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The Effect of Addiction on Environmental Taxation in a First and Second-best world

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Abstract

We examine the effect of addictive behavior on a socially optimal environmental tax. If utility in part depends on past consumption and individuals are time-consistent, the socially optimal environmental tax is shown to be equal to the conventional Pigovian tax. In a second-best world where the social planner has a restriction on the future environmental tax level, the current optimal tax is no longer equal to the Pigovian tax. We extend the analysis with time-inconsistent (myopic) individuals to both the first (no restriction on future environmental tax) and second-best world (restriction on future environmental tax). Also, the importance of addiction in an environmental framework is discussed.

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1 Introduction

The connection between psychology and economics has been given increased attention during the last decade (see e.g. Loewenstein, 1992; and Rabin, 1998, for extensive overviews). Acknowledging the importance of economics as a behavioral science has resulted in several seminal articles over the years giving important insights on how to model behaviors that been explored by psychologists, but not commonly used in traditional economic modeling. Such research gives a new depth and possibility for more realistically explaining human behavior in an economic framework. Inspired by the growing body of literature on the connection between psychology and economics, we focus on the effect of a utility that is dependent not only on current consumption but also on past consumption. We choose to frame this as an addiction, and as discussed below, we argue that our results can be translated to a more general habit formation framework. Furthermore, we expand this model by assuming that the consumption of the addictive good also generates a negative external effect on the environment. An individual can choose to consume either an addictive good that has a negative external effect on the environment, or to consume a non-addictive good, which has no effect on the environment. To be able to present the key features of the model in a clear and tractable way, we use a discrete two-period model. In line with Stigler and Becker (1977), we allow for both beneficial and harmful goods. This means that the utility of an individual is affected either negatively or positively by previous consumption of the addictive good. The model presented in this article differs foremost from the existing literature in that we allow for a second-best solution in combination with time-inconsistent preferences. Our contribution to the literature is threefold. Firstly, in Section 2 we introduce a restriction on the tax level in period two. Hence, the social planner can only choose the tax in period one, given a fixed tax in period two. Following this we solve for the optimal second-best tax in period one, given the restriction on the tax in period two. Secondly, in Section 3, the theoretical framework used in the article enables us to incorporate time-inconsistency into both the first-best setting (no restriction on the tax in period two) and into the second-best setting (restriction on the tax in period two). Thirdly, we connect the theoretical analysis to a highly significant environmental problem – the climate change. As is shown the optimal tax under addiction is equal to the Pigovian tax, which is a tax equal to the shadow price or marginal damage of the externality (Pigou, 1946). This is in line with the well known finding that only the cost that individuals pose on others should give rise to government action. Still, we argue that this result is not trivial, and to the best of our knowledge optimal environmental tax has not been studied in an addictive framework before. Further, when the tax in period two is fixed and individuals are time-inconsistent policies aimed at reducing externalities are affected. More specifically, in a first-best setting with time-inconsistent individuals *the level* of the optimal environmental tax is affected by addiction. In a second-best setting the optimal environmental tax for a rational addictive good is shown to be increasing in *the strength* of addiction (assuming time-consistent individuals), and increasing in *the strength* of addiction as well as dependant upon *the character* of the addiction (beneficial or harmful) when individuals are time-inconsistent.

The assumption in standard economic theory that utility is separable over time has been continuously challenged over the years. The literature on utility that is non-separable over time can be divided into two parts (Chaloupka, 1991). The first part is represented by a body of literature that has been referred to as endogenous tastes or habit formation (see e.g. Gorman, 1967; Pollak, 1970, 1976; and Boyer, 1983). The other part consists of the research on "rational addiction" (Stigler and Becker, 1977; Becker and Murphy, 1988; Becker et al., 1991, 1994), which explains the existence of addiction in an economic framework. But following the work by Phlips (1983), where he shows that rational addiction can be seen as a special case of a more general habit formation model, we argue that our results can be translated to the more general case, still acknowledging that rational addiction is a more restrictive case than a general habit formation model.

