benefit because (being below average smokers) the lump sum subsidy they receive is larger than the tobacco taxes they pay. Conversely, on the one hand, less self-controlled smokers experience a welfare gain, since taxation discourages excessive smoking. On the other hand, they suffer because (being above average smokers) the subsidy they cash is smaller than the taxes they pay. The nice feature of regulation

33 These figures are quite in line with those reported by the Centers for Disease Control and Prevention (2012), according to which, over the period 1998-2010, the ratio of state tobacco revenues to state and federal tobacco control appropriations was approximately 30 to 1.

34 The level of the individual welfare measure, see Eq. (20), depends on income $I$. Hence Table 2 reports the changes in welfare in absolute terms, which are independent of $I$, rather than in percentage terms.
policy is that for all types of individuals the welfare gain outweighs the welfare loss. This is shown in the first row of columns 12-15 of Table 2, where the overall welfare change induced by the optimal tax is positive for all types of smokers. Rows 2-9 of columns 12-15 show that tobacco control policy determines a Pareto improvement also when it is optimal to use both policy instruments. However, as antismoking campaign programs become more effective, the welfare gains of the less self-controlled smokers get larger (Table 2, columns 12-13), while those of the more self-controlled smokers get smaller (columns 14-15). The reason is that an instrument (taxation) that impacts almost uniformly on the consumption decisions of all types of agents is displaced by one (antismoking campaigns) that targets more effectively the less self-controlled types.\footnote{In the specification of Table 2, tobacco regulation determines a Pareto improvement because the only source of smokers’ heterogeneity is their degree of self control $\kappa$. With additional sources of heterogeneity, Pareto improvements are in general unfeasible, though O’Donoghue and Rabin (2006) define conditions for taxation to determine quasi Pareto improvements.}

Note that the results reported in Table 2 are, in qualitative terms, robust to different model specifications and parameterization. For instance, we control for the robustness of our results by considering different distributions of $\kappa$, as well as by allowing ‘low’ values of $\kappa$ in order to fit situations in which smokers not only lack self-control, but also underestimate the health harms. We also consider a linear functional form for $\beta$ in $z$ and a linear demand for tobacco. In all cases, our qualitative results carry through.\footnote{Results are available from the authors upon request.}

In Table 3 we examine how smokers’ heterogeneity impacts on the structure of the optimal policy, extending the analysis of Table 2 (where the only source of heterogeneity are the four values of the baseline degree of self-control $\kappa$) by allowing for heterogeneity also in $\gamma$, $\rho$, $\theta$ and $\mu$. In particular, we consider three possible values of $\gamma$ (5, 10, 15), each one paired with two values of $\rho$, so that there are two types of smokers for each value of $\gamma$: with low and with high tobacco demand. Specifically, $\gamma = 5$ is associated with $\rho = \{10.1, 14.8\}$, $\gamma = 10$ with $\rho = \{16.4, 18.7\}$, and $\gamma = 15$ with $\rho = \{21.8, 23.4\}$. This implies that the aggregate demand of tobacco, evaluated at $t = z = 0$, is equal to 5 or 15 for low health costs types ($\gamma = 5$), to 10 or 20 for types with $\gamma = 10$, and to 15 or 25 for types with $\gamma = 15$. That is, there is a positive correlation between $\gamma$ and $\rho$ to reflect the natural observation that, \textit{coeteris paribus}, smokers with higher health costs are usually those that also consume more tobacco. For each one of the six subgroups $(\gamma, \rho)$, we set the parameter $\sigma$ such that, after aggregating over $\kappa$, the elasticity of demand, evaluated at $t = z = 0$, is equal to 0.5. Finally, for the remaining parameters,
variability in $\{\beta^0_x\}$ % $\Delta%$ $\%$ $\Delta%$

