Obesity and smoking: can we kill two birds with one tax?

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Abstract

The debate on tobacco and fat taxes often treats smoking and eating as independent behaviors. However, the available evidence shows that they are interdependent, which implies that policies against smoking or obesity may have larger scope than expected. To address this issue we propose a dynamic rational model where eating, smoking and physical exercise are simultaneous choices that jointly affect body weight and addiction to smoking. Focusing on direct and cross-price effects we study the impact of tobacco and food taxes and we show that in both cases a single policy tool can reduce both smoking and body weight.

Keywords: Addiction; Fat Tax; Obesity; Physical Exercise; Tobacco.

JEL code: D91, H31, I18.

1 Introduction

Smoking and obesity are two major causes of preventable death and have a significant impact on the health care system (Cawley and Meyerhoefer, 2012; Mokdad et al., 2004). To reduce their prevalence, national governments have introduced taxes, educational interventions, advertising campaigns, and provision of assistance and tutoring.[1] Notably, the evaluation of such policies aimed at reducing obesity and smoking prevalence usually focuses on their direct effects. For example, tobacco taxes are considered to be effective if they reduce smoking, and taxes on energy-dense food (often called fat taxes) are effective if they reduce obesity rates. This approach can be appropriate when the indirect effects of the policy interventions are negligible. When considering smoking and obesity, however, this appears not to be the case: recent empirical evidence indeed suggests that not only have antismoking policies reduced smoking prevalence, but have also reduced the obesity epidemic through healthier eating and increased physical exercise (Gruber and Frakes, 2006; Courtemanche, 2009; Wehby and Courtemanche, 2012, Dragone et al., 2013).[2]

To understand how these outcomes can emerge, in this paper we propose a dynamic model which studies smoking, eating and physical exercise as concurrent choices. We consider a setting which builds on the literature suggesting that they are intrinsically dynamic phenomena (Becker and Murphy, 1988; Gruber and Kőszegi, 2001; Levy, 2002; Charness and Gneezy, 2009; Dragone, 2009; Dragone and Savorelli, 2012) and that they are related through

[1] The potential justification for these government interventions is generally based on the finding that smoking, unhealthy eating and obesity produce significant externalities and internalities (see, e.g. Cawley and Ruhm, 2012).

[2] The empirical results are mixed. Some researchers identify a positive correlation between cigarette prices or taxes and body mass index (BMI) (Chou et al., 2004; Rashad and Grossman, 2004; Baum, 2009), while others0 find the opposite result (Gruber and Frakes, 2006). Courtemanche (2009) has reconciled these results showing that, if lags of cigarette prices or taxes are included in the empirical specification, all above mentioned papers deliver the result that cigarette price/taxes are negatively associated with BMI and obesity. Consistent results are also reported in Wehby and Courtemanche (2012) and Dragone et al. (2013).

two distinct pathways: their impact on individual metabolism and body weight (Chiolero et al., 2008; Caudwell et al., 2011, Donny et al., 2011; Mineur et al., 2011), and their role on individual preferences (Schane et al., 2009; Dunbar et al., 2010; Debevec and Diamond, 2012).

For expositional simplicity and to better highlight the intuition behind the results, we first present a baseline model where the agent chooses only between food consumption, smoking and a composite good. In this baseline model we show the conditions under which the demand for smoking can be partially imputed to the demand for weight control. This result rationalizes the empirical finding that smoking initiation is sometimes driven by the desire to reduce appetite and control body weight and, analogously, that fear of gaining body weight plays an important role in the decision to (not) quit smoking (Moran et al., 2004; Cawley et al., 2004, 2014; Spring et al., 2009). We also show that a variety of unhealthy behaviors can be optimal, including situations in which a person smokes, is overweight and is restraining food consumption, or smokes, is underweight and overconsumes, even if the agent fully takes into account present and future consequences of her current behavior.

Focusing on direct and cross-price effects, we then study and compare the impact of tobacco and food taxes. We hereby highlight two main results. First, we identify the conditions under which a tax-based policy produces undesirable trade-offs, such as a reduction in smoking prevalence but an increase in obesity. Importantly, this is only one possible case, as there exist conditions under which a policy-maker can implement a single policy action which curbs both smoking and obesity. We will define this as a ”two-birds-with-one-tax” result. Second, comparing alternative policy tools, we find that food taxes and tobacco taxes have an asymmetric effect at concurrently fighting obesity and smoking. The intuition for this result is that increasing the price of food reduces food consumption, and consequently body weight, which in turn makes smoking less desirable as a dieting device. In contrast, an increase in cigarette prices curbs tobacco consumption, but also reduces the "dieting" effect of nicotine. As a consequence, body weight decreases only if the reduction in smoking is accompanied by a strong reduction in food intake that more than compensates for a slower metabolism.

Our qualitative results, including the possibility of obtaining two-birds-with-one-tax results or compensatory behavior, also hold when extending the model to consider different types of food (say: junk vs. healthy food), or alternative choices on caloric output. As an example of the latter case, we extend the baseline model and include the choice of physical exercise, and we show that the results, even if analytically more cumbersome, are analogous to the ones presented in the baseline model.

Our paper's main contribution to the existing literature is threefold. First, our theoretical model provides an analytical rationale for the above mentioned empirical findings, with particular reference to the result that higher tobacco taxes have contributed to reduce obesity (Gruber and Frakes, 2006; Courtemanche, 2009; Wehby and Courtemanche, 2012), to decrease caloric intake and to improve the quality of the diet in the population (Dragone et al., 2013), and to increase physical exercise (Courtemanche, 2009; Wehby and Courtemanche, 2012). Second, based on the available medical and sociological literature, we design a dynamic model that clearly emphasizes the interdependences between smoking, eating behavior and exercising, and the importance of the substitutability among health-related behaviors. Third, we study rational smoking, rational eating and physical exercise as joint choices which reciprocally affect each other in an intertemporal framework (e.g. Becker and Murphy, 1988;

Gruber and Kőszegi, 2001; Levy, 2002; Dragone, 2009; Dragone and Savorelli, 2012). On the one hand, this allows studying the implications of the taxation of addictive goods in the context of interdependent health-related behaviors, on the other hand it contributes to the literature on fat taxes, which has been mainly addressed in static models (Schroeter et al., 2008; Yaniv et al., 2009; Lusk and Schroeter, 2012). More generally, our model provides a theoretical reference to understand the occurrence of ”clusters of risky behaviors” that are often observed at the empirical level, to identify the conditions under which policy actions produce undesirable health trade-offs, and the conditions under which the interdependence between health-related behaviors provides an additional justification for policy interventions.

The paper is structured as follows. In section 2 we present and solve the benchmark model of smoking and eating behavior. In section 3 we study the effects of taxing tobacco or food and we compare their effects. In section 4 we discuss the role of impatience and exogenous shocks to the survival probability of the individual. In section 5 we extend the model to include the choice on physical exercise. Section 6 discusses the implications and the limits of our exercise for policy-making and it introduces challenges for the future research agenda.

2 A model of rational smoking and eating

In this section we present a model of rational smoking and eating based on Becker and Murphy (1988) and Levy (2002). The model will be extended to include physical exercise in section 5.

Consider a representative agent whose utility function $U(s, c, q, a, w)$ depends on smoking s, food consumption c, a composite good q, past smoking experiences a, and body weight

w. To focus on the substitutability between eating and smoking choices, and the effects of price changes on body weight and addiction to smoking, food is simply represented as a basket of different types of food whose composition does not change over time.[3] The utility function $U(\cdot)$ is continuously differentiable and jointly concave. Smoking features reinforcement between past and current consumption, and tolerance (Becker and Murphy, 1988). Reinforcement implies that the marginal utility of current smoking increases with past smoking ($U_{sa} > 0$), hence the more a person has smoked in the past, the more she desires to smoke. Tolerance means that utility from a given amount of smoking is lower when past smoking is greater ($U_a \leq 0$ for $a \geq 0$).[4] Besides the interdependence between past and current smoking, we also assume interdependence between smoking and eating. In particular, based on medical evidence (Chiolero et al., 2008; Mineur et al., 2011), we allow for current smoking to affect the marginal utility of food consumption (i.e. $U_{cs} \neq 0$). Moreover, smoking accelerates metabolism (due to the metabolic effect of nicotine), which contributes to reduce the accumulation of body weight. Hence the evolution of body weight w depends on past and current eating behavior, as well as on current smoking: $\dot{w}(t) = g(c(t), w(t), s(t))$ with $g_c \geq 0$ for $c(t) \geq 0$, $g_w < 0$ for $w(t) > 0$ and $g_s \leq 0$ for $s(t) \geq 0$. Addiction to smoking evolves over time depending on current and past smoking choices: $\dot{a}(t) = f(s(t), a(t))$, with $f_s \geq 0$ for $s \geq 0$ and $f_a \leq 0$ for $a \geq 0$.

Since an individual's longevity is impossible to ascertain before time of death, we assume that the agent's life is finite, but with uncertain terminal time T. Given the initial body

[3] Our approach is thus complementary to those that focus on the cross-elasticities between different types of goods (say, junk and healthy food) as in, e.g., Schroeter et al. (2008), Yaniv et al. (2009), Lusk and Schroeter (2012). Our model can be extended to make this distinction, but this would not change our message nor our results.

[4] More precisely: $U_a = 0$ for $a = 0$ (no addiction to smoking) and $U_a < 0$ for $a > 0$ (some addiction to smoking). These assumptions are formally equivalent to assume that past smoking experiences are harmful.

weight w_0, addiction to smoking a_0 and wealth b_0, the agent must choose the path of food consumption, smoking and consumption of the composite good that satisfies the following intertemporal problem:

$$
\begin{aligned}
\max_{s(t),c(t),q(t)} \quad & \mathbb{E}\left[\int_0^T e^{-\tilde{\rho}t} U\left(s\left(t\right), c\left(t\right), q\left(t\right), a\left(t\right), w\left(t\right)\right) dt\right] && (1)\\
\text{s.t. } \dot{a}\left(t\right) &= f\left(s\left(t\right), a\left(t\right)\right) && (2)\\
\dot{w}(t) &= g\left(c\left(t\right), w\left(t\right), s\left(t\right)\right) && (3)\\
\dot{b}\left(t\right) &= rb\left(t\right) + M - p^c c\left(t\right) - p^s s\left(t\right) - q\left(t\right) && (4)\\
a\left(0\right) &= a_0, \quad w\left(0\right) = w_0, \quad b\left(0\right) = b_0 \\
c\left(t\right) &\geq 0, \quad s\left(t\right) \geq 0, \quad q\left(t\right) \geq 0 \\
w\left(t\right) &> 0, \quad a\left(t\right) \geq 0,
\end{aligned}
$$

where $\tilde{\rho} > 0$ is the intertemporal discount rate representing the agent's impatience, r is the market interest rate, M is the instantaneous wage of the agent and $b\left(t\right)$ is the available wealth; p^c and p^s are the market prices of food and smoking, while the price of the composite good is normalized to one.

The objective function (1) represents the expected intertemporal utility function of an agent with stochastic terminal time. A notable and very useful result is that (1) can be written as $\int_0^{\overline{T}} \left[1 - F\left(t\right)\right] e^{-\tilde{\rho}t} U\left(\cdot\right) dt$, where $1 - F\left(t\right)$ is the probability of living beyond time t and $\overline{T}$ is the upper bound of the distribution (Yaari, 1965). For tractability reasons, in the remainder of the paper we will focus on the special case where $f\left(T\right) = \hat{\rho} e^{-\hat{\rho}T}$, i.e. where the density function associated to $F\left(T\right)$ is exponential. Relaxing this assumption does not affect our main results.[5] Under this assumption the expected intertemporal utility of the agent (1) can be equivalently written as follows:

$$\mathbb{E}\left[\int_0^T e^{-\tilde{\rho}t} U(\cdot)\,dt\right] = \int_0^\infty e^{-\hat{\rho}t} e^{-\tilde{\rho}t} U(\cdot)\,dt = \int_0^\infty e^{-\rho t} U(\cdot)\,dt, \tag{5}$$

where $\rho = \tilde{\rho} + \hat{\rho}$ is an overall discount rate that depends on impatience ($\tilde{\rho}$) and on the hazard rate ($\hat{\rho}$).