Given that the consumption choices an individual makes today affect future preferences, it is of interest to take into account the psychological findings that humans are myopic or time-inconsistent, since we expect that this can have important policy implications, especially when preferences change over time. As pointed out in O'Donoghue and Rabin (1999), the models of rational addiction do not take into account that humans are time-inconsistent. O'Donoghue and Rabin show that a harmful addiction combined with time-inconsistent behavior will, in most addictive models, yield an over-consumption today, due to a desire that can be satisfied today and that is associated only with a future cost, which is given less weight. The literature on time-inconsistency has been explored in different settings, and it is not our intention to survey the literature in this introduction, but rather to just mention a few important contributions of Frederick, Loewenstein, and O'Donoghue (2002), Laibson (1997), O'Donoghue and Rabin (1999), Pollak (1968) and Strotz (1956). There is overwhelming empirical evidence that people's preferences are not time-consistent. Therefore, we expand the model by introducing time-inconsistency as proposed by O'Donoghue and Rabin

(1999), following earlier work by Phelps and Pollak (1968). Expanding the rational addiction model by allowing for time-inconsistency has recently been done in two articles by Gruber and Köszegi (2001, 2002). The authors study the implication of time-inconsistency, using hyperbolic discounting, on optimal cigarette policy. Our results are in line with Gruber and Köszegi, in that a harmful addiction when individuals are time-inconsistent should give rise to a higher taxation than if individuals are time-consistent. Another study that take a slightly different approach is Orphanides and Zervos (1998) study on myopia and (harmful) addiction. The authors present a model in which they show that myopia can arise even when preferences are time-consistent (and stable). The authors conclude that addiction is more or less "consistent with the standard axioms of rational, forward looking utility maximization", and urge for more research on welfare implications and public policy design, which is the focus of this paper.

There are numerous articles on addiction focusing especially on cigarette addiction (see e.g. Chaloupka, 1991; and Becker et al., 1994). Addiction is defined present when an increase in the present consumption of a good increases future consumption of the same good (given constant prices). Following Becker and Murphy (1988), this is true if and only if individuals demonstrate adjacent complementarity (a concept introduced by Ryder and Heal, 1973). This concept indicates that an increase in present consumption raises the marginal utility of future consumption. In empirical and experimental studies on addiction, and in particular on harmful addiction, two criteria for addiction to be present are often referred to. Firstly, consumption of a good today should increase the consumption of the same good in the future (often in the literature referred to as reinforcement), which is close to the above described concept of adjacent complementarity. Secondly, the utility of a given amount of the good consumed in the future is either negatively (harmful addiction) or positively (beneficial addiction) affected by an increase in current consumption. Due to the focus on cigarette addiction in the literature, most articles only consider harmful addictions.

In the context of this paper, it is of relevance to consider the existence of addictive goods that have a negative external effect on the environment that could be characterized as either beneficial or harmful addictions. For example, transportation contributes to environmental degradation in a highly significant way. Two-thirds of all CO emissions, one-third of all CO2 emissions, one-third of all NO2 emissions, and one-quarter of all VOC's (volatile organic compounds) can be attributed to transportation. Psychological findings support the fact that driving is habitual (Gärling et al., 2002a, 2002b) and even addictive (Reser, 1980). Furthermore, in a recent study by Carrasco et.al. (2002) the authors empirically test for habits in different consumption goods using a household panel data. The authors find evidence of habit formation in transport, which points to the importance of studies such as this one, taking habits and environmental problems into account. More importantly, it will be of crucial importance whether the addiction is beneficial or harmful, since this will affect the optimal policy response. There are no empirical studies on the type of addiction to such environmentally harmful goods, and therefore we will consider both cases (beneficial and harmful addictions), and leave up to important future research to empirically test for type of addiction.

Except for transportation, psychologists have not, as far as we know, studied environmental goods in an addictive framework, but addiction has been shown to be present and then explored in such areas as work

(Rorlich, 1981), internet use (Griffiths, 2000), television use (McIlwraith, 1998), sex (Perry et al., 1998), religion (Vanderheyden, 1999) and exercise (Griffiths, 1997).

2 Optimal Environmental Taxation and Addiction

2.1 The Model

To be able to capture the effect of an addictive good on an optimal environmental policy we define a general utility function over two periods, assuming that the usual assumptions of completeness, transitivity, and continuity hold. The model includes a social planner and a representative agent, an addictive environmentally bad good (a^i) and a non-addictive good (n^i), which does not affect the environment. Superscripts denote in which period the good is consumed, $i = 1, 2$. We model the negative external effect on the environment as a damage function $D(a^i)$ (sometimes written in short as D^i), where $\frac{\partial D(a^i)}{\partial a^i} > 0$. Addiction is modeled as a stock effect, which incorporates both beneficial and harmful addictions. We define the stock effect as the amount of the addictive good consumed in period one. Hence, in period one we do not have any addictive effect, but in period two utility will be dependent not only on the two goods consumed during the period, but also on the stock effect, i.e. the consumption of a in period one. The social planner maximizes total utility for a representative agent according to:

$$W_S = u^1(a^1, n^1) - D(a^1) + \frac{1}{1+\rho}u^2(a^1, a^2, n^2) - \frac{1}{1+\rho}D(a^2). \qquad (1)$$

Correspondingly, the total utility for the representative agent can be written as:

$$W_{ra} = u^1(a^1, n^1) - \bar{D}^1 + \frac{1}{1+\rho} u^2(a^1, a^2, n^2) - \frac{1}{1+\rho} \bar{D}^2. \qquad (2)$$

The social planner and the individual differ only in how they treat the effect of environmental damage. The representative agent treats environmental damage as a constant given at the optimal level of the addictive good, $\bar{D}(a^i)$. Utility is hence defined as a function of the two consumption goods of which one is addictive and environmentally harmful, minus environmental damage.