<table>
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<tr>
<th></th>
<th>$\bar{\zeta}$</th>
<th>$E[\beta^0_x]$</th>
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<th>$z^*$</th>
<th>$E[\beta^*]$</th>
<th>$z^*$</th>
<th>$\frac{z^*}{\bar{\zeta}}$</th>
<th>$E[\beta^*]$</th>
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<td>$\kappa, \rho$</td>
<td>1.416</td>
<td>0.042</td>
<td>49.2</td>
<td>0.000</td>
<td>0.960</td>
<td>0.00</td>
<td>-21.4</td>
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<td>(1b)</td>
<td>$\kappa, \rho, \gamma$</td>
<td>1.416</td>
<td>0.042</td>
<td>48.8</td>
<td>0.136</td>
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<tr>
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<td>$\kappa, \rho, \theta$</td>
<td>1.416</td>
<td>0.042</td>
<td>49.2</td>
<td>0.000</td>
<td>0.960</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>(1d)</td>
<td>$\kappa, \rho, \mu$</td>
<td>1.416</td>
<td>0.042</td>
<td>49.2</td>
<td>0.000</td>
<td>0.960</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
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<td>$\kappa, \rho, \gamma, \theta, \mu$</td>
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<td>0.102</td>
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<td>0.099</td>
<td>0.976</td>
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<td>3.05</td>
</tr>
<tr>
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<td>$\kappa, \rho, \gamma, \theta, \mu$</td>
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<td>0.425</td>
<td>27.9</td>
<td>0.131</td>
<td>0.978</td>
<td>35.33</td>
<td>4.03</td>
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</table>

(†) Percentage change with respect to variability in $\kappa$ and $\rho$ only.

Table 3: Smokers’ heterogeneity and the optimal policy mix

heterogeneity is introduced by allowing for two values of $\theta$ (0.6, 0.9) and of $\mu$ (0.5, 1.5). Uniform distributions of the various parameters are assumed throughout. When heterogeneity is not allowed along a specific dimension, the corresponding parameter is set at the value used in Table 2 ($\gamma = 10$, $\rho = 17.7$, $\theta = 0.75$, $\mu = 1$). Finally, note that, for all parameters but for $\rho$, variability is introduced as a mean preserving spread (variability in $\rho$ is set to obtain a mean preserving spread in tobacco demand evaluated at $t = z = 0$).

Columns 4-5 of Table 3 report the optimal policy $(t^*, z^*)$ for three of the $\bar{\zeta}$ values considered in Table 2, under various dimensions of smokers’ heterogeneity. Adding variability in $\rho$ to variability in $\kappa$, shows that the optimal policy is unaffected (the values in rows 1a, 2a and 3a of Table 3 are exactly the same reported in the corresponding entries of Table 2). The formal proof that the optimal tax rate is independent of the distribution of $\rho$ (with $\gamma$ single valued) has already been provided by O’Donoghue and Rabin (2006). Our numerical analysis shows that this result also applies to the case of two policy instruments (tax and prevention programs). Novel results are obtained when
introducing heterogeneity in $\gamma$, $\theta$ and $\mu$. In particular, allowing for variability in $\gamma$ makes the marginal benefits of prevention programs larger (as already noted in a theoretical perspective when discussing Eq. 45), thus determining a substantial increase in $z^*$ while having a negligible impact on $t^*$.

In this perspective, our numerical analysis confirms the insights gained in Section 6, namely that while the optimal tax rate depends on the parameters characterizing the average smoker, the optimal expenditure on antismoking campaigns depends on the degree of smokers’ heterogeneity.

This holds true also when allowing for heterogeneity in $\theta$ or $\mu$, although the implications in terms of optimal policy are less clearcut. Adding variability in $\theta$ to that in $\kappa$ and $\rho$ reduces, coeteris paribus, the optimal expenditure $z^*$, with no significant impact on $t^*$ (see rows 1c, 2c and 3c of Table 3). The addition of variability in $\mu$ has instead a non monotonic effect on $z^*$, while still having a negligible impact on $t^*$.

Overall, the insights of the numerical analysis in Table 3 suggest that, for a given characterization of the representative smoker, changes in the degree of smokers’ heterogeneity have no effect on the optimal tax rate but a significant effect on the expenditure on antismoking campaigns.