Taken at face value, the objective function (5) represents the overall discounted stream of utility of an infinitely-lived agent. As we have just shown, an alternative interpretation is possible, whereby the objective function (5) represents the expected intertemporal utility of an agent with stochastic life and whose hazard rate is constant. This provides a bridge between finite and infinite horizon models, as well as an appealing and microfounded justification for considering infinite horizon problems.[6]

When considering individual preferences, we must take into account that biological factors interact with individual tastes and social factors. For example, nicotine is an appetite suppressor and has a satiating effect on food consumption (Mineur et al., 2011), but it is also true that smokers tend to crave smoking more when they are eating (Dunbar et al., 2010) and in social contexts (Schane et al., 2009; Debevec and Diamond, 2012). For this reason, we choose to make no assumption concerning the complementarity or substitutability in prefer-

[5] Agents that discount the future exponentially constitute the benchmark in the literature on rational addiction and rational eating (e.g., Becker and Murphy, 1988; Dockner and Feichtinger, 1991; Levy, 2002). Halevy (2005) proves that a Bayesian decision-maker that discounts time exponentially is always time-consistent, irrespective of the survival function used to describe the probability of dying. This result extends Strotz (1955)'s analysis to a scenario where the time of death is stochastic and allows choosing a treatable survival function such as the exponential one we use in this paper.

[6] Realism would suggest that the hazard rate is also affected by individual actions and health condition. For example, one of the main reasons people would like to stop smoking is that they are concerned about smoking increasing the chance of dying. The model can be extended to allow for state-dependent survival probabilities, in the spirit of Levy (2002) and Dragone (2009). This extension does not affect the main results and the message of the paper, although the analytical development is much more cumbersome.

ences between smoking and eating. In addition, to simplify the exposition without affecting the main results, we will consider the case where no saving nor borrowing is possible, and replace the dynamic budget constraint (4) with the static budget constraint. Consistent with the literature, we will consider linear dynamics for the evolution of addiction to smoking and body weight:

$$\dot{a}(t) = s(t) - \delta_a a(t), \tag{6}$$

$$\dot{w}(t) = c(t) - \varepsilon s(t) - \delta_w w(t), \tag{7}$$

where $\delta_a, \delta_w \in (0,1)$ represent the decay rate of addiction to smoking and body weight, respectively (Becker and Murphy, 1988; Levy, 2002; Dragone, 2009),[7] and $\varepsilon \geq 0$ represents the metabolic channel through which smoking affects body weight (Filozof et al., 2004; Chiolero et al., 2008). Finally, we will consider the following quasi-linear specification for the utility function

$$U(s(t), c(t), a(t), w(t)) + q(t), \tag{8}$$

under the assumptions that past smoking does not interact with the marginal utility of current food consumption ($U_{ac} = 0$), and that body weight does not interact with the marginal utility of current and past smoking ($U_{ws} = U_{wa} = 0$) nor with the marginal utility of current consumption ($U_{cw} = 0$). These assumptions are made for expositional convenience, as they imply that all income effects are captured by changes in the demand for the composite good q and that the law of demand holds both in the short and in the long-run.[8]

[7] For expositional convenience, we will set $\delta_a = \delta_w = \delta$.

[8] These assumptions are not too restrictive. In the Appendix we show that, even in the more general case with income effects and addictive food, the policy implications of the model still hold true.

2.1 The optimal solution

The current-value Hamiltonian function associated to the problem is (omitting the time index):

$$H = U\left(c, s, w, a\right) + M - p^{c}c - p^{s}s + \mu\left(s - \delta a\right) + \lambda\left(c - \varepsilon s - \delta w\right),$$

where μ and λ are the shadow values of body weight and past smoking, respectively. Given joint concavity, the following conditions, together with the appropriate transversality conditions and equations (6) and (7), are necessary and sufficient for an internal solution (arguments are omitted for brevity):

$$H_c = 0 \Leftrightarrow U_c - p^c = -\lambda \tag{9}$$

$$H_s = 0 \Leftrightarrow U_s - p^s = -\mu + \varepsilon\lambda \tag{10}$$

$$\dot{\mu} = \left(\delta + \rho\right)\mu - U_a \tag{11}$$

$$\dot{\lambda} = \left(\delta + \rho\right)\lambda - U_w. \tag{12}$$

The first order conditions (9) and (10) simultaneously determine the optimal food consumption and smoking choices at each point in time. Note that, in a dynamic framework, the optimal choice of food consumption and smoking in general does not correspond to the satiating choice in which $U_c = U_s = 0$, nor to the solution of a boundedly rational agent that neglects how her current eating and smoking choices are going to affect her future utility.[9] This occurs because in a forward-looking framework the agent takes into account the shadow prices of addiction and body weight, and their evolution over time as a consequence of her

[9] The optimal solution for an agent with bounded rationality for which $\lambda = \mu = 0$ at all t is reported in the Appendix.

smoking and eating behavior. Accordingly, since food consumption only affects the determination of body weight, condition (9) only depends on λ. Since nicotine can affect body weight by accelerating the individual metabolism (as measured by ε), optimal smoking also depends on body weight. For this reason both costate variables, λ and μ, appear in (10).

2.2 Long-run equilibrium

To determine the long-run dynamic properties of the optimal choices of the agent, we focus on the steady state of the problem where food consumption, smoking, addiction to smoking and body weight are optimally chosen and are stable over time.[10] Before describing the possible types of steady state that are consistent with the model, we introduce some terminology analogous to that in Levy (2002) and Dragone and Savorelli (2012).

We assume that there exists an exogenous weight $w^H > 0$ such that the agent's utility would be lower if $w < w^H$ or $w > w^H$. We say the agent is *overweight* if $U_w < 0$ (the agent would increase her utility by decreasing body weight) and, conversely, she is *underweight* if $U_w > 0$ (she would increase utility by increasing body weight). Note that our economic definitions of overweight and underweight are based solely on the agent's utility, not on the medical definition of those categories.[11]

In the cases of food consumption c and smoking s, a key assumption of this paper is that the respective bliss points are endogenous. We assume that there exists an endogenous satiation level $c^F > 0$ for the representative agent such that the agent's utility would be

[10] As discussed in Becker and Murphy (1988) the distinction between stable and unstable equilibria has important policy implications that cannot be appreciated in a static framework. The conditions characterizing stable steady states in the present model are reported in the Appendix.

[11] According to WHO guidelines, a person has "normal" body weight if 18.5 <BMI< 25, she is "severely underweight" if her BMI is lower than 16.5, "moderately underweight" if 16.5 ≤BMI< 17, "mildly underweight" if 17 ≤BMI< 18.5, "overweight" if 25 ≤BMI< 30, and "obese" if BMI≥ 30. Here we thus assume that within this range of values there exists a weight w^H that maximizes weight-related utility for the representative agent.

lower if $c > c^F$ or $c < c^F$.[12] We thus say that the agent is *overconsuming* if $U_c < 0$ and is *underconsuming* if $U_c > 0$. Analogously, we say that the agent is *oversmoking* if $U_s < 0$ and *undersmoking* if $U_s > 0$.[13] Notice that the "undersmoking" case entails both the possibility that the agent smokes a positive amount ($s > 0$), as well as the case of no smoking ($s = 0$). This would occur if, e.g., a person likes smoking but is smoking less then should would like to.

Proposition 1 *In steady state the following conditions hold,*

$$U_w = (\delta + \rho)(p^c - U_c) \tag{13}$$

$$U_a = (\delta + \rho)(p^s - U_s) + \varepsilon U_w \tag{14}$$

$$\delta w^{ss} = c^{ss} - \varepsilon s^{ss} \tag{15}$$

$$\delta a^{ss} = s^{ss}, \tag{16}$$

where the superscript ss denotes the steady state.

Proof. See Appendix. ■

Equation (13) shows the existence of a trade-off between marginal utility of eating and marginal utility of body weight. Analogously, equation (14) shows the trade-off between the marginal utility of smoking, the marginal harm of the addiction to smoking and the marginal impact of smoking on body weight.[14] The steady state body weight increases with food

[12] Such satiation level depends on biological and genetic factors, as well as by the satiating effect of nicotine.

[13] The personal preferable smoking level depends on past smoking experiences and on factors such as, e.g., individual tastes, education and peer-pressure.

[14] Alternatively, equation (13) can be expressed as a relation between the marginal utility of body weight and the corresponding shadow value: $U_w = (\delta + \rho)\lambda$. Hence, when an individual is overweight, in steady state the shadow price λ is negative, and when she is underweight it is positive. Also equation (14) can be expressed as a relation between the marginal harm of addiction to smoking, the shadow value of addiction to smoking μ and the metabolic effect of smoking on body weight λ, $U_a = (\delta + \rho)(\lambda - \varepsilon\mu)$.

consumption, and decreases with smoking (eq. 15), while steady state addiction to smoking tracks the changes in steady state smoking (eq. 16).

Can an agent rationally reach a healthy condition where she is not addicted to smoking and she has an optimal body weight? Yes, this is possible, although this outcome can emerge only as a special case.[15] In general, the following four types of steady state associated to some addiction to smoking and to a non-optimal body weight can result:

(i) Being overweight, underconsuming, and oversmoking;

(ii) Being overweight, underconsuming, and undersmoking;

(iii) Being underweight, overconsuming, and undersmoking;

(iv) Being underweight, underconsuming, and undersmoking.

Oversmoking is optimal only for an overweight agent, as she would otherwise restrict smoking because it is harmful. Outcome (i) describes such a situation, in which an overweight agent is already underconsuming food and smokes "too much" in order to maintain her body weight under control. This theoretical result is consistent with the evidence of those people who are overweight and declare they initiated smoking, even if they recognized it is harmful, to control their body weight (Cawley et al., 2004, 2014). Notably, this result emerges only when smoking has a metabolic effect on body weight ($\varepsilon > 0$), which rationalizes its use as a sort of dieting device. Outcomes (ii) and (iii) describe, respectively, the case where an overweight agent underconsumes food to avoid getting even more overweight (Levy, 2002; Dragone, 2009) and the one where an underweight agent overconsumes food to avoid getting even more underweight (Dragone and Savorelli, 2012). Outcome (iv) describes the case where

[15] In this special steady state smoking is nil ($s^{ss} = a^{ss} = 0$) and body weight is optimal $\left(w^{ss} = w^H\right)$, which means that $U_w = U_a = 0$ when $\dot{c} = \dot{s} = \dot{w} = \dot{a} = 0$. Accordingly, conditions (13) and (14) imply that, in this steady state, $U_c/U_s = p^c/p^s$ holds. Interestingly, this is the same condition characterizing the familiar static optimizing condition under budget constraint. The reason is that, in this specific steady state, the shadow value of addiction to smoking and body weight is nil (see 11 and 12).

underconsuming food, despite being underweight, is optimal. Such outcome is due to the fact that, if the price of food is high, the agent optimally substitutes the composite good for food (say: cars for food), and possibly ends up eating below the satiation level even if she is underweight.[16]

Notice that all four cases, including undersmoking, entail the possibility that the agent is a smoker. As any positive level of smoking is harmful for health ($U_a < 0$ for any $a > 0$), all four cases are thus of potential interest for the policy maker. For cases (i) and (ii) there is the possibility that both smoking and obesity occur, while for (iii) and (iv) that smoking and being underweight occur.[17] In such cases, for example, a smoking tax could either increase or decrease body weight, depending on the complementarity/substitutability of smoking and food consumption in the utility function. Taxes can thus generate either a trade-off (e.g. reducing obesity but increasing smoking) or a simultaneous reduction in smoking and obesity. The next sections investigate under which conditions tobacco taxes or food taxes can produce these outcomes.