Since we treat the stock effect in our model as the lagged value of the addictive good, we fulfill adjacent complementarity by the necessary and sufficient condition $\frac{\partial^2(u^2)}{\partial a^2 \partial a^1} > 0$ (Becker and Murphy, 1988); that is, present consumption of the addictive good increases the marginal utility of future consumption of the addictive good. Following the work of Stigler and Becker (1977), an addiction is harmful if $\frac{\partial u^2}{\partial a^1} < 0$, and beneficial if $\frac{\partial u^2}{\partial a^1} > 0$ (observe that $\frac{\partial u^1}{\partial a^1} > 0$ always holds).

To be able to concentrate on the effect of addiction, and keep the model as tractable as possible, we assume an exogenously given total production equal to y^i in each period and normalized prices equal to one, and assume that it is neither possible to save nor to borrow. The budget constraint for the social planner can then be written as:

$$a^1 + n^1 = y^1 \text{ for period one} \qquad (3)$$

and

$$a^2 + n^2 = y^2 \text{ for period two.} \qquad (4)$$

Assuming that good a^i is taxed in each period, and that the tax revenue is returned to the individual via a lump sum tax m^i, the representative agent's budget constraint can be written as:

$$t^1 a^1 + n^1 = m^1 + y^1 \tag{5}$$

for period one, where $t^1 = 1+$the tax in period one (τ_1) and

$$t^2 a^2 + n^2 = m^2 + y^2 \tag{6}$$

for period two, where $t^2 = 1+$the tax in period two (τ_2).

2.2 First-best Solution

Social Planner

The social planner maximizes total utility for a representative agent (there is a large number of homogenous individuals in the economy) over two periods with respect to the budget restriction.

$$W_S = u^1(a^1, \underbrace{y^1 - a^1}_{n^1}) - D(a^1) + \frac{1}{1+\rho} u^2(a^1, a^2, \underbrace{y^2 - a^2}_{n^2}) - \frac{1}{1+\rho} D(a^2). \tag{7}$$

The corresponding first order conditions for the social planner are (subscript denote the partial derivative with respect to the corresponding variable, and will henceforth be used interchangeably with the derivative):

$$u^1_{a^1} - u^1_{n^1} - D^1_{a^1} + \frac{1}{1+\rho} u^2_{a^1} = 0 \Rightarrow$$

$$u^1_{a^1} + \frac{1}{1+\rho} u^2_{a^1} = u^1_{n^1} + D^1_{a^1}. \tag{8}$$

$$\frac{1}{1+\rho} \left(u^2_{a^2} - u^2_{n^2} - D^2_{a^2} \right) = 0 \Rightarrow$$

$$u^2_{a^2} = u^2_{n^2} + D^2_{a^2}. \tag{9}$$

Equations (8) and (9) can be interpreted as the marginal rate of substitution of good a for good n, equalized to their price ratio $(= \frac{1}{1})$. For an interior optimum, this must hold. Hence, social optimum implies that the marginal utility of consuming one more unit of good a in period one plus the discounted marginal utility of the same good in period two (the stock effect), must be equal to the marginal utility of consuming one more unit of good n in the first period plus the marginal negative external effect of good a consumed in period one (8). Also, the marginal utility of consuming one more unit of good a in the second period must be equal to the marginal utility of consuming one more unit of good n in period two plus the marginal negative external effect of consuming one more unit of good a in the second period (9).

Individual

The representative agent maximizes total utility over two periods with respect to the individual budget restriction:

$$W_{ra} = u^1(a^1, \underbrace{m^1 + y^1 - t^1 a^1}_{n^1}) - \bar{D}^1 + \frac{1}{1+\rho} u^2(a^1, a^2, \underbrace{m^2 + y^2 - t^2 a^2}_{n^2}) - \frac{1}{1+\rho} \bar{D}^2.$$

The corresponding first order conditions for the individual are:

$$u^1_{a^1} - t^1 u^1_{n^1} + \frac{1}{1+\rho} u^2_{a^1} = 0 \Rightarrow$$

$$u^1_{a^1} + \frac{1}{1+\rho} u^2_{a^1} = t^1 u^1_{n^1}. \tag{10}$$

$$\frac{1}{1+\rho} \left(u^2_{a^2} - t^2 u^2_{n^2} \right) = 0 \Rightarrow$$

$$u^2_{a^2} = t^2 u^2_{n^2}. \tag{11}$$

The first order conditions (10) and (11) for the individual imply that the marginal rate of substitution between good a^i and n^i must equal the "economic rate of substitution" between the two goods (the price of good a^i divided by the price of good n^i). Observe that the stock effect, i.e. the discounted marginal utility of good a^1 in period two, is included in "the total marginal utility of good " a^1 ; see Equation (10). This follows from the assumption of a "rational addiction", which means that the individual takes all future costs and benefits into account (the individual knows that he/she gets addicted).