### 7.2 Externalities and smoking bans

We finally perform a numerical analysis allowing for the effects of externalities and smoke-free legislation in our fully fledged model with different consumption locations. We assume throughout that the smoking ban can be costlessly enforced. Smokers have identical preferences for consumption locations, that are defined by Eq. (49), where we let $\alpha^l = 40$, $\dot{a}^l = 0.5$, $l = 1, 2, 3$. As for the other taste parameters, we consider two scenarios. In the first, the only source of heterogeneity is the baseline self-control parameter $\kappa$, which takes the four values considered in Tables 2 and 3. The per-unit-of-tobacco-consumption cost to comply with the smoking ban is fixed at $\xi = 0.4$ (i.e.

\[ \text{The comparison of rows 1a and 1b of Table 3 shows that, for } \tilde{\zeta} = 1.416, \text{it is } z^* = 0 \text{ with variability in } (\kappa, \rho) \text{ whereas it is } z^* = 0.118 \text{ with variability in } (\kappa, \rho, \gamma). \text{ For } \tilde{\zeta} = 4.248 \text{ and for } \tilde{\zeta} = 14.16, \text{the introduction of variability in } \gamma \text{ determines an increase in the optimal expenditure on prevention programs by 56% and by 32%, respectively.}\]

\[ \text{For } \tilde{\zeta} = 4.248, \text{adding variability in } \mu \text{ reduces } z^* \text{ by } 15\%, \text{ while for } \tilde{\zeta} = 14.16 \text{ it increases } z^* \text{ by } 2\%.\]

\[ \text{The ambiguity of the results could be due to the fact that a general prevention program is an imperfect instrument when the behavioral responses of smokers are highly heterogeneous. In this case, it is possible that an array of specific prevention programs, each one targeted to a different but relatively homogeneous group, could do better than a general program. We leave this issue for future research.}\]

\[ \text{The other parameters, all single valued, are also assigned the same values as above.}\]
For \( \eta = 0 \), it is optimal to set \( r = 0 \); for \( \eta = 0.5, 1 \), it is optimal to set \( r = 1 \).

Table 4: Optimal tobacco regulation with three instruments

40% of the producer price of tobacco). This first scenario is useful, albeit simple, since it permits a direct comparison with the numerical results in Table 2. In the second scenario, we allow for heterogeneity in all parameters along the same lines of Table 3.

As for the compliance cost \( \xi \), we consider two possible values: 0.3 and 0.5, uniformly distributed. Note that under this second scenario the results, which are based on the model with three consumption locations, are not directly comparable with those of Table 3 that are instead based on the simplified model with only one consumption location.\(^{41}\)

The results under both scenarios are reported in Table 4. For each scenario, we consider two values of \( \tilde{\xi} \) (4.248 and 14.16) and three values of the external cost per-unit-of-tobacco-consumption (0, 0.5 and 1) assuming that the externalities are the same in type 2 (non regulable) and in type 3 (regulable) locations, by setting \( \eta^2 = \eta^3 = \eta \). The

\(^{41}\)This follows from the observation that, with three consumption locations, the variability in the taste parameter \( \rho \) of the utility function (48), now location specific, represents an additional source of smokers’ heterogeneity in terms of variability in the preferences for consumption bundles in the different locations.

<table>
<thead>
<tr>
<th>Scenario I: variance in ( \kappa ) only</th>
<th>Scenario II: variance in ( \kappa, \rho, \gamma, \theta, \mu, \xi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \tilde{\xi} )</td>
<td>( \eta )</td>
</tr>
<tr>
<td>4.248</td>
<td>0.0</td>
</tr>
<tr>
<td>4.248</td>
<td>0.5</td>
</tr>
<tr>
<td>4.248</td>
<td>1.0</td>
</tr>
<tr>
<td>14.16</td>
<td>0.0</td>
</tr>
<tr>
<td>14.16</td>
<td>0.5</td>
</tr>
<tr>
<td>14.16</td>
<td>1.0</td>
</tr>
</tbody>
</table>
benchmark case of zero external costs is useful because it helps understanding the role of the various policy instruments in regulating tobacco efficiently.