3 The effect of prices on individual behavior

In this section we study the effect of increases in the price of smoking (through, e.g. excise taxes on tobacco) and of increases in the price of food (through, e.g. taxes on junk food). For both cases we will determine short- and long-run effects, that depend on the degree of interdependence among variables in the utility function and on how addiction and body

[16] Dragone and Savorelli (2012) show that the same outcome can alternatively occur when there is social pressure to be thin.

[17] Note that smoking and under/oversmoking are not the same concept. One can smoke a positive amount of cigarettes ($s > 0$), and either smoke more than she likes ($U_s < 0$: outcome i) or smoke less then she would like ($U_s > 0$: outcomes ii, iii, iv). Hence all four steady states are possible, and all of them can be of some interest for the policy maker which is both concerned about smoking and people having an unhealthy weight (either overweight or underweight).

weight evolve over time. In particular, we will show the conditions under which a price-based policy intervention implies trade-offs between health-related behaviors (smoking and eating) and health-related outcomes (addiction to smoking and body weight), and conditions under which a two-birds-with-one-tax result obtains and no trade-off between health-related outcomes is expected.

We will emphasize three main factors. The first one is the simultaneous interdependence between current food consumption and current smoking. A priori, we take no stance on the sign of this interdependence because, while there is medical evidence showing that nicotine is an appetite suppressor (Mineur et al., 2011), the sociological and psychological evidence suggests that, depending on individual lifestyles, situational cues and peer effects, eating can increase the desirability of smoking (Schane et al., 2009; Debevec and Diamond, 2012). When the first effect is dominant, we say that smoking has a satiating effect on eating ($U_{cs} < 0$), as the marginal utility of food consumption decreases when smoking increases (and, conversely, the marginal utility of food consumption increases when smoking decreases). When the second effect is dominant, smoking has a reinforcing effect on eating ($U_{cs} > 0$). The second factor concerns the intertemporal dependence between past and current smoking which depends on reinforcement ($U_{sa} > 0$) and tolerance ($U_a \leq 0$). The third factor concerns the metabolic effect of current smoking on body weight ($\varepsilon \geq 0$). This form of interaction does not directly affect preferences, but it is a pure dynamic effect that affects the evolution of body weight. Hence, it is not taken into account by an agent that neglects the future, but it will play a major role in our intertemporal framework.

3.1 Increasing the price of smoking

We first focus on the direct effect of an increase in the price of smoking. The following applies:

Proposition 2 *When the price of smoking increases, smoking decreases both in the short- and in the long-run.*

Proof. See Appendix. ■

The result above replicates a main finding in Becker and Murphy (1988): addicts do respond to incentives, and they reduce the consumption of the addictive good when it becomes more expensive, both in the short- and long-run. This prediction is consistent with the empirical literature, which estimates the elasticity of the demand for smoking to be negative, and to range between -0.3 and -0.5 (see, e.g., Chaloupka and Warner, 2000; Cawley and Rhum, 2012). Novel results emerge when considering the effects of an increase in the price of smoking on food consumption and body weight.

Proposition 3 *When the price of smoking increases:*

1. *In the short-run food consumption decreases if* $U_{cs} > 0$*, and increases otherwise;*
2. *In the long-run:*
   - *Food consumption decreases if* $U_{cs} > \sigma_1$*, and increases otherwise;*
   - *Body weight decreases if* $U_{cs} > \sigma_2$*, and increases otherwise;*

where $\sigma_1 = \varepsilon U_{ww} / \left[\delta\left(\delta + \rho\right)\right] \leq 0$ *and* $\sigma_2 = -\varepsilon U_{cc} \geq 0$.

Proof. See Appendix. ■

The instantaneous reaction of food consumption to the increased price of smoking only depends on the interdependence between current smoking and eating. Accordingly, smoking and food consumption are complements in the short-run if smoking reinforces eating; and they are substitutes in the short-run if smoking has a satiating effect on food consumption.[18] In the long-run the picture becomes more complex, as the interdependences, both at the biological and at the preference level, between smoking, eating and body weight must take into account the metabolic effect of smoking, as well as impatience and the survival probability.

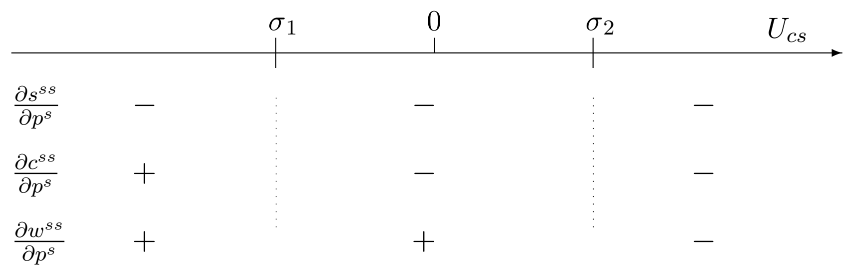

Figure 1: Long run effects of an increase in the price of smoking on smoking, food consumption and body weight.

As observed above, smoking is always reduced after its price increases. This produces two main effects: it slows down individual metabolism (which, per se, would contribute to body weight gain), and it affects the optimal amount of food satiation. We can distinguish three cases (see Figure 1). When $U_{cs} < \sigma_1 < 0$, the reduction in smoking increases appetite, which translates into increased food consumption. In other words, smoking substitutes for food consumption and the agent behaves as if she were compensating reduced smoking with food (see, e.g., Caan et al., 1996; Chiolero et al., 2008). The combined effect of a slower metabolism and of higher food consumption implies that body weight increases. When in-

[18] Recall that only substitution effects between smoking and food are at work because, due to the quasi-linear utility specification, all income effects are captured by changes in the demand for the composite good q.

stead $\sigma_1 < U_{cs} < \sigma_2$, the slower metabolism due to reduced smoking becomes relatively more important than the effect of smoking on appetite, which induces body weight to increase. To counteract excessive body weight gain, the agent reduces food consumption. This only partially compensates for the slower metabolism, however, and weight gain ultimately increases. This case is interesting because it preludes to the possibility that an antismoking policy, although effective in promoting healthier lifestyles (reducing smoking and food intake), also increases body weight and therefore implies a trade-off between health-related outcomes. This difference is clearly crucial when evaluating the desirability of a price-based policy intervention. Finally, when $0 < \sigma_2 < U_{cs}$ the reduction in smoking decreases appetite. This induces a reduction in food consumption that more than compensates for the slower metabolism, and it ultimately results in reduced body weight. Hence increasing the price of smoking leads to the two-birds-with-one-tax result, both in terms of health-related behaviors and in terms of health-related outcomes. This case is clearly most welcome for the policy maker, as it implies no disagreement between improving health-related behaviors and outcomes. Importantly, the complementarity between smoking, eating and body weight is consistent with recent empirical research suggesting that not only have antismoking policies reduced smoking prevalence in the population, but also obesity (Courtemanche, 2009; Wehby and Courtemanche, 2012) and food intake (Dragone et al., 2013).

3.2 Increasing the price of food

A critical issue when considering taxes that are addressed to specific types of food, such as fat taxes, is that the empirical evidence on their effectiveness is mixed.[19] This may be due,

[19] For example, Allais et al. (2010) find that a fat tax has ambiguous effects on nutrients purchased by French households and some effect on body weight. When accounting for substitutions between food categories and types of beverages, Finkelstein et al. (2013) find that a 20% tax on sugar-sweetened beverages results in a

e.g., to the difficulties in targeting specific unhealthy products or categories of food, and to the substitutability opportunities available to consumers (Schroeter et al., 2008). Given the overwhelming evidence that the law of demand holds, however, we would expect that there exists some level of food taxes that reduces food consumption and, ultimately, body weight (Andreyeva et al., 2010; Powell and Chaloupka, 2009). When considering a unique type of food, as in our setup, this is a straightforward result:

Proposition 4 *When the price of food increases, food consumption decreases both in the short- and in the long-run.*

Proof. See Appendix. ■

Given our interest in cross-interdependencies, we now consider cross-price effects. As shown in the following Proposition, the short- and long-run reaction of smoking to changes in the price of consumption mirrors the reactions of food consumption to changes in the price of smoking. The main difference with the previous case concerns the response of body weight. In a setting where body weight is only affected by food consumption, higher price of food should lead to lower body weight. Here, instead, body weight does not necessarily decrease when food consumption decreases due to the metabolic effect of smoking on body weight.

Proposition 5 *When the price of food increases:*

1. *In the short-run smoking decreases if* $U_{cs} > 0$*, and increases otherwise;*

2. *In the long-run:*

   - *Smoking decreases if* $U_{cs} > \sigma_1$*, and increases otherwise;*

decrease in store-bought energy of 24.3 kcal per day per person, an average weight loss of 1.6 pounds during the first year and a cumulated weight loss of 2.9 pounds in the long run. See Elston et al. (2009); Andreyeva et al. (2010) and Cawley and Ruhm (2012) for a review and discussion.

Figure 1: Increasing the price of food. Panel (a) shows the long run effects on smoking, body weight and food consumption. Panel (b) shows how an increase in the discount rate shifts thresholds lines σ_1 and σ_3, while σ_2 is unaffected. Stability of the steady state occurs in the area below the $|J| = 0$ locus.

- *Body weight decreases if $U_{cs} < \sigma_3$, and increases otherwise;*

where $\sigma_3 = -\left[(2\delta + \rho) U_{sa} + U_{aa} + \delta (\delta + \rho) U_{ss}\right] / \left[\delta (\delta + \rho) \varepsilon\right].$

Proof. see Appendix. ■

Figure 2 graphically depicts the results of the above proposition. Notice that $\sigma_1 = \sigma_3$ and $\sigma_2 = \sigma_3$ when $|J| = 0$, hence the intersections of lines σ_1 and σ_2, and lines σ_1 and σ_2 always lay on the $|J| = 0$ curve (see Appendix A.6.3 for the proof).[20] Consider now panel (a) in Figure 2. When the satiating effect of smoking on food consumption is large enough ($U_{cs} < \sigma_1$), food consumption and body weight are complements, while food consumption and smoking are substitutes. Hence the increase in the price of food can reduce obesity, but the agent optimally substitutes smoking for food, which implies a trade-off between increased smoking and reduced obesity. This compensatory behavior is analogous to the case considered in the previous section and it depends only on the satiating effect of smoking on appetite being

[20] In Figure 2 we consider the case where stability of the steady state requires $|J| > 0$ as a necessary condition and where all thresholds σ_1, σ_2 and σ_3 are feasible.

large enough. On the right of the vertical line indicated by σ_1, the reduction in food intake is accompanied by a reduction in smoking. The reason is that the food tax directly discourages eating, which helps controlling body weight accumulation and reduces the incentives to smoke for losing weight. The intensity of the reduction in smoking depends on the intensity of U_{sa}: the higher the reinforcing effect of past smoking on current smoking, the higher the reduction in current smoking after an increase in the price of food. This is what happens above the σ_3 line, where the reduction in smoking is large and the consequent slowing down of the metabolism offsets the reduction in food intake. As a consequence, body weight increases. Below the σ_3 line, instead, smoking is not very addictive. Consequently, although smoking is reduced, the effect on individual metabolism is dominated by the reduced food intake. As a result, the agent will eat, weigh and smoke less. In other words, policies that contribute to reduce body weight also make smoking less attractive, a result that highlights a possibility that does not appear to have been fully considered in the debate on eating policies against obesity, and that seems particularly interesting when considering those people who smoke as a weight control method.