The optimal addictive environmental tax when individuals are time-consistent is found by setting the respective first order conditions for the social planner and the individual equal.

$u^1_{n^1} + D^1_{a^1} = (1 + \tau_1)u^1_{n^1}$ where $t^1 = 1 + \tau_1$ and

$u^2_{n^2} + D^2_{a^2} = (1 + \tau_2)u^2_{n^2}$ where $t^2 = 1 + \tau_2$.

Given the respective first order conditions for the social planner and the individual, the socially optimal environmental tax (optimal addictive tax) in period one is equal to:

$$\tau_1^* = \frac{D^1_{a^1}}{u^1_{n^1}} \tag{12}$$

and for period two:

$$\tau_2^* = \frac{D^2_{a^2}}{u^2_{n^2}}. \tag{13}$$

Hence, the optimal environmental tax in period one and period two is equal to the Pigovian tax in terms of the numeraire good (n^i).

Proposition 1 *The socially optimal environmental tax for a rational addictive good that has an environmental negative external effect is equal to the Pigovian tax.*

Given Proposition one, a social planner is correct by setting the optimal environmental tax equal to the Pigovian tax in a society where individuals are addicted to a good that gives rise to a negative external effect (it can easily be shown that the same optimal tax condition holds for a society without addiction). What is the intuition behind this result? We have framed the problem in this section in line with Stigler and Becker (1977) and Becker and Murphy (1988), which implies rational agents. Given that individuals are *rational* and have an addiction, a social planner should set the tax equal to the marginal damages for all victims in terms of their willingness to pay. In this setting to be addictive does not affect the market imperfection of the negative externality *per se*. Still, the size and time path of the Pigovian tax are affected by the assumption of rational addiction. Both the numerator and the denominator in the tax expressions are affected by addiction. Hence, the total effect on the time path of the Pigovian tax is ambiguous.

2.3 Second-best Solution

In this section the social planner is assumed to be restricted when it comes to the optimal choice of tax in period two. We assume that the social planner can only choose the tax in period one, but faces a fixed tax (lower than the optimal tax found in the first-best case) in period two. A political restriction such as this one is not a theoretical nuisance, but rather a reality that frequently faces policymakers, especially when it comes to climate change. It is likely that the climate change gives rise to extremely high costs in the future, and therefore we expect the optimal tax that should be imposed in the future to be high (or very high). Such a tax might not be politically feasible. Hence, the social planner needs to choose the optimal tax in period one (the second-best solution) given the tax in period two. The social planner maximizes

$$W_S = u^1(a^1, \underbrace{y^1 - a^1}_{n^1}) - D(a^1) + \frac{1}{1+\rho}u^2(a^1, a^2, \underbrace{y^2 - a^2}_{n^2}) - \frac{1}{1+\rho}D(a^2)$$

with respect to τ_1.

The first-order condition can then be written as:

$$\frac{\partial u^1}{\partial a^1}\frac{\partial a^1}{\partial \tau_1} + \frac{\partial u^1}{\partial n^1}\frac{\partial n^1}{\partial a^1}\frac{\partial a^1}{\partial \tau_1} - \frac{\partial D^1}{\partial a^1}\frac{\partial a^1}{\partial \tau_1} +$$
$$\frac{1}{1+\rho}\left[\frac{\partial u^2}{\partial a^1}\frac{\partial a^1}{\partial \tau_1} + \frac{\partial u^2}{\partial a^2}\frac{\partial a^2}{\partial \tau_1} + \frac{\partial u^2}{\partial n^2}\frac{\partial n^2}{\partial a^2}\frac{\partial a^2}{\partial \tau_1} - \frac{\partial D^2}{\partial a^2}\frac{\partial a^2}{\partial \tau_1}\right] = 0$$

or

$$\left[\frac{\partial u^1}{\partial a^1} - \frac{\partial u^1}{\partial n^1} - \frac{\partial D^1}{\partial a^1} + \frac{1}{1+\rho}\frac{\partial u^2}{\partial a^1}\right]\frac{\partial a^1}{\partial \tau_1} = \frac{1}{1+\rho}\left[-\frac{\partial u^2}{\partial a^2} + \frac{\partial u^2}{\partial n^2} + \frac{\partial D^2}{\partial a^2}\right]\frac{\partial a^2}{\partial \tau_1} \quad (14)$$

since and $\frac{\partial n^1}{\partial a^1} = -1$ and $\frac{\partial n^2}{\partial a^2} = -1$.