With no external costs ($\eta = 0$) and no smoking bans ($r = 0$), the optimal policy ($t^*, z^*$) in columns 3-4 of the first row of Table 4 is the same as in the third row of Table 2. In this case, there is no need of a smoking ban, as it reduces social welfare. Still it is interesting to understand what happens if it is introduced. Setting $r = 1$ crowds out $z^*$, which falls by 6%, while $t^*$ remains essentially unaffected (the increase from 35.2% to 35.7% is due to the shift of consumption from type 3 to type 1 and type 2 locations). The reason is that, with no externalities, the introduction of the smoking ban has no effect on the inefficiencies addressed by taxation, i.e., the internal costs of smoking. This holds true also for antismoking campaigns. However, since the latter are costly while taxation is costless, optimality requires to reduce $z$ in response to the introduction of a smoking ban.

The picture is quite different when the level of the external costs is such that a smoking ban is desirable in terms of social welfare, which is the case for $\eta = 0.5$ and $\eta = 1$. Indeed, by looking at rows 2-3 of Table 4, we see that shifting from $r = 0$ to $r = 1$ has a strong negative impact on the optimal tax rate — that falls from 70.3% to 56.1% (row 2) and from 105.5% to 76.2% (row 3). Conversely, the introduction of the ban increases the optimal expenditure on prevention programs — that increases by 4% and by 18.1%, respectively (rows 2-3, column 7). The intuition is simple. If the external costs due to smoking in type 3 locations are such that a smoking ban is socially worth, its introduction makes no longer necessary to correct for the externalities by means of taxation, since the ban — that is perfectly enforced by assumption in our setup — drives to zero the externalities in type 3 locations. In terms of Eq. (43), the fourth component of the optimal tax rate goes to zero. However, the reduction in the tax rate, and the fact that smokers react to the smoking ban by shifting part of their consumption to type 2 non-regulable locations (where smoking causes external costs) make useful to increase the expenditure on antismoking campaigns. The effect of the smoking ban on consumption choices is reported in columns 10-12 of Table 4. For instance, in the third row, where $\bar{c} = 4.25$ and $\eta = 1$, the introduction of the ban increases consumption by 19% in type 1 and type 2 locations while it reduces it by 13.9% in type 3 locations, which results in an overall increase of consumption by 8%.

The other numerical examples in Table 4, scenario I for $\bar{c} = 14.16$ and scenario II for $\bar{c} = \{4.248, 14.16\}$, provide the same qualitative results illustrated above. Provided
that a smoking ban increases social welfare, its introduction lowers the optimal tax rate while it increases the optimal expenditure on prevention programs.\footnote{In the numerical examples of Table 4 we have considered only situations in which the optimality conditions imply a corner solution for \( r \), namely \( r^* = 0 \) for \( \eta = 0 \) and \( r^* = 1 \) for \( \eta = \{0.5, 1\} \). With different specifications of parameters, or with positive and convex costs of enforcement of the smoking ban, it is possible to obtain also interior solutions in \( r \).}

8 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 mass media campaigns and smoking bans.

We find that antismoking programs and smoking restrictions can usefully complement taxation in controlling tobacco consumption. The optimal tax corrects for the average marginal internalities induced by smoking and for the marginal externalities caused by smoking in consumption locations that cannot be regulated by means of free-air measures. Efficiency implies that taxation and smoking bans are substitute instruments for correcting the externalities in consumption locations where free-air legislation can be effectively enforced. Finally, antismoking campaigns contribute to social welfare by reducing excessive tobacco consumption by the less self-controlled smokers and by those that suffer larger health costs due to smoking.

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. 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).