3.3 Two birds with one tax: comparing tobacco and food taxes

In this section we compare the relative merits of antismoking and antiobesity interventions. Our interest is on those policies that either raise the cost of smoking or the cost of food and that result in a decrease in both smoking and obesity. On the basis of the results shown in the previous section we can state the following two-birds-with-one-tax result:

Proposition 6 *Price-based policies can obtain two-birds-with-one-tax results:*

- *When $U_{cs} > \sigma_2$ tobacco taxes reduce both smoking and obesity;*

- *When $\sigma_1 < U_{cs} < \sigma_3$ food taxes reduce both smoking and obesity.*

Graphical inspection of Figure 2 shows that all points on the right of the σ_2 line also satisfy the condition $\sigma_1 < U_{cs} < \sigma_3$, although the reverse is not true. This implies that all cases in which tobacco taxes obtain a two-birds-with-one-tax result are also cases where food taxes would obtain it, although food taxes can obtain a two-birds-with-one-tax result even when tobacco taxes would not yield it. The reason for this asymmetry is that reducing food consumption helps reducing body weight, which directly reduces the incentives to demand smoking as a weight control method. This reduction in smoking translates into a reduction in addiction to smoking. When taxing tobacco, instead, the consequent reduced smoking would drive body weight to increase, which reduces the incentives to demand food. This does not necessarily translate into a body weight decrease, however, because decreased food consumption and decreased smoking affect body weight in opposite directions. As a result, body weight decreases only if the reduction in food consumption is large enough, which occurs when $U_{cs} > \sigma_2$. This results in the following Corollary.

Corollary 1 *Fat taxes are more likely to simultaneously reduce obesity and smoking than tobacco taxes.*

It is important to stress that our statement of likelihood refers to the parameters space where these taxes produce two-birds-with-one-tax results: the larger the parameter set where the two-birds-with-one-tax result emerges, the more likely an agent will satisfy the required conditions for such result.[21] Note also that the above results hold under the simplifying assumptions that smoking does not affect the marginal utility of body weight, and that

[21] We implicitly assume that there exists some positive probability mass in each area of the parameters space where the long-run equilibrium has saddle point stability.

addiction to smoking does not affect the marginal utility of food consumption ($U_{sw} = U_{ac} = 0$). In the more general case where the cross interactions U_{sw} and U_{ac} are not nil, the result in Corollary 1 holds under the conditions specified below:

Proposition 7 *Define threshold* $\bar{\varepsilon} = \rho\left(U_{sw} - U_{ac}\right) / \left[\delta\left(\delta+\rho\right)U_{cc} + 2\delta U_{cw} + U_{ww}\right]$.

- *If the metabolic effect of smoking on body weight is above the threshold,* $\varepsilon > \bar{\varepsilon}$*, fat taxes reduce both body weight and smoking in a wider range of cases than tobacco taxes;*

- *If the metabolic effect of smoking on body weight is below the threshold,* $\varepsilon < \bar{\varepsilon}$*, tobacco taxes reduce both body weight and smoking in a wider range of cases than food taxes.*

- *In the particular case where* $\varepsilon = \bar{\varepsilon}$*, tobacco taxes and fat taxes reduce both body weight and smoking in the same range of cases.*

Proof. See Appendix. ■

The above Proposition generalizes the result obtained in the benchmark case and confirms that interdependence is critical for assessing how price changes affect behavior. Interestingly, the asymmetric impact of fat or tobacco taxes on behavior can be assessed in terms of a threshold on the metabolic effect of smoking on body weight, and there exists only one special case ($\varepsilon = \bar{\varepsilon}$) in which tobacco and fat taxes obtain a two-birds-with-one-tax result in the same range of cases. Graphically this occurs because (the analogue of) the vertical lines σ_1 and σ_2 of Figure 2 overlap. In all remaining cases, the two lines do not overlap and one type of tax has more chances to produce a two-bird result than the other.

4 Impatience and health shocks

A recent body of research suggests that impatience is often associated to risky health-related behavior (Cawley and Ruhm, 2012) and that impatient individuals gain more weight than patient individuals when food prices decrease (see Courtemanche et al., 2014, and references therein). In this section we show under what conditions these results can be rationalized within our theoretical framework.

In our model the trade-off between short- and long-run costs and benefits is compactly represented by the discount rate ρ. Higher values of ρ characterize more impatient individuals, i.e. individuals that give relatively more value to present payoffs than to future ones, or individuals with a lower probability of survival. Taking the derivatives of the steady state levels of smoking and eating with respect to impatience, we can prove that for overweight smokers higher impatience leads smoking to increase if (see Appendix):

$$U_{cs} > \sigma_2 + \frac{\delta\left(\delta+\rho\right)U_{cc} + U_{ww}}{\delta\left(\delta+\rho\right)}\frac{U_a}{U_w}, \tag{17}$$

and it leads food consumption to increase if

$$U_{sa} < -\frac{U_{aa} + \delta\left(\delta+\rho\right)\left(\varepsilon U_{cs} + U_{ss}\right)}{2\delta+\rho} - \frac{\delta\left(\delta+\rho\right)U_{cs} - \varepsilon U_{ww}}{2\delta+\rho}\frac{U_a}{U_w}. \tag{18}$$

In the special case where the agent does not smoke and is not overweight, changes in the level of impatience (or, equivalently, exogenous shocks to the survival probability of the agent) have no effect on smoking and eating. More in general, increasing impatience produces ambiguous results on smoking and eating behavior. This allows us to conclude that impatience is not sufficient *per se* to determine whether a person is more likely to smoke or eat large amounts of food, as this critically depends on how individual preferences endogenously change over time, on individual metabolism and on the health condition of the agent, among other factors.

In addition, it is not necessarily the case that more patient agents should have lower body weight, as it would instead be predicted by models where interdependencies among eating, body weight and smoking are not explicitly taken into account (see, e.g., Courtemanche et al., 2014). To see it, observe that, when a person's body weight increases, also the right hand side of condition (17) increases, which expands the range of cases where increasing impatience reduces smoking behavior. Unfortunately we cannot prove the same to hold for food consumption and body weight because the results depend on whether $U_a/U_w \gtreqless \varepsilon$, i.e. whether the marginal rate of substitution between addiction to smoking and body weight is larger or smaller than ε (which can be interpreted as a marginal rate of transformation between smoking and food consumption in the body weight equation of motion). The above considerations lead to the following Proposition:

Proposition 8 *Higher impatience is more likely to increase food consumption the more a person is overweight.*

Proof. See Appendix. ■

We can also assess how individual's elasticity to price, and therefore to price-based policies, depends on impatience. This is relatively straightforward because higher impatience shifts the threshold σ_1 to the right, but does not affect σ_2 (see Fig. 2, panel b). This increases the range of cases where smoking and eating are long-run substitutes (see Propositions 3 and 5), and the following holds:

Proposition 9 *For more impatient agents price-based policies are more likely to trigger compensatory health-related behavior:*

1. *tobacco taxes are more likely to increase food consumption;*

2. *food taxes are more likely to increase smoking.*

To get an intuition for the above Proposition, recall that compensatory behaviors occur in the short-run when $U_{cs} < 0$ (Propositions 3 and 5). In the long-run, instead, future payoffs are explicitly taken into account and, as shown in Section 3, compensatory behaviors can occur only if U_{cs} is negative and large in absolute value ($U_{cs} < \sigma_1 < 0$). The above Proposition shows that this requirement becomes less binding the more impatient the agent. In other words, the less far-sighted the agent, the more her long-run reaction to a price change becomes similar to the short-run reaction because more impatient agents weight less future utility.

When moving from behaviors to outcomes (i.e. from flow variables to stock variables), we are particularly interested in the parametric cases where both body weight and addiction to smoking decrease after a price increase. Given that the σ_2 line is not affected by ρ, changes in impatience have no effect on the likelihood of obtaining a two-birds-with-one-tax result with antismoking policies. The range of cases where an increase in the price of food triggers a two-birds-with-one-tax results, instead, changes. As graphically illustrated in Figure 2 (panel b), when food prices increase the line σ_1 shifts to the right, which reduces the likelihood of a two-birds-with-one-tax outcome; at the same time, however, σ_3 rotates clockwise, which instead increases the range of cases that produce the two-birds-with-one-tax result. This implies that higher food prices make more likely a decrease in body weight, although this is not necessarily a two-birds-with-one-tax result because smoking can increase. Hence, although on a theoretical ground impatience produces ambiguous results on the likelihood of obtaining a two-birds-with-one-tax result when increasing the price of food, we can conclude that a decrease in body weight is more likely for more impatient agents. This result is consistent with Courtemanche et al. (2014)'s finding that cheaper food leads to the largest weight gains among the most impatient individuals.

5 The role of physical exercise

In this section we extend the analysis to physical exercise to allow for a richer model featuring multiple sources of interdependence, both at the biological and at the preferences' level, between smoking, eating, body weight and physical exercise. The effect of physical exercise on body weight is essentially the same played by smoking on individual metabolism, as both reduce body weight. Physical exercise also affects individual appetite, which impacts on caloric intake and body weight accumulation (Caudwell et al., 2011). Conversely, smoking diminishes lung capacity, and being obese makes exercising more difficult, which result in additional costs for the agent practicing physical activity (Cheng et al., 2003, Nagaya et al., 2007).

All these features can be represented by allowing physical exercise to affect individual preferences, the equation of motion of body weight and the budget constraint. Let x denote physical exercise and consider the following objective function

$$U(s, c, a, w, x) + q. \tag{19}$$

Liking or disliking physical exercise is a matter of individual preferences, which means we do not make any a priori assumption about the sign of U_x. The new substitution possibilities depend on how the marginal utility of exercise interacts with the other variables, for example the effect of physical exercise on appetite (U_{cx}), or the effect of body weight on the marginal utility (or disutility) of physical exercise (U_{wx}). It is reasonable to assume that present and past smoking make physical exercise more difficult, i.e. that U_{sx} and U_{ax} are negative (Washko et al., 2011), but we make not additional assumption on the sign of the remaining interaction terms.

Denote with $\gamma > 0$ the marginal contribution of physical exercise to caloric expenditure (the intensity of exercise) and with p^x its price, which can include both the opportunity cost of the time spent to exercise or the gym's fee. Then body weight accumulates according to

$$\dot{w} = c - \varepsilon s - \delta w - \gamma x \tag{20}$$

and the budget constraint is

$$M = p^c c + p^s s + p^x x + q. \tag{21}$$

Addiction to smoking accumulates as in the benchmark model (eq. 6).

The solution of this problem is qualitatively similar to the solution presented in the previous sections, although the critical thresholds are more cumbersome.[22] In particular we can confirm the existence of a variety of steady states which are possibly associated to clusters of risky health behaviors, and the possibility for the policy maker to implement policies that obtain two-birds-with-one-tax results.

[22]The analytical derivation of these results are available upon request.

As an illustration, let us focus on the interaction between smoking and exercising. As observed above, they play a similar role in the model because they both contribute to caloric expenditure and they both affect individual preferences. To appreciate the specific impact of this interdependence, consider an extreme case where all cross derivatives in preferences are nil, except for the impact of smoking on the marginal utility of exercise, U_{sx}. At the steady state, we can show that an increase in the price of tobacco always reduces smoking and increases physical exercise. The overall effect on body weight depends on the intensity of physical exercise, i.e. to the contribution of physical exercise to body weight reduction, as measured by the threshold $\bar{\gamma} \equiv \varepsilon U_{xx}/U_{sx} > 0$. If exercising does not burn enough calories ($\gamma < \bar{\gamma}$), body weight increases after an increase in the price of tobacco because the slowing down of metabolism due to reduced smoking more than offsets the reduced calorie intake (through less eating) and the increased calorie expenditure (through more exercise). If instead physical exercise is intense enough ($\gamma > \bar{\gamma}$), its effect becomes dominant and body weight decreases. Interestingly, this result can be obtained even if it is accompanied by an increase in food consumption. We conclude that, when physical exercise is sufficiently intense, a two-bird result can result because one policy tool (increasing the price of smoking) can reduce both addiction to smoking and body weight. This result is consistent with the evidence showed by Courtemanche (2009), who finds that people make healthier exercise decisions and reduce their body weight as a consequence of antismoking policies.