It should be noted that the corresponding first-order condition for the individual in period one is still given by Equation (10):

$u^1_{a^1} + \frac{1}{1+\rho}u^2_{a^1} = t^1 u^1_{n^1}$.

It can be easily shown that the condition for the optimal tax in period one (Equation (12)) in a first-best world falls out from Equation (14) if we apply the result from the first-best case (Equation (9)), i.e. $-u^2_{a^2} + u^2_{n^2} + D^2_{a^2} = 0$.

If we solve for $\frac{\partial u^1}{\partial a^1}$ in Equation (10), we get $\frac{\partial u^1}{\partial a^1} = (1+\tau_1)\frac{\partial u^1}{\partial n^1} - \frac{1}{1+\rho}\frac{\partial u^2}{\partial a^1}$. Substituting this into Equation (14) and solving for τ_1, we find the condition for the second-best tax in period one:

$$\tau_1 = \frac{\frac{\partial a^2}{\partial \tau_1}}{\frac{\partial a^1}{\partial \tau_1}} \frac{1}{\frac{\partial u^1}{\partial n^1}} \left[\frac{\partial D^2}{\partial a^2} - \frac{\partial u^2}{\partial a^2} + \frac{\partial u^2}{\partial n^2} \right] \frac{1}{1+\rho} + \underbrace{\frac{\frac{\partial D^1}{\partial a^1}}{\frac{\partial u^1}{\partial n^1}}}_{\text{Pigou tax}}. \tag{15}$$

We can write Equation (15) in a slightly different way given the first-order condition for the individual in period two (Equation [11]). Hence, if $\frac{\partial u^2}{\partial n^2} - \frac{\partial u^2}{\partial a^2} = -\frac{\partial u^2}{\partial n^2}\bar{\tau}_2$, where $\bar{\tau}_2$ is equal to the restricted tax, then (15) can be written as:

$$\tau_1 = \underbrace{\frac{\frac{\partial a^2}{\partial \tau_1}}{\frac{\partial a^1}{\partial \tau_1}} \frac{1}{\frac{\partial u^1}{\partial n^1}} \left[\frac{\partial D^2}{\partial a^2} - \frac{\partial u^2}{\partial n^2}\bar{\tau}_2 \right] \frac{1}{1+\rho}}_{\text{Correction due to restriction on tax in period two}} + \underbrace{\frac{\frac{\partial D^1}{\partial a^1}}{\frac{\partial u^1}{\partial n^1}}}_{\text{Pigou tax}}. \tag{16}$$

To be able to analyze this expression more easily, we rewrite it once more (multiplying the first expression in the bracket by $\frac{\frac{\partial u^2}{\partial n^2}}{\frac{\partial u^2}{\partial n^2}}$), and acknowledge that $\frac{\partial a^2}{\partial \tau_1} = \frac{\partial a^2}{\partial a^1}\frac{\partial a^1}{\partial \tau_1} \Rightarrow \frac{\frac{\partial a^2}{\partial \tau_1}}{\frac{\partial a^1}{\partial \tau_1}} = \frac{\frac{\partial a^2}{\partial a_1}\frac{\partial a^1}{\partial \tau_1}}{\frac{\partial a^1}{\partial \tau_1}} = \frac{\partial a^2}{\partial a^1}$:

$$\tau_1 = \underbrace{\frac{\partial a^2}{\partial a^1} \frac{\frac{\partial u^2}{\partial n^2}}{\frac{\partial u^1}{\partial n^1}} \left[\frac{\frac{\partial D^2}{\partial a^2}}{\frac{\partial u^2}{\partial n^2}} - \bar{\tau}_2 \right] \frac{1}{1+\rho}}_{\text{Correction due to restriction on tax in period two}} + \underbrace{\frac{\frac{\partial D^1}{\partial a^1}}{\frac{\partial u^1}{\partial n^1}}}_{\text{Pigou tax}}. \tag{17}$$