In our framework, as in most of the literature on sin goods, the market for tobacco is perfectly competitive. In terms of the normative analysis conducted in this work, introducing imperfect competition does not greatly affects the results. Market power implies that the formula of the optimal tax rate shown in Eq. (43) contains an additional negative term, expressing a subsidy component to correct for the fact that firms price above marginal costs. Imperfect competition can instead be important from a positive perspective, since big firms spend a huge amount of resources to lobby policy makers in order to lessen tobacco regulation policies, and they also make information campaigns to counteract public prevention programs. This leads to a political economic analysis of tobacco regulation (see, e.g. Haavio and Kotakorpi, 2011, for an analysis of voting, but focusing only on taxation).

Market power matters also for taxation. 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.
References


A.1 Appendix. The WHO indicators

As described at (http://www.who.int/tobacco/mpower/en/), in 2008 the World Health Organization introduced the MPOWER package to assist in the country level implementation of six effective measures to reduce demand for tobacco products. Each measure reflects at least one provision of the WHO Framework Convention on Tobacco Control. Three of these measures, or policy instruments, are the ones on which we focus in our theoretical analysis: taxation, antismoking media campaigns, and smoking bans (the other three measures in the MPOWER package, not covered by our theoretical framework, are: monitoring tobacco use, enforcement of bans on tobacco advertising, promotion and sponsorship, offer help to quit tobacco use).

We next report the Metadata Registry provided by the WHO for each one of the three indicators represented in Figures 1, 2 and 3 of Section 2, and in Table B1 of this Appendix.

Tobacco taxation
(http://apps.who.int/gho/data/node.wrapper.imr?x-id=374)

Country provided information on taxes and prices is assessed to yield indicators to describe the comparative level of taxes on tobacco products in countries. Taxes assessed include excise tax, value added tax (VAT), import duty (when the cigarettes were imported) and any other taxes levied. Only the price of the most popular brand of cigarettes is considered. In the case of countries where different levels of taxes applied to cigarettes are based on either length, quantity produced or type (e.g. filter vs. nonfilter), only the rate that applied to the most popular brand is used in the calculation. Given the lack of information on country and brandspecific profit margins of retailers and wholesalers, their profits were assumed to be zero (unless provided by the national data collector). The implementation status of the Raise tobacco taxes measure was classified by grouping countries into five groups. The groupings for this indicator are: 1 = Data not reported; 2 = ≤ 25% of retail price is tax; 3 = 26 – 50% of retail price is tax; 4 = 51 – 75% of retail price is tax; 5 = > 75% of retail price is tax.

Anti-tobacco mass media campaigns
(http://apps.who.int/gho/data/node.wrapper.imr?x-id=2723)

The implementation status of the Antitobacco mass media measure was classified by grouping countries into five groups. The groups for this indicator are: 1 = Data not reported; 2 = No national campaign conducted in the reporting period with a duration of at least three weeks; 3 = National campaign conducted with 1-4 appropriate characteristics*; 4 = National campaign conducted with 5-6 appropriate characteristics*, or with 7 characteristics excluding airing on TV and/or radio; 5 = National campaign conducted with at least 7 appropriate characteristics* including airing on TV and/or radio.

* Characteristics of a high quality campaign are: the campaign was part of a tobacco control programme; before the campaign, research was undertaken or reviewed to gain a thorough understanding of the target audience; campaign communications materials were pretested with
the target audience and refined in line with campaign objectives; air time (radio, television) and/or placement (billboards, print advertising, etc.) was obtained by purchasing or securing it using either the organization’s own internal resources or an external media planner or agency (this information indicates whether the campaign adopted a thorough media planning and buying process to effectively and efficiently reach its target audience); the implementing agency worked with journalists to gain publicity or news coverage for the campaign; process evaluation was undertaken to assess how effectively the campaign had been implemented; an outcome evaluation process was implemented to assess the campaign impact.

**Smoking bans**

(http://apps.who.int/gho/data/node.wrapper.imr?x-id=341)

Country’s legislation is assessed to determine whether smokefree laws exist in each of the following places at either the national or subnational level: healthcare facilities, educational facilities other than universities, universities, government facilities, indoor offices, restaurants, pubs and bars, public transport. The implementation status of the Smokefree environments measure was classified by grouping countries into five groups. The groupings for this indicator are: 1 = Data not reported/not categorized*; 2 = Up to two public places completely smokefree; 3 = Three to five public places completely smokefree; 4 = Six to seven public places completely smokefree; 6 = All public places completely smokefree (or at least 90% of the population covered by complete subnational smokefree legislation).