6 Conclusion

In this paper we have presented a dynamic model to jointly study the interaction between smoking, eating behavior and physical exercise over time. Consistent with the empirical evidence, we have found that a variety of behaviors may emerge, including clusters of unhealthy behaviors leading to being overweight and addicted to smoking, or being underweight and underconsuming food.

We have shown that targeting single health-related behaviors can have larger scope than expected, and that this is not necessarily bad news. Although it is possible for both antismoking and antiobesity policies to obtain undesirable trade-offs for the policy maker, there exist conditions under which a single policy tool, such as the introduction of excises on tobacco, suffices to induce an overall health improvement by jointly reducing smoking *and* obesity rates in the population. Given that smoking and obesity are major issues in the agenda of health authorities, the possibility of identifying a policy tool that reduces long-run obesity and smoking in a large range of cases is a particularly welcome result.

The reader may be tempted to interpret our results as a praise for fat taxes versus smoking taxes, or as suggesting that smoking taxes should be withdrawn or reduced in favor of the introduction of higher taxes on food. It is probably worth emphasizing that our results do not deliver such a message and that in general neither fat taxes can be said to be better than smoking taxes, nor vice versa. Our setup should not be taken as a suggestion in favor or one policy or the other because a policy evaluation exercise requires specific choices concerning the policy objectives and the way trade-offs should be dealt with, as well as more information than the one required by our model. The core aim of our analysis is to provide a theoretical framework that rationalizes the existing empirical results in the economic literature on real-world policy interventions that have already been implemented, such as the introduction of tobacco excise taxes, and that have obtained two-birds-with-one-tax results on smoking and eating (e.g., Gruber and Frakes, 2006; Courtemanche 2009, Wehby and Courtemanche, 2012, Dragone et al., 2013). In addition, the parallel analysis of fat taxes and tobacco taxes shows that two-birds-with-one-tax results can be obtained with both tools, although under different conditions, which further emphasizes the role and the importance of interdependent behaviors when debating, designing and evaluating policy interventions.

Our paper has some limitations, which should be taken into account when considering policy implications.[23] We have considered consistent, intertemporal choices of a forward looking agent. An interesting direction of research concerns the explicit consideration of self-control problems. This possibility is particularly compelling, as the case of smokers and dieters unsuccessfully trying to quit or to lose weight is the typical example of dynamically inconsistent behavior.

Also, the actual relative desirability of fat taxes or tobacco excises should be weighed against real-world issues related to their implementation, as there are substantial intrinsic differences between eating and smoking (see, e.g., Levy and Oblak, 2009 for an extended discussion). Potential government intervention may be motivated in either case as both smoking and obesity increase the cost of medical treatments for others sharing the same healthcare system, and also the cost of private health insurance through risk-pooling (Evans et al., 1999; Chaloupka and Warner, 2000; Gruber, 2001; Gruber and Kőszegi, 2001, 2004; Finkelstein et al., 2004; Philipson and Posner, 2008; Cawley and Meyerhoefer, 2012; Cawley and Ruhm, 2012). However, smoking produces direct externalities through second-hand smoking, but eating produces only indirect externalities. In our analysis we have focused on individual decision-making and abstracted from externalities, as it is a first necessary step to understand how agents respond to incentives when smoking and eating choices are

[23]We thank an anonymous referee for suggesting this discussion.

interdependent. The next logical step in this line of investigation is to consider externalities explicitly, both in terms of health care costs and of health consequences on other people, which is critical information if the policy maker wants to determine the socially most desirable policy intervention.

A second crucial difference between the two kinds of policies we have considered is that eating is necessary for survival, but smoking is not. In addition, the decision of smoking is fully determined by individual's choices, while an important determinant of body weight and obesity is genetics (combined with behavior). This means that if across-the-board taxes were introduced, they would affect the whole population (including healthy individuals), while smoking taxes will directly affect only smokers. In the current debate this potential concern may be partially solved by considering taxes on specific categories of food (say, fat-taxes on energy-dense food), rather than taxes on all types of food. In our model, for expositional simplicity we have studied the effect of the latter type of taxes, but it can be easily shown that two-birds-with-one-tax results, or the emergence of compensatory behaviors, can obtain even in a richer scenario where one distinguishes between healthy and unhealthy food.

One may still regard the introduction of fat taxes as unfair, especially if their purpose is to reduce smoking, as in practice the entire population would be penalized to restrict the behaviour of a subset of it. This would not be the case for tobacco excises. However, if the share of overweight and obese people is very large (as it currently is in the US and in the UK), introducing a fat tax could accrue net benefits also to the non-overweight through reduced direct and indirect externalities on both obesity and smoking. In addition, the collected revenue could be used to promote further anti-smoking or anti-obesity policies. Thus, beyond fairness considerations, such interventions should not be ruled out a priori, and all costs and benefits should be considered (Philipson and Posner, 2008). Finally, a further concern for the policy maker could be the regressivity of both taxes, which is exacerbated by the fact that cigarettes and junk food are disproportionally consumed by poor individuals (Philipson and Posner, 2008; Gospodinov and Irvine, 2009; Haavio and Kotakorpi, 2011). As some studies show that obesity is positively correlated with inequality, fat taxes or tobacco excises might exacerbate inequality (see Pickett et al. 2005; Elston et al., 2009). In addition, if obesity is also a social phenomenon, policy interventions aimed at reducing its prevalence may have persistent and amplified effects, which should be taken into account (Dragone and Savorelli, 2012; Strulik, 2014). Note also that we have focused on a partial equilibrium analysis. A policy maker which aims at maximizing social welfare may also want to consider the possible effects on the supply side, i.e. on the food or tobacco industry.

A crucial point for welfare analysis relates to the actual objective function of the policy maker (for a discussion see Brouwer et al., 2008; Dragone and Savorelli, 2012). From an economic standpoint the appropriate objective function is social welfare, which incorporates information on both the individual pleasure for eating and smoking and the health consequences of these choices. From a public health perspective, instead, the maximand is typically the health condition, which is only one part of the individual utility function.[24] In the latter case, a policy maker may be only interested in assessing whether health increases after a policy intervention, but this may not coincide with utility maximization. Although there may exist cases in which both welfare and health increase (see Dragone and Savorelli, 2012), in general one should expect trade-offs between welfare and health to emerge.[25]

[24]The choice of a health policy maker choosing health as maximand can be motivated by the fact that health can be measured, while interpersonal utility comparisons are problematic in theory and practice (see for an extended discussion Brouwer et al., 2008). In our framework, for example, body weight and past smoking can be objectively measured.

[25]See the Appendix for details.

A related concern for the policy maker could be the relative assessment of the sensitivity of the objective function to a 1% increase in the price of cigarettes versus the same increase in the price of food. In general this comparison yields ambiguous results.[26] Note also that we have focused on a representative agent and abstracted from population heterogeneity: this is a reasonable starting point but, admittedly, it bears a limitation which should be carefully considered when discussing welfare desirability. In particular, when heterogeneity is introduced the above results should take into account the distribution of parameters in the population, and different price elasticities across different subgroups of the population.[27]

To conclude, this paper provides a conceptual framework to highlight that interdependences, both at the preference and at the biological level, are critical factors to be taken into account and, potentially, exploited by the policy maker. We believe this perspective is relevant for policy making and worth being used when studying interdependent health-related behaviors, such as consumption of multiple drugs, health investments and unsafe sexual behavior. This is left for future research.

Conflict of interest: The authors have no conflict of interest.

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[26] See the Appendix for details.

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A Appendix

A.1 The solution under bounded rationality

Here we study the extreme case in which the agent does not take into account the future consequences of her current eating and smoking choices on future body weight and addiction to smoking. In other words, we consider the case where, at each time t, the agent maximizes (8) given the budget constraint, her current body weight and her current addiction to smoking, but without taking into account (6) and (7). This case is instructive because it allows us to determine the optimal solution of an agent that, due to informational or cognitive constraints, does not consider (or is not able to determine) the rational forward-looking path of choices that would maximize her intertemporal utility. The agent thus takes into account current addiction and body weight when choosing the optimal level of smoking and food consumption, but she ignores that future addiction and body weight will change as a consequence of her current choices. As shown in the main text, this naïve approach is not optimal for a forward-looking agent, because it does not allow her to take into full consideration how the future evolution of addiction and body weight will impact on future utility.

Given current body weight and addiction to smoking, the optimal choice of food consumption and smoking satisfies the following condition:

$$\frac{U_c}{U_s} = \frac{p^c}{p^s}, \tag{22}$$

which is formally equivalent to the familiar static optimization solution under budget constraint where the marginal rate of substitution between two goods equals the ratio of the corresponding market prices. However, here the solution is not static because the optimal amount of smoking and eating depends on addiction to smoking and body weight. Since addiction and body weight change as a consequence of the choices of the agent, they are going to affect U_c/U_s and, consequently, the optimal level of food consumption and smoking that satisfies (22) will change over time. This process stops when (22) holds and $\dot{w} = \dot{a} = 0$. Whether this condition is associated to being over/underweight, or under/overconsuming, requires additional specific assumptions. For a forward-looking agent, instead, we have shown that $U_c/U_s = p^c/p^s$ results in steady state if and only if the agent has a healthy body weight and is not addicted to smoking.

A.2 Proof of Proposition 1

It is convenient to express the conditions (9)-(12) as a system of differential equations where only control and state variables appear. Differentiating (9) and (10), replacing (11), (12), and using (9), (10), the following dynamic system results

$$\dot{s} = \frac{1}{\psi}\left(AU_{cs} - BU_{cc}\right) \tag{23}$$

$$\dot{c} = \frac{1}{\psi}\left(BU_{cs} - AU_{ss}\right) \tag{24}$$

$$\dot{a} = s - \delta a \tag{25}$$

$$\dot{w} = c - \varepsilon s - \delta w. \tag{26}$$

where

$$\begin{aligned} A &= (\delta+\rho)\left(p^c - U_c\right) - U_w, && (27) \\ B &= (\delta+\rho)\left(p^s - U_s\right) - U_a + \dot{a}U_{sa} + \varepsilon U_w, && (28) \\ \psi &= U_{cc}U_{ss} - U_{cs}^2 > 0, \end{aligned}$$

In steady state, conditions (23)-(26) must be equal to zero. Since $\psi > 0$ holds by assumption, this implies the following:

$$\begin{aligned} U_w &= (\delta+\rho)\left(p^c - U_c\right) \\ U_a &= (\delta+\rho)\left(p^s - U_s\right) + \varepsilon U_w \\ \delta w^{ss} &= c^{ss} - \varepsilon s^{ss} \\ \delta a^{ss} &= s^{ss} \end{aligned}$$

A.3 Asymptotic stability of the steady state

At the steady state, the eigenvalues of the Jacobian matrix J of the dynamic system (23)-(26) are (Dockner, 1985)

$$e_{1,2,3,4} = \frac{\rho}{2} \pm \sqrt{\frac{\rho^2}{4} - \frac{K}{2} \pm \frac{1}{2}\sqrt{K^2 - 4|J|}}$$

where $|J|$ is the determinant of the Jacobian,

$$\begin{aligned} |J| = {} & \frac{1}{\psi}\left[(2\delta+\rho)U_{sa} + U_{aa} + \delta(\delta+\rho)U_{ss}\right]\left[\delta(\delta+\rho)U_{cc} + U_{ww}\right] \\ & -\frac{1}{\psi}\left[\delta^2(\delta+\rho)^2 U_{cs}^2 - \delta\varepsilon(\delta+\rho)\left(\varepsilon U_{cc} + 2U_{cs}\right)U_{ww}\right], \qquad (29) \end{aligned}$$

and

$$K = -2\delta(\delta+\rho) - \frac{1}{\psi}\left[(2\delta+\rho)U_{sa} + U_{aa}\right]U_{cc}$$
$$-\frac{1}{\psi}\left[U_{ss} + \varepsilon(\varepsilon U_{cc} + 2U_{cs})\right]U_{ww}.$$

After some algebraic manipulations, it can be shown that $K^2 > 4|J|$. The conditions $|J| > 0$ and $K < 0$ are sufficient for saddle point stability (Dockner, 1985). The former condition requires

$$U_{sa} < -\frac{\delta(\delta+\rho)U_{ss} + U_{aa}}{2\delta+\rho} + \frac{\delta^2(\delta+\rho)^2 U_{cs}^2 - \delta\varepsilon(\delta+\rho)(\varepsilon U_{cc} + 2U_{cs})U_{ww}}{(2\delta+\rho)\left[\delta(\delta+\rho)U_{cc} + U_{ww}\right]} = \alpha_1,$$

the latter requires

$$U_{sa} < \frac{2\delta(\delta+\rho)\psi - \left[U_{ss} + \varepsilon(\varepsilon U_{cc} + 2U_{cs})\right]U_{ww} - U_{aa}U_{cc}}{(2\delta+\rho)U_{cc}} = \alpha_2.$$

Hence stability of the steady state requires $U_{sa} < \min\{\alpha_1, \alpha_2\}$. Figure 2 is drawn for the case where $\alpha_1 < \alpha_2$, i.e. stability is guaranteed when $|J| > 0$.