We can divide the correction part into three different effects. The first part, $\frac{\partial a^2}{\partial a^1}$ we refer to as the strength of addiction. The larger this effect, the higher the optimal tax in period one. This means that the larger the effect on the consumption of a in period two (through the effect given by the condition $\frac{\partial^2(u^2)}{\partial a^2 \partial a^1} > 0$), given from a change in consumption of a in the first period, the higher is the optimal tax in period one. Hence, the stronger the addiction, the larger the optimal tax in period one. This indicates that addiction makes the optimal second-best tax more efficient, since there is a connection between the consumption patterns of good a in period one and two. The taxes in period one and period two can in this sense be seen as substitutes (though imperfect). The second part is the intertemporal marginal rate of substitution for good n. The third part is the difference between the Pigovian tax in period two, and the actual tax (the restricted tax) in period two. Unfortunately, given our general model we cannot with certainty state that the optimal tax in period one is linear in the period two tax, i.e. the lower the period two tax, the higher the corresponding second-best tax in period one, since all three effects interact. What we can say is that if we imagine a "worst case" scenario, in which the social planner sets $\bar{\tau}_2 = 0$, and we solve for τ_1, we get:

$$\tau_1 = \frac{\partial a^2}{\partial a^1} \frac{\frac{\partial u^2}{\partial n^2}}{\frac{\partial u^1}{\partial n^1}} \frac{1}{1+\rho} \frac{\frac{\partial D^2}{\partial a^2}}{\frac{\partial u^2}{\partial n^2}} + \frac{\frac{\partial D^1}{\partial a^1}}{\frac{\partial u^1}{\partial n^1}}.$$

Where:
$\left(\frac{\partial a^2}{\partial a^1}\right)$ = "Strength of addiction", $\left(\frac{\frac{\partial u^2}{\partial n^2}}{\frac{\partial u^1}{\partial n^1}} \frac{1}{1+\rho}\right)$ =Intertemporal marginal rate of substitution, $\left(\frac{\frac{\partial D^2}{\partial a^2}}{\frac{\partial u^2}{\partial n^2}}\right)$ =Marginal damage in period two in terms of the numeraire good in period two (=the Pigou tax in period two), and $\left(\frac{\frac{\partial D^1}{\partial a^1}}{\frac{\partial u^1}{\partial n^1}}\right)$ =Pigou tax.

The optimal tax in period one varies between this "worst case" scenario, and the Pigovian tax. We can now state the following:

Proposition 2 *The second-best environmental tax for a rational addictive good is increasing in the strength of addiction.*

3 Optimal Environmental Taxation, Addiction and Time-inconsistent Behavior

3.1 The Model

As discussed in the introduction, there is psychological evidence that individuals might not behave "rationally." When studying habits and addictions, it is relevant to discuss the effects of time-inconsistency. Also, as shown in Section 2.2, introducing addiction when the individual is rational does not change the optimal tax condition. In this section we pose the question of how time-inconsistency affects the first and second-best solution in Section 2, or more specifically what role does addiction play on optimal taxation when we move from rational towards myopic individuals? We follow the approach of O'Donoghue and Rabin (1999), and state that individuals are myopic if they value the future less than the present. This way of modeling time-inconsistency has been used previously by several authors (for an overview see p.106 in O'Donoghue and Rabin, 1999, and p.366 in Frederick, Loewenstein, and O'Donoghue, 2002). By introducing a parameter $0 < \beta < 1$, we can rewrite the individual utility function as Equation (18) below, where β describes the fact that individuals are time-inconsistent (myopic), i.e. they place a larger weight on the present utility than on future utility.

Individual

The representative agent maximizes total utility over two periods with respect to the individual budget restriction.

$$\begin{aligned} W_{ra} = u^1(a^1, \underbrace{m^1 + y^1 - t^1 a^1}_{n^1}) - \bar{D}^1 + \\ \beta \left[\frac{1}{1+\rho} u^2(a^1, a^2, \underbrace{m^2 + y^2 - t^2 a^2}_{n^2}) - \frac{1}{1+\rho} \bar{D}^2 \right]. \quad (18) \end{aligned}$$

The corresponding first order conditions for the individual are:

$$u^1_{a^1} - t^1 u^1_{n^1} + \beta \frac{1}{1+\rho} u^2_{a^1} = 0 \Rightarrow$$

$$u^1_{a^1} + \beta \frac{1}{1+\rho} u^2_{a^1} = t^1 u^1_{n^1}. \quad (19)$$

$$\beta \frac{1}{1+\rho}\left(u^2_{a^2} - t^2 u^2_{n^2}\right) = 0 \Rightarrow$$

$$u^2_{a^2} = t^2 u^2_{n^2}. \tag{20}$$

The difference between the time-consistent individual in Section 2 and a myopic individual in this section is seen by comparing Equations (19) and (10). Less weight is put on future utility, and this is reflected in the condition for the marginal rate of substitution where the stock effect, i.e. the discounted marginal utility of good a^1 in period two, is multiplied by β.