*In several countries, in order to significantly expand the creation of smokefree places, including restaurants and bars, it was politically necessary to include exceptions to the law that allowed for the provision of designated smoking rooms. The requirements for designated smoking rooms are so technically complex and stringent that, for practical purposes, few or no establishments are expected to implement them. Because no data were requested on the number of complex designated smoking rooms actually constructed, it is not possible to know whether these laws have resulted in the complete absence of such rooms, as intended. For this reason, these few countries have not been categorized in the analyses for this indicator.

***** insert Table A.1 here *****
A.2 Appendix. Optimality conditions

Optimality condition: antismoking campaigns. From Eq. (38), setting $\tilde{\Omega}_t^* = 0$ and solving for $t$ we get $t^*(z, r)$ such that:

$$t^* E [\tilde{x}_t^*] = E [(1 - \beta) \delta \tilde{y}_t^*] + \tilde{\Gamma}_t^*.$$

We substitute $t = t^*(z, r)$ into Eq. (39) and then we manipulate it as follows:

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

Using Eq. (41) to substitute for $\tilde{\Gamma}_t^*$ and $\tilde{\Gamma}_r^*$ we finally get Eq. (44).

Optimality condition: smoking bans. We substitute $t = t^*(z, r)$ into Eq. (40) and then we manipulate it as follows:

$$\tilde{\Omega}_r^* = E [t^* - (1 - \beta) \delta \gamma \tilde{x}_r^*] - \tilde{\Gamma}_r^* - C_r - E [\xi (\tilde{a}^3 \tilde{x}^3)^*] =$$
$$= \text{cov} [(t^* - (1 - \beta) \delta \gamma), \tilde{x}_r^*] + E [(t^* - (1 - \beta) \delta \gamma)] E [\tilde{x}_r^*] - \tilde{\Gamma}_r^* - C_r - E [\xi (\tilde{a}^3 \tilde{x}^3)^*] =$$
$$= \text{cov} [(1 - \beta) \delta \gamma, \tilde{x}_r^*] + \left( \frac{\text{cov} [(1 - \beta) \delta \gamma, \tilde{x}_r^*]}{E [\tilde{x}_r^*]} + \frac{\tilde{\Gamma}_r^*}{E [\tilde{x}_r^*]} \right) E [\tilde{x}_r^*] - \tilde{\Gamma}_r^* - C_r - E [\xi (\tilde{a}^3 \tilde{x}^3)^*] =$$
$$= -E [\tilde{x}_r^*] \left( \frac{\text{cov} [(1 - \beta) \delta \gamma, \tilde{x}_r^*]}{E [\tilde{x}_r^*]} - \frac{\text{cov} [(1 - \beta) \delta \gamma, \tilde{x}_r^*]}{E [\tilde{x}_r^*]} \right) +$$
$$-E [\tilde{x}_r^*] \left( \frac{\tilde{\Gamma}_r^*}{E [\tilde{x}_r^*]} - \frac{\tilde{\Gamma}_r^*}{E [\tilde{x}_r^*]} \right) - C_r - E [\xi (\tilde{a}^3 \tilde{x}^3)^*].$$

Using Eqs. (41)-(42) to substitute for $\tilde{\Gamma}_t^*$ and $\tilde{\Gamma}_r^*$, respectively, we finally get Eq. (47).
Figure 1a: Taxation and Antismoking campaigns (2014)

Figure 1b: Taxation and Smoking bans (2014)

Figure 1c: Antismoking campaigns and Smoking bans (2014)
Table A.1: Tobacco regulation indicators (year 2014)

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TOT: total indicator; TAX: taxation; AC: antismoking campaigns; BAN: smoking bans