A.4 Increasing the price of smoking

Short-run effect. For given values of the state and costate variables, the instantaneous reaction to a change in the price of smoking p^s is obtained by applying the implicit function theorem to (9) and (10):

$$\begin{aligned}\frac{\partial s(t)^*}{\partial p^s} &= \frac{U_{cc}}{\psi} < 0 \\ \frac{\partial c(t)^*}{\partial p^s} &= -\frac{U_{cs}}{\psi}.\end{aligned}$$

This implies that, in the short-run, smoking decreases, while food intake decreases if $U_{cs} > 0$ and it increases otherwise.

Long-run effect. The change in the steady state demand for smoking as a response to a change in the price of smoking is given by the following expression:

$$\frac{\partial s^{ss}}{\partial p^s} = -\frac{|P|}{|J|},$$

where P is

$$P = \begin{bmatrix} \partial\dot{s}/\partial p^s & \partial\dot{s}/\partial c & \partial\dot{s}/\partial a & \partial\dot{s}/\partial w \\ \partial\dot{c}/\partial p^s & \partial\dot{c}/\partial c & \partial\dot{c}/\partial a & \partial\dot{c}/\partial w \\ \partial\dot{a}/\partial p^s & \partial\dot{a}/\partial c & \partial\dot{a}/\partial a & \partial\dot{a}/\partial w \\ \partial\dot{w}/\partial p^s & \partial\dot{w}/\partial c & \partial\dot{w}/\partial a & \partial\dot{w}/\partial w \end{bmatrix}.$$

Since the following holds

$$|P| = -\delta(\delta+\rho)\frac{\delta(\delta+\rho)U_{cc} + U_{ww}}{\psi} > 0.$$

and a necessary condition for a stable steady state is that the determinant of the Jacobian matrix is positive, then

$$\frac{\partial s^{ss}}{\partial p^{s}} = \delta\left(\delta+\rho\right)\frac{\delta\left(\delta+\rho\right)U_{cc}+U_{ww}}{\psi|J|} < 0.$$

Similarly, we can compute the change in steady state food consumption and body weight and obtain:

$$\frac{\partial c^{ss}}{\partial p^{s}} = \delta\left(\delta+\rho\right)\frac{\varepsilon U_{ww}-\delta\left(\delta+\rho\right)U_{cs}}{\psi|J|} \tag{30}$$

$$\frac{\partial w^{ss}}{\partial p^{s}} = -\delta\left(\delta+\rho\right)^{2}\frac{\varepsilon U_{cc}+U_{cs}}{\psi|J|}. \tag{31}$$

This implies the following:

$$\begin{aligned}\frac{\partial c^{ss}}{\partial p^{s}} &> 0 \quad\Leftrightarrow\quad U_{cs}<\sigma_1\\ \frac{\partial w^{ss}}{\partial p^{s}} &> 0 \quad\Leftrightarrow\quad U_{cs}<\sigma_2,\end{aligned}$$

where

$$\begin{aligned}\sigma_1 &= \frac{\varepsilon}{\delta\left(\delta+\rho\right)}U_{ww}\leq 0,\\ \sigma_2 &= -\varepsilon U_{cc}\geq 0.\end{aligned}$$

A.5 Increasing the price of food

Short-run effect. To obtain the instantaneous reaction to a change in the price of food, we apply the implicit function theorem to (9) and (10):

$$\begin{aligned}
\frac{\partial c\left(t\right)^{*}}{\partial p^{c}} &= \frac{U_{ss}}{\psi} < 0; \\
\frac{\partial s\left(t\right)^{*}}{\partial p^{c}} &= -\frac{U_{cs}}{\psi}.
\end{aligned}$$

This implies that, in the short-run, food consumption decreases, while smoking decreases if $U_{cs} > 0$ and it increases otherwise.

Long-run effect. In the long-run, the impact of a permanent change in the price of consumption on food consumption, body weight and smoking is the following:

$$\frac{\partial c^{ss}}{\partial p^{c}} = \delta\left(\delta+\rho\right)\frac{\left(2\delta+\rho\right)U_{sa}+U_{aa}+\delta\left(\delta+\rho\right)U_{ss}+\varepsilon^{2}U_{ww}}{\psi|J|} \tag{32}$$

$$\frac{\partial w^{ss}}{\partial p^{c}} = \left(\delta+\rho\right)\frac{\left(2\delta+\rho\right)U_{sa}+U_{aa}+\delta\left(\delta+\rho\right)U_{ss}+\delta\varepsilon\left(\delta+\rho\right)U_{cs}}{\psi|J|}, \tag{33}$$

$$\frac{\partial s^{ss}}{\partial p^{c}} = \delta\left(\delta+\rho\right)\frac{\varepsilon U_{ww}-\delta\left(\delta+\rho\right)U_{cs}}{\psi|J|}. \tag{34}$$

It can be shown that $\partial c^{ss}/\partial p^{c}$ is always negative when the concavity condition on the utility function and the necessary condition for stability ($|J| > 0$) hold. The same is not true for $\partial w^{ss}/\partial p^{c}$. When the metabolic effect is non negligible, $\varepsilon > 0$, condition (33) implies:

$$\frac{\partial w^{ss}}{\partial p^{c}} > 0 \quad \Leftrightarrow \quad U_{cs} > \sigma_{3}$$

where

$$\sigma_3 = -\frac{(2\delta + \rho)\, U_{sa} + U_{aa} + \delta\,(\delta + \rho)\, U_{ss}}{\delta\,(\delta + \rho)\,\varepsilon}.$$

In passing by, note that $\sigma_3 = 0$ is the bifurcation condition for instability of the steady state in the Becker and Murphy (1988) model. In the special case where there is no metabolic effect of smoking ($\varepsilon = 0$), then $\partial w^{ss}/\partial p^c = (\partial c^{ss}/\partial p^c)/\delta < 0$. Finally, condition (34) implies

$$\frac{\partial s^{ss}}{\partial p^c} > 0 \quad \Leftrightarrow \quad U_{cs} < \sigma_1.$$

A.6 General case with income effects and addictive food

Here we consider the general case in which income effects and addictiveness of food are allowed for. The Hamiltonian of the associated problem is the following

$$H = U\,(c, s, w, a) + V\,(M - p^c c - p^s s) + \mu\,(s - \delta a) + \lambda\,(c - \varepsilon s - \delta w)\,,$$

where $V\,(\cdot)$ is the utility from the composite good, with $V_q > 0$ and $V_{qq} < 0$.

A.6.1 Optimality conditions and short-run effects

The first order conditions of the problem are

$$H_c = 0 \Leftrightarrow U_c - p^c V_q = -\lambda \tag{35}$$

$$H_s = 0 \Leftrightarrow U_s - p^s V_q = -\mu + \varepsilon\lambda \tag{36}$$

$$\dot{\mu} = (\delta + \rho)\,\mu - U_a \tag{37}$$

$$\dot{\lambda} = (\delta + \rho)\,\lambda - U_w. \tag{38}$$

We can use (35) and (36) to obtain the short-run responses of smoking and food consumption when prices change. The following holds for smoking

$$\frac{\partial s^*}{\partial p^s} = \left((p^c)^2 V_{qq} + U_{cc}\right) \zeta V_q + s(p^c U_{cs} - p^s U_{cc})\zeta V_{qq} \tag{39}$$
$$\frac{\partial s^*}{\partial p^c} = -\left(p^c p^s V_{qq} + U_{cs}\right) \zeta V_q + c(p^c U_{cs} - p^s U_{cc})\zeta V_{qq} \tag{40}$$

where the first terms in parenthesis represent the standard (static) substitution effect and the second terms represent the income effect, and

$$\zeta = \left[V_{qq}\left((p^c)^2 U_{ss} - 2p^c p^s U_{cs} + p^s U_{cc}\right) + \left(U_{cc}U_{ss} - U_{cs}^2\right)\right]^{-1} > 0.$$

Let

$$\sigma^s_{p^s} = -\frac{U_{cc}V_q + \left((p^c)^2 V_q - s p^s U_{cc}\right) V_{qq}}{s p^c V_{qq}}$$
$$\sigma^s_{p^c} = \frac{cU_{cc} + p^c V_q}{c p^c V_{qq} - V_q} p^s V_{qq}$$

be the threshold values such that $\partial s^*/\partial p^s = 0$ and $\partial s^*/\partial p^c = 0$, respectively. Note that in the quasi-linear case where $V_q = 1$ and $V_{qq} = 0$, (39) is always negative and the sign of (40) depends only on the sign of U_{cs}, which is consistent with the results stated in the main text.

The short-run demand for food consumption depends on prices as follows:

$$\frac{\partial c^*}{\partial p^s} = -\left(p^c p^s V_{qq} + U_{cs}\right) \zeta V_q + s(p^s U_{cs} - p^c U_{ss})\zeta V_{qq} \tag{41}$$
$$\frac{\partial c^*}{\partial p^c} = \left((p^s)^2 V_{qq} + U_{ss}\right) \zeta V_q + c(p^s U_{cs} - p^c U_{ss})\zeta V_{qq} \tag{42}$$

where the first terms in parenthesis represent the standard (static) substitution effect and the second terms represent the income effect. Let

$$\begin{aligned}
\sigma^c_{p^s} &= \frac{sU_{ss} + p^s V_q}{sp^s V_{qq} - V_q} p^c V_{qq} \\
\sigma^c_{p^c} &= -\frac{U_{ss}V_q + \left((p^s)^2 V_q - cp^c U_{ss}\right) V_{qq}}{cp^s V_{qq}}
\end{aligned}$$

be the threshold values such that $\partial c^*/\partial p^s = 0$ and $\partial c^*/\partial p^c = 0$, respectively. In the quasi-linear case the sign of (41) depends only on the sign of U_{cs}, while (42) is always negative, which is again consistent with the results stated in the main text.

As it is well known, the law of demand holds provided income effects do not offset the substitution effects. From inspection of (39) and 42) the following holds:

Proposition 10 *In the short-run the law of demand holds if U_{cs} is large enough. More precisely:*

- *When the price of smoking increases, smoking decreases iff $U_{cs} > \sigma^s_{p^s}$;*
- *When the price of food increases, food consumption decreases iff $U_{cs} > \sigma^c_{p^c}$.*

Clearly, for a quasi-linear utility function the law of demand always hold. We can also study the cross elasticity of smoking and food consumption.