3.2 Time-inconsistent Individuals and the First-best Solution

The first order conditions for the social planner are the same as in the problem for time-consistent individuals in Section 2, and following (8) and (9) a social optimum implies that:

$u^1_{a^1} + \frac{1}{1+\rho} u^2_{a^1} = u^1_{n^1} + D^1_{a^1}$ and

$u^2_{a^2} = u^2_{n^2} + D^2_{a^2}$ must hold.

The optimal addictive environmental tax when individuals are time-inconsistent is found by setting the respective first order conditions for the social planner and the individual equal.

$u^1_{n^1} + D^1_{a^1} - \frac{1}{1+\rho} u^2_{a^1}(1-\beta) = (1+\tau_1) u^1_{n^1}$ and

$u^2_{n^2} + D^2_{a^2} = (1+\tau_2) u^2_{n^2}$.

Hence, the socially optimal environmental tax (optimal addictive tax) when individuals are time-inconsistent in period one is equal to:

$$\tau_1^* = \frac{D_{a^1}^1}{u_{n^1}^1} - \frac{1}{u_{n^1}^1(1+\rho)} u_{a^1}^2 (1-\beta) \tag{21}$$

and in period two:

$$\tau_2^* = \frac{D_{a^2}^2}{u_{n^2}^2}. \tag{22}$$

Firstly, from (21) we see that given addiction and that individuals are myopic the optimal environmental tax is no longer equal to the Pigovian tax. Since $u_{n^1}^1 > 0$ and $0 < \beta < 1$, we find that the sign of the deviation from the Pigovian tax in period one is solely dependent on whether $u_{a^1}^2$ is negative or positive, i.e. if the addiction is beneficial or harmful. Also, we can divide the expression for optimal taxation into two parts, one part that corrects for the environmental damage (which is equal to the Pigovian tax), and one part that corrects for addiction in combination with myopic behavior. Hence, the more myopic the individuals are the less is addiction internalized, and the larger is the correction. The tax in period two should be set equal to the Pigovian tax (which is an artifact of the two-period model). We state the following proposition:

Proposition 3 *(1) If individuals are beneficially addicted* $\left(u_{a^1}^2 > 0\right)$ *and myopic, then the optimal environmental tax is smaller than the Pigovian tax.*

(2) If individuals are harmfully addicted $\left(u_{a^1}^2 < 0\right)$ *and myopic, then the optimal environmental tax is larger than the Pigovian tax.*

If individuals are time-inconsistent then addiction to a good that gives rise to a negative external effect on the environment, affects optimal environmental taxation. If the addiction is harmful, the optimal environmental tax should be larger than the Pigovian tax, while for a beneficial addiction the optimal environmental tax should be lower. Also, the more time-inconsistent an individual is in a given society, i.e. the more the individual value present utility opposed to future utility, the larger should the deviation from the Pigovian tax be. This result is based on the fact that a harmful addiction, combined with time-inconsistent behavior, yields an over-consumption today, which is due to a desire that can be satisfied today and that is associated only with a future cost, which is given less weight. When an individual experiences beneficial addiction, the individual consumes too little today since he/she understates the future benefit of consumption tomorrow. What does this tell us about environmental taxation? If a social planner wants to correct for environmental damage, and individuals are addictive and time-inconsistent, then the optimal tax is crucially dependent on whether the addiction is harmful or beneficial.

Comparative Statics

It is also of interest to study the effect of a *change* in time-inconsistency on *optimal* taxation ($\frac{\partial \tau_1^*}{\partial \beta}$). We know that β affects the consumption choice of the individual. Furthermore, we know that we have a Pareto optimal tax (Equation (21)), and hence the final consumption is the same in optimum, even if the individual gets more or less myopic. If we take the derivative of the optimal tax with respect to β, we find:

$\frac{\partial \tau_1^*}{\partial \beta} = \frac{u^2_{a^1}}{u^1_{n^1}(1+\rho)}$, which means that a decrease in myopia (higher value of β) should result in an increase in the optimal environmental tax for a beneficial good, while for a harmful good the level of the optimal tax should decrease. Hence, a marginal decrease in myopia (a marginal increase in β) increases the level of the optimal tax ($\frac{\partial \tau_1^*}{\partial \beta} > 0$), for a beneficial addictive good. Correspondingly, a marginal decrease in myopia (a marginal increase in β) decreases the level of the optimal tax ($\frac{\partial \tau_1^*}{\partial \beta} < 0$), for a harmful addictive good.