Proposition 11 *In the short-run,*

- *When the price of smoking increases, food consumption decreases iff $U_{cs} > \sigma^c_{p^s}$*
- *When the price of food increases, smoking decreases iff $U_{cs} > \sigma^s_{p^c}$.*

For a quasi-linear utility function, $\sigma^s_{p^c} = \sigma^c_{p^s} = 0$.

A.6.2 Optimal dynamics and long-run equilibrium

The dynamic equations for optimal food consumption and smoking are as follows:

$$\begin{aligned}
\dot{c} &= B(p^c p^s V_{qq} + U_{cs}) - A\left((p^s)^2 V_{qq} + U_{ss}\right) \\
\dot{s} &= A(p^c p^s V_{qq} + U_{cs}) - B\left((p^c)^2 V_{qq} + U_{cc}\right)
\end{aligned}$$

where

$$\begin{aligned}
A &= \frac{U_{cw}(c - \delta w - \varepsilon) + (\delta + \rho)(p^c V_q - U_c) - U_w}{\left((p^c)^2 V_{qq} + U_{cc}\right)\left((p^s)^2 V_{qq} + U_{ss}\right) - (p^c p^s V_{qq} + U_{cs})^2} \\
B &= \frac{U_{sa}(s - a\delta) + (\delta + \rho)(p^s V_q - U_s) + \varepsilon U_w - U_a}{\left((p^c)^2 V_{qq} + U_{cc}\right)\left((p^s)^2 V_{qq} + U_{ss}\right) - (p^c p^s V_{qq} + U_{cs})^2}
\end{aligned}$$

The associated Jacobian matrix is

$$J = \begin{pmatrix}
\frac{\partial \dot{s}}{\partial s} & \frac{\partial \dot{s}}{\partial c} & \frac{\partial \dot{s}}{\partial a} & \frac{\partial \dot{s}}{\partial w} \\
\frac{\partial \dot{c}}{\partial s} & \frac{\partial \dot{c}}{\partial c} & \frac{\partial \dot{c}}{\partial a} & \frac{\partial \dot{c}}{\partial w} \\
-1 & 0 & -\delta & 0 \\
-\varepsilon & 1 & 0 & -\delta
\end{pmatrix}$$

where

$$
\begin{aligned}
\frac{\partial \dot{s}}{\partial s} &= \delta+\rho-\varepsilon U_{cw}(U_{cs}+p^c p^s V_{qq})\zeta ; \frac{\partial \dot{s}}{\partial c}=-\varepsilon U_{cw}\left(V_{qq}\left(p^c\right)^2+U_{cc}\right)\zeta \\
\frac{\partial \dot{s}}{\partial a} &= \left(V_{qq}\left(p^c\right)^2+U_{cc}\right)(U_{aa}+(2\delta+\rho)U_{sa})\zeta \\
\frac{\partial \dot{s}}{\partial w} &= -(2\delta+\rho)\left(V_{qq}p^s p^c+U_{cs}\right)U_{cw}\zeta-(\varepsilon U_{cc}+p^c(\varepsilon p^c+p^s)V_{qq}+U_{cs})U_{ww}\zeta \\
\frac{\partial \dot{c}}{\partial s} &= \varepsilon U_{cw}\left(V_{qq}\left(p^s\right)^2+U_{ss}\right)\zeta ; \frac{\partial \dot{c}}{\partial c}=\delta+\rho+\varepsilon U_{cw}(U_{cs}+p^c p^s V_{qq})\zeta \\
\frac{\partial \dot{c}}{\partial a} &= -(U_{cs}+p^c p^s V_{qq})(U_{aa}+(2\delta+\rho)U_{sa})\zeta \\
\frac{\partial \dot{c}}{\partial w} &= (2\delta+\rho)\left(V_{qq}\left(p^s\right)^2+U_{ss}\right)U_{cw}\zeta+(\varepsilon U_{cs}+p^s(\varepsilon p^c+p^s)V_{qq}+U_{ss})U_{ww}\zeta
\end{aligned}
$$

The long-run equilibrium is characterized by the following equations:

$$
\begin{aligned}
U_w &= -(\delta+\rho)(U_c-p^c V_q) \\
U_a &= (\delta+\rho)\left[p^s V_q-U_s+\varepsilon\left(p^c V_q-U_c\right)\right] \\
s &= a\delta \\
c &= \delta(\varepsilon a+w)
\end{aligned}
$$

A.6.3 Price effects in the long-run

Computing the long-run effects of a change in the price of smoking we obtain the following

$$
\begin{aligned}
\frac{\partial s^{ss}}{\partial p^s} = & \left[\delta\left(\delta+\rho\right)\left(U_{cc}+\left(p^c\right)^2 V_{qq}\right)+\left(2\delta+\rho\right)U_{cw}+U_{ww}+\delta\left(\delta+\rho\right)\left(p^c\right)^2 V_{qq}\right]\frac{\zeta\delta(\delta+\rho)}{|J|}V_q \\
& -s\{p^s[\delta\left(\delta+\rho\right)U_{cc}+\left(2\delta+\rho\right)U_{cw}+U_{ww} \\
& +p^c[\varepsilon\left(\delta U_{cw}+U_{ww}\right)-\delta\left(\delta+\rho\right)U_{cs}]\}\frac{\zeta\delta(\delta+\rho)}{|J|}V_{qq}
\end{aligned}
$$

The first line of the above expression captures the substitution effects, with the first term representing the static substitution effect (see 14). The second and third lines capture income effects. This holds also when considering how changes in the price of food affect the demand for food in the long-run, as:

$$
\begin{aligned}
\frac{\partial c^{ss}}{\partial p^{c}} \quad = \quad & \left[\delta(\delta+\rho)\left((p^{s})^{2} V_{qq}+U_{ss}\right)+U_{aa}+(2\delta+\rho)U_{sa}+\varepsilon^{2}U_{ww}\right]\frac{\zeta\delta(\delta+\rho)}{|J|}V_{q} \\
& -(\varepsilon a+w)\left\{p^{c}\left[U_{aa}+(2\delta+\rho)U_{sa}+\delta(\delta+\rho)U_{ss}+U_{ww}\varepsilon^{2}\right]\right. \\
& \left.-p^{s}\left[\varepsilon U_{ww}+(\delta+\rho)\left(\varepsilon U_{cw}-\delta U_{cs}\right)\right]\right\}\frac{\zeta\delta^{2}(\delta+\rho)}{|J|}V_{qq}
\end{aligned}
$$

The main difference of the general case with respect to the case considered in the main text is that, with no quasi-linearity and income effects, the long-run law of demand may fail to hold even if the short-run demand follows the laws of demand. Let $\theta^{s}_{p^{s}}$ and $\theta^{c}_{p^{c}}$ be the threshold value such that $\partial s^{ss}/\partial p^{s}=0$ if $U_{cs}=\theta^{s}_{p^{s}}$ and $\partial c^{ss}/\partial p^{c}=0$ if $U_{cs}=\theta^{c}_{p^{c}}$; the following holds

Proposition 12 *In the long-run the law of demand holds if U_{cs} is large enough. More precisely:*

- *The demand for smoking decreases with the price of smoking if $U_{cs}>\theta^{s}_{p^{s}}$;*
- *The demand for food consumption decreases with the price of food if $U_{cs}>\theta^{c}_{p^{c}}$.*

The case where the long-run law of demand does not hold for smoking or food does not affect the results of the model, which concern the cases where both body weight and smoking decrease as a response to a price change, because the cases where the law of demand does not hold in the long-run are never associated to a decrease in body weight and smoking. This can be ascertained from the following

$$\begin{aligned}
\frac{\partial c^{ss}}{\partial p^s} &= \left\{(\delta+\rho)\left[\varepsilon U_{cw} - \delta\left(U_{cs} + p^c p^s V_{qq}\right)\right] + \varepsilon U_{ww}\right\} \frac{\zeta\delta(\delta+\rho)}{|J|} V_q \\
&\quad + s\{p^s\left[(\delta+\rho)\left(\delta U_{cs} - \varepsilon U_{cw}\right) - \varepsilon U_{ww}\right] \\
&\quad - p^c[U_{aa} + (2\delta+\rho)\, U_{sa} + \delta\,(\delta+\rho)\, U_{ss} + \varepsilon^2 U_{ww}]\} \frac{\zeta\delta\,(\delta+\rho)}{|J|} V_{qq} \\
\frac{\partial w^{ss}}{\partial p^s} &= -[p^c\left(\varepsilon p^c + p^s\right)(\delta+\rho)\, V_{qq} + (\delta+\rho)\left(\varepsilon U_{cc} + U_{cs}\right) - \varepsilon U_{cw}] \frac{\zeta\delta(\delta+\rho)}{|J|} V_q \\
&\quad + s\{\delta p^s\left[(\delta+\rho)(\varepsilon U_{cc} + U_{cs}) + \varepsilon U_{cw}\right] \\
&\quad - p^c[U_{aa} + (2\delta+\rho) U_{sa} + \delta\,(\delta+\rho)\left(U_{ss} + \varepsilon U_{cs}\right) - \delta\varepsilon^2 U_{cw}]\} \frac{\zeta(\delta+\rho)}{|J|} V_{qq}
\end{aligned}$$

and, for a change in the price of food:

$$\begin{aligned}
\frac{\partial s^{ss}}{\partial p^c} &= \left\{\varepsilon U_{ww} - \delta\left[(\delta+\rho)(p^c p^s V_{qq} + U_{cs}) - \varepsilon U_{cw}\right]\right\} \frac{\zeta\delta(\delta+\rho)}{|J|} V_q \\
&\quad - (\varepsilon a + w)\{p^c\left[\varepsilon(U_{ww} + \delta U_{cw}) - \delta(\delta+\rho) U_{cs}\right] \\
&\quad + p^s\delta\left[U_{ww} + \delta(\delta+\rho) U_{cc} + (2\delta+\rho) U_{cw}\right]\} \frac{\zeta\delta^2(\delta+\rho)}{|J|} V_{qq} \\
\frac{\partial w^{ss}}{\partial p^c} &= \left(\varepsilon p^c + p^s\right) p^s \frac{\zeta\delta\,(\delta+\rho)^2}{|J|} V_q V_{qq} \\
&\quad + [U_{aa} + (2\delta+\rho) U_{sa} + \delta(\delta+\rho)\left(U_{ss} + \varepsilon U_{cs}\right) - \delta\varepsilon^2 U_{cw}] \frac{\zeta\,(\delta+\rho)}{|J|} V_q \\
&\quad + (\varepsilon a + w)\{\delta p^s[(\delta+\rho)\left(\varepsilon U_{cc} + U_{cs}\right) + \varepsilon U_{cw}] \\
&\quad - p^c[U_{aa} + (2\delta+\rho) U_{sa} + \delta(\delta+\rho)\left(U_{ss} + \varepsilon U_{cs}\right) - \delta\varepsilon^2 U_{cw}]\} \frac{\zeta\delta\,(\delta+\rho)}{|J|} V_{qq}
\end{aligned}$$

Clearly, when $V_{qq} = 0$, $V_q = 1$ and $U_{cw} = 0$ (as in the main text), the above relations considerably simplify and change sign when U_{cs} is equal to σ_1, σ_2 or σ_3, as shown in Figure 2. The general case is represented in Figure 3, where we plot the loci associated to the combinations of (U_{cs}, U_{sa}) where the above relations change sign. It can be shown that the lines $\partial s^{ss}/\partial p^c = 0$, $\partial s^{ss}/\partial p^c = 0$ and $\partial w^{ss}/\partial p^c = 0$ intersect in one point on the curve $|J| = 0$ (point A). The locus $\partial w^{ss}/\partial p^c = 0$ also intersects $\partial w^{ss}/\partial p^s = 0$ in one point of the curve $|J| = 0$ (point B). The area where both smoking and body weight decrease after an increase in the price of food lies below the $\partial w^{ss}/\partial p^c = 0$ line and on the right of $\partial s^{ss}/\partial p^c = 0$ line (represented by the light and the dark areas in the figure). The analogue area for the case in which the price of smoking decreases is represented by the dark area only, on the right of the $\partial w^{ss}/\partial p^s = 0$. We conclude that the results presented in the main text also hold when income effects and addictiveness of food are explicitly considered. In particular, increasing the price of food is more likely to reduce both obesity and smoking than increasing the price of smoking.

Figure 2

Figure 3: General case with income effects and addictive food. When the price of smoking increases, body weight and smoking decrease in the darker area; when the price of food increases,

body weight and smoking decrease in both the light and dark areas.

A.7 Proof of Proposition 7

This section generalizes the conditions reported in Section 3 for the general case where U_{ac}, U_{cw}, U_{sw} and U_{aw} are not nil. After a change in the price of smoking, the following holds:

$$
\begin{aligned}
\frac{\partial s^{ss}}{\partial p^s} &< 0 \quad \Leftrightarrow \quad U_{cw} < -\frac{\delta\left(\delta+\rho\right) U_{cc} + U_{ww}}{2\delta+\rho} \\
\frac{\partial c^{ss}}{\partial p^s} &< 0 \quad \Leftrightarrow \quad U_{cs} > \tilde{\sigma}_1 \\
\frac{\partial w^{ss}}{\partial p^s} &< 0 \quad \Leftrightarrow \quad U_{cs} > \tilde{\sigma}_2
\end{aligned}
$$

where

$$
\begin{aligned}
\tilde{\sigma}_1 &= \sigma_1 + \frac{\varepsilon U_{cw} - U_{ac}}{\delta} - \frac{U_{sw}}{\delta+\rho} - \frac{U_{aw}}{\delta\left(\delta+\rho\right)} \\
\tilde{\sigma}_2 &= \sigma_2 - \frac{U_{ac}}{\delta} - \frac{\varepsilon U_{cw}}{\delta+\rho} - \frac{U_{sw}}{\delta+\rho}
\end{aligned}
$$

Note that $\tilde{\sigma}_2 > \tilde{\sigma}_1$ if steady state smoking follows the law of demand ($\frac{\partial s^{ss}}{\partial p^s} < 0$). After a change in the price of food, the following holds:

$$
\begin{aligned}
\frac{\partial s^{ss}}{\partial p^c} &< 0 \quad \Leftrightarrow \quad U_{cs} > \hat{\sigma}_1 \\
\frac{\partial c^{ss}}{\partial p^c} &< 0 \quad \Leftrightarrow \quad U_{sa} < -\frac{U_{aa} + \delta\left(\delta+\rho\right) U_{ss} + \varepsilon\left[\varepsilon U_{ww} - 2U_{aw} - (2\delta+\rho)U_{sw}\right]}{2\delta+\rho} \\
\frac{\partial w^{ss}}{\partial p^c} &< 0 \quad \Leftrightarrow \quad U_{cs} < \tilde{\sigma}_3
\end{aligned}
$$

where

$$
\begin{aligned}
\hat{\sigma}_1 &= \tilde{\sigma}_1 + \rho\frac{U_{ac} - \varepsilon U_{cw} - U_{sw}}{\delta\left(\delta+\rho\right)} \\
\tilde{\sigma}_3 &= \sigma_3 + \frac{U_{aw}}{\delta\left(\delta+\rho\right)} + \frac{\varepsilon U_{cw} - U_{ac} + U_{sw}}{\delta+\rho}
\end{aligned}
$$

When steady state smoking respects the law of demand, increasing the price of smoking produces both a reduction in smoking and body weight if $U_{cs} > \tilde{\sigma}_2$. This result is analogue to the one presented in the main text.

Moreover, it can be shown that the loci $U_{cs} = \hat{\sigma}_1$ and $U_{cs} = \tilde{\sigma}_3$ intersect on the locus where $|J| = 0$. Hence, increasing the price of food reduces both smoking and body weight if $U_{cs} > \hat{\sigma}_1$, which is the analogue of the result presented in the text.

To compare the two policy interventions it is sufficient to assess whether $\tilde{\sigma}_2$ is larger or smaller than $\hat{\sigma}_1$. Notice that their value does not depend on U_{sa} (which implies that they can be represented as vertical lines in the analogue of Figure 2) and that they are linearly dependent on ε.

In the text we considered the simplified case where $U_{ac} = U_{cw} = U_{sw} = U_{aw} = 0$, which implies $\tilde{\sigma}_2 > 0 > \tilde{\sigma}_1 = \hat{\sigma}_1$, as reported in Figure 2. In the general case, the comparison implies the following:

$$\tilde{\sigma}_2 > \hat{\sigma}_1 \quad \Leftrightarrow \quad \varepsilon > \bar{\varepsilon} = \rho \frac{U_{sw} - U_{ac}}{\delta (\delta + \rho) U_{cc} + 2\delta U_{cw} + U_{ww}}$$

which leads to Proposition 7. Note that the denominator of the above expression is negative when steady state smoking respects the law of demand.

A.8 Incresing impatience: proof of Proposition 8

Taking the derivatives with respect to ρ yields:

$$\begin{aligned}
\frac{\partial s^{ss}}{\partial \rho} &= \frac{\delta (\delta + \rho) U_{cc} + U_{ww}}{(\delta + \rho) \psi |J|} U_a - \frac{\delta^2 (\varepsilon U_{cc} + U_{cs})}{\psi |J|} U_w \\
\frac{\partial c^{ss}}{\partial \rho} &= \delta \frac{\delta (\delta + \rho) U_{cs} - \varepsilon U_{ww}}{(\delta + \rho) \psi |J|} U_a - \delta \frac{U_{aa} + \delta (\delta + \rho) \varepsilon U_{cs} + (2\delta + \rho) U_{sa} + \delta (\delta + \rho) U_{ss}}{\psi |J|} U_w \\
\frac{\partial w^{ss}}{\partial \rho} &= \frac{1}{(\delta + \rho) \psi |J|} \left[U_{aa} + \delta (\delta + \rho) \varepsilon^2 U_{cc} + 2\delta\varepsilon (\delta + \rho) U_{cs} + (2\delta + \rho) U_{sa} + \delta (\delta + \rho) U_{ss} \right] U_w \\
&\quad - \delta \frac{\varepsilon U_{cc} + U_{cs}}{\psi |J|} U_a
\end{aligned}$$

Note that the locus $\frac{\partial s^{ss}}{\partial \rho} = 0$ is a vertical line in the (U_{cs}, U_{sa}) space. For $U_w < 0$ and $U_a < 0$ (overweight smoker) it shifts to the right when body weight increases (U_w further decreases), which implies that the range of cases where smoking increases with impatience shrinks when body weight increases. The locus $\frac{\partial c^{ss}}{\partial \rho} = 0$ is also a line. It intersects the locus $|J| = 0$ in two points, one of which corresponds to $U_{cs} = \sigma_1$ and the other intersecting $|J| = 0$ in the same point where the $\frac{\partial s^{ss}}{\partial \rho} = 0$ locus intersects it. Changes in body weight, as assessed by the U_w, have ambiguous effects on $\frac{\partial c^{ss}}{\partial \rho}$, depending on whether U_a is larger or smaller than εU_w. Similar results hold for body weight.

A.9 Health concerns and elasticity of health

Consider individual utility V as determined by two components: health H and non-health Z, i.e. $V = H + Z$. The elasticity of utility to a change in the price of smoking (η_{V,p^s}) can be written as a weighted sum of the elasticity of health $\left(\eta_{H,p^s}\right)$ and of the elasticity of non-health related utility $\left(\eta_{Z,p^s}\right)$:

$$\eta_{V,p^s} = \sigma\eta_{H,p^s} + (1-\sigma)\,\eta_{Z,p^s} \tag{43}$$

where $\sigma = H/V \in [0,1]$ is the relative weight given to health, i.e. how much health contributes to the overall assessment of individual utility V, and, conversely, $(1-\sigma) = Z/V$ is the importance of non-health related utility on overall utility. We know that $U_{cs} > \sigma_2$ implies $\eta_{H,p^s} > 0$, i.e. health improves after increasing the price of smoking because both addiction to smoking and body weight decrease. In such a case a public health perspective would strongly favor the policy intervention, although this may reduce the overall utility V through reduced satisfaction obtained from non-health related utility. In other words, although the policy intervention can improve individual's health, the agent's overall utility may be lower if the health gain does not compensate for the non-health utility loss (due to the fact that people would be induced to eat and smoke less than they prefer). When instead $U_{cs} < \sigma_2$, body weight is expected to increase, which implies that even the health assessment becomes in general ambiguous, as it requires trading off reduced smoking and increased body weight.[28]

Let us focus on a public health perspective and assume that the health component of the utility function depends on addiction to smoking and body weight $H(a,w)$. Hence the

[28]Similar considerations apply to the case of food taxes, as $U_{cs} > \sigma_2$ is a sufficient condition for health to improve $(\eta_{H,p^c} > 0)$. When $U_{cs} > \sigma_2$ both cigarette taxes and food taxes are health-improving.

elasticity of health with respect to the two prices is:

$$\eta_{H,p^s} = \left(\frac{\partial H}{\partial w} \frac{\partial w}{\partial p^s} + \frac{\partial H}{\partial a} \frac{\partial a}{\partial p^s} \right) \frac{p^s}{H^{ss}} \tag{44}$$

$$\eta_{H,p^c} = \left(\frac{\partial H}{\partial w} \frac{\partial w}{\partial p^c} + \frac{\partial H}{\partial a} \frac{\partial a}{\partial p^c} \right) \frac{p^c}{H^{ss}} \tag{45}$$

which allows us to write the relative difference in the elasticity of health with respect to the two prices as follows;

$$\begin{aligned} \eta_{H,p^s} - \eta_{H,p^c} &= \frac{\partial H}{\partial w} \frac{w}{H^{ss}} \left(\frac{\partial w}{\partial p^s} \frac{p^s}{w} - \frac{\partial w}{\partial p^c} \frac{p^c}{w} \right) + \frac{\partial H}{\partial a} \frac{a}{H^{ss}} \left(\frac{\partial a}{\partial p^s} \frac{p^s}{a} - \frac{\partial a}{\partial p^c} \frac{p^c}{a} \right) \\ &= \eta_{H,w} \left(\eta_{w,p^s} - \eta_{w,p^c} \right) + \eta_{H,a} \left(\eta_{a,p^s} - \eta_{a,p^c} \right). \end{aligned} \tag{46}$$

The sign of (46) depends on the sensitivity of health to changes in body weight and addiction to smoking (i.e. on $\eta_{H,w}$ and $\eta_{H,a}$) and on the relative elasticities of body weight and addiction with respect to p^c and p^s (i.e. on $\eta_{w,p^s} - \eta_{w,p^c}$ and $\eta_{a,p^s} - \eta_{a,p^c}$). The result of this comparison is in general ambiguous, and it is a matter of empirical investigation. In some cases, however, a precise theoretical prediction can be made. For example, suppose the representative agent is overweight and addicted to smoking, so that $\eta_{H,w}$ and $\eta_{H,a}$ are negative, and that both body weight and addiction to smoking are more elastic to the price of tobacco than to the price of food (i.e. $\eta_{w,p^s} > \eta_{w,p^c}$ and $\eta_{a,p^s} > \eta_{a,p^c}$). In such a case health is unambiguously more sensitive to a 1% increase in the price of smoking than to an increase in the price of food.