The result is analogous to Proposition three. A harmful addiction, combined with time-inconsistent behavior, yields an over-consumption today, since future negative effects of the consumption are given less weight, and if myopia decreases, the individual takes more of the harmful effect from period two into account, and the individual would like to decrease consumption of the addictive good in period one. Hence, the social planner must decrease the tax level for optimal consumption to hold. For a beneficial addiction combined with time-inconsistent behavior, the individual would like to increase consumption of the addictive good today, since future benefits are given more weight today, and this forces the social planner to increase the tax level.

3.3 Time-inconsistent Individuals and the Second-best Solution

The result from Section 3.2 implies that the correction for environmental damage and time-inconsistency can be treated separately. In this section we briefly show that the correction for a restriction on the tax in period two does not interact with the correction for time-inconsistency. The first-order condition for the individual is the same as for the first-best solution (Equation (19)), while the corresponding first-order condition for the social planner is equal to Equation (14). Substituting Equation (19) into Equation (14) and solving for τ_1 for yields the optimal second-best tax:

$$\tau_1 = \underbrace{\frac{\partial a^2}{\partial a^1}\frac{\frac{\partial u^2}{\partial n^2}}{\frac{\partial u^1}{\partial n^1}}\left[\frac{\frac{\partial D^2}{\partial a^2}}{\frac{\partial u^2}{\partial n^2}} - \bar{\tau}_2\right]\frac{1}{1+\rho}}_{\text{Correction due to restriction on tax in period two}} + \underbrace{\frac{\frac{\partial D^1}{\partial a^1}}{\frac{\partial u^1}{\partial n^1}}}_{\text{Pigou tax}} - \underbrace{\frac{\frac{\partial u^2}{\partial a^1}}{\frac{\partial u^1}{\partial n^1}}\frac{1}{1+\rho}(1-\beta)}_{\text{Myopic effect of addiction}} .$$

When comparing this solution to the case without time-inconsistency (Equation (17)), we find that the correction for addiction due to time-inconsistency is separate from the correction for the second-best case, and the Pigovian tax. Also, and perhaps even more interesting, proposition three is valid for a second-best solution.

Proposition 4 *The second-best environmental tax for an addictive good, when individuals are time-inconsistent, is increasing in the strength of addiction, but at the same time dependent on the character (harmful or beneficial) of the addiction.*

4 Concluding Remarks

In this paper we have modeled addictive behavior in line with Stigler and Becker (1977) and Becker and Murphy (1988) for time-consistent individuals in a first and second-best setting, and then extended the model to time-inconsistent individuals. We posed the question of how addictive behavior affects an optimal environmental tax, when the consumption of the addictive good causes a negative external effect on the environment. We know that a negative environmental externality vindicates that a corrective policy is implemented. Given that preferences of individuals are not driven by addiction, we know that the optimal environmental tax should be equal to the Pigovian tax, i.e. a tax equal to the shadow price or marginal damage of the externality. Our results show that the conventional Pigovian tax is still valid when addictive behavior is present, and this hinges upon the assumption of *rational* addiction, individuals do take into account that they are addictive. Furthermore, it is important to emphasize that the *level* of the tax might, or most probably will, differ between two different societies (one in which individuals are addictive and one in which they are not), and that addiction affects the time path of the Pigovian tax.

When it is no longer a possibility for the social planner to set the first-best tax in period two, the optimal tax in period one is no longer the Pigovian tax. The optimal second-best tax in period one is a function of *(i)* the strength of addiction *(ii)* the difference between the marginal damage in period two and the given tax in period two and *(iii)* the intertemporal marginal rate of substitution of the non-addictive good. This tax is always larger than the Pigovian tax (assuming that the given tax in period two is always lower than the Pigovian tax in period two), and approaches the Pigovian tax as the given tax in period two approaches the first-best tax.

When we consider myopic or time-inconsistent behavior, the results for a general model over two periods are clear - a beneficial addiction in combination with myopia implies an optimal environmental tax lower than the Pigovian tax, and a harmful addiction in combination with myopia implies an optimal environmental tax larger than the Pigovian tax. Harmful addiction is indisputably more studied and discussed than beneficial addiction. However, our framework, where consumption of the addictive good gives rise to a negative external effect on the environment, shows that it is essential to first empirically study the existence of such addictive behavior, but then also, and perhaps more importantly, study the corresponding type of addiction (harmful or beneficial), since this is of crucial importance for optimal environmental taxation. Keeping in mind that our model is naturally a simplification of reality, our results suggest that the tax on gasoline should be set lower than the marginal damage of the externality, given the empirical evidence that people in general are time-inconsistent and *if* we assume that driving a car is a beneficial addiction. Distinguishing between harmful and beneficial addiction is left to important future research. We hope that this simple model applied to the environmental economics area has further strengthened the importance of considering psychological aspects of economics, which has been emphasized in recent economic literature.

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