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ENVIRONMENTAL TAXATION – EMPIRICAL AND THEORETICAL APPLICATIONS

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Tillägnan
"Tanken på dig är som molnskuggans ilande flykt
över slätten
en oväntad förbindelse mellan himmel och jord
en blickens vilande färd mot horisonternas bortom
en gnistrande ljuv påminnelse om livets korthet."
(Erik Lindegren)

Dedicated to Per.

Contents

Abstract

Paper 1: The Phase-Out of Leaded Gasoline in the EU: A Successful Failure?

The objective of this paper is to analyze in both descriptive and econometric terms the phase-out of leaded gasoline consumption in the EU countries. The phase-out process is characterized by increased consumption of unleaded gasoline. We analyze the importance of price differences, share of catalytic converters, income per capita, and country characteristics in the phase-out process. Since the expected maintenance costs of using unleaded gasoline in cars without catalytic converters compared to the use of leaded gasoline differ insignificantly according to available evidence, and consumers still use leaded gasoline even though unleaded gasoline is cheaper; we interpret this as a lack of reliable information. The results indicate that countries, which have not yet phased out leaded gasoline, should do this by either banning leaded gasoline or use a larger tax differential complemented with information.

Paper 2: The Determinants of Sulfur Emissions from Oil Consumption in Swedish Manufacturing Industry, 1976-1995.

Using a structural decomposition analysis, we analyze the causes of reduction of emitted sulfur originating from oil consumption in the manufacturing industry in Sweden during 1976-1995. Our decomposition results provide a good point of departure for a discussion on the causes of the large reduction of emitted sulfur. The Swedish case is of interest since Sweden is one of the countries that have pursued the most ambitious policy when it comes to combating the precursors of acid rain. A large part, 59 percent between 1989 and 1995, of the reduction of emitted sulfur from the manufacturing industry can be attributed to the announcement and implementation of the Swedish sulfur tax. Two

thirds of the reduction during 1976-1995 is captured by substitution between oil and other energy sources. The price of electricity has had a significant effect for the sulfur reduction via substitution between oil and electricity. Furthermore, one third of the reduction during 1976-1995 is explained by decreased energy intensity.

Paper 3: Political Economy Obstacles to Fuel Taxation.

Many studies have shown that fuel demand is quite elastic and that the best way to reduce fuel use (to deal with global warming) is by taxing fuel. Yet it seems almost impossible to do so, particularly in those countries with low prices and high demand. We show, by a Granger non-causality test, using data on rich OECD countries that the direction of causality is ambiguous. We find evidence that the causality runs from consumption to price rather than, or in addition to, the conventional causality from price to quantity. We believe that one of the reasons for this is that lobby groups influence the political decisions regarding taxation of gasoline consumption. Not only do low prices (low taxes) encourage high consumption but high levels of consumption also lead to considerable lobbying to defend those low prices (low taxes). Following our results we argue that it is essential to take into account the political environment as an important factor when designing environmental policy instruments such as gasoline taxes.

Paper 4: The Effect of Addiction on Environmental Taxation in a First and Second-best World.

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.

Paper 5: Habit Formation in Environmental Quality: Dynamic Optimal Environmental Taxation.

In this article we propose a model in which individuals experience habit formation in environmental quality. Further, a consumption good causes a negative external effect on the environment. A benevolent social planner maximize utility given the negative effect of the consumption good on the environment, taking into account that there is habit formation in environmental quality. Given a simple model we show that the level and time path of the corresponding optimal environmental tax is affected by the assumption of habit formation; more specifically the stronger the habit, the higher the optimal level of environmental quality in steady state, and the faster the transition towards the steady state tax level. Furthermore the initial value of the habit stock is of crucial importance for the time path of the tax. Also, we solve for, and analyze, dynamics and the existence and characteristics of equilibria in the model and discuss how the characteristics of habit formation affect steady state.

Preface

When I started to think about this Preface, it struck me how many people I want to thank. During these years of writing my thesis, different people have supported me at different "levels." Some have directly supported me in my research, while some have given more intellectual stimulation and helped me in my research in a broader sense. Then there are people who have watched my mental as well as physical health during this period. Some people have been there for a shorter while and some for longer times, and some, I hope, for life!

My first encounter with environmental economics is synonymous with Thomas Sterner. He literally opened his door for me as an undergraduate student, and I still remember that I was surprised to see an economics professor wearing clogs (träskor). This filled me with trust, due to the fact that I have a father who has insisted of wearing clogs my whole life. Thomas got me interested in the exciting world of environmental economics, and since that day his door has always been open for me, and he has shared his great knowledge and visions with me, both as a supervisor and as a fellow researcher. Moreover, he is a friend and I hope this friendship will last for a long time.

Olof Johansson-Stenman, my supervisor (I have two), "saved" my thesis so many times that I can hardly count them. Of course, innumerable times he has also rejected my ideas, but that is why it is so fascinating to work with Olof - you learn to defend, rethink, and do better economic research. To me, he embodies knowledge, and I am forever grateful that I had the opportunity to share some of his knowledge, and hope that I can return to his sofa to discuss economics even in the future. Thanks for everything Olof!

Henrik Hammar has been the coauthor of three of my papers. We

started the graduate program together, and since then he has become one of my closest friends. Without you, Henrik, life would have been poorer. You stimulate my intellectual capacity, and we have discussed everything from decomposing sulfur, Linus' day at the daycare center, to the possible existence of God. No question is too banal or too complex for Henrik. I hope we can continue our research together. I respect you as a researcher and human, and you will forever be in my heart.

When writing a thesis you should be utterly aware that you are dependant on people who can help you. Not all people are there for you twenty-four hours a day, 365 days a year, but I am fortunate enough to have such a person - Fredrik Carlsson. I have enjoyed every minute of knowing you. Thanks for all the time you have taken to discuss research questions with me. Not that we agree upon everything (far from it), but when I have been held hostage by my own thesis you have come and rescued me. I look forward to doing research with you in the future, as well as going exercising (maybe I will try an aerobics class one day), and I look forward to continue our discussions on things we do not agree about. Still, I know that you think I am right sometimes- you are just too stubborn to admit it!

Other people who have given me valuable comments and inputs are: Gardner Brown, Clas Ericson, Henk Folmer, Lennart Hjalmarsson, Per Hörfelt, Susanna Lundström, Peter Martinsson, Karl-Göran Mäler, Katarina Nordblom, Ola Olsson, Sjak Smulders, participants at the 9th Ulvön Conference 2002, participants at Nordic Workshop on Tax Policy and Public Economics in Uppsala 2002, and participants at the 7th Spring Meeting of Young Economists 2002 at the University of Paris. Furthermore I would like to thank researchers at the Resources for the Future, Washington D.C., where I spent four months, for inputs in my work.

A special thanks should go to my colleague and friend Susanna Lundström who has contributed to my thesis as well as protecting my sanity. Some days have been tough, and your door is always open. The same goes for Mattias Erlandsson. Next summer I hope we will go climbing together, and then none of us can blame the thesis for not getting out there!

I would also like to thank Francisco Alpizar, Peter Martinsson, Ola Olsson, Håkan Eggert, Martine Visser, Gunnar Köhlin, Johan Adler, and Anna Brink for making the time spent writing my thesis more fun as well as more intellectually stimulating with all our discussions! Thanks also to the members of the Environmental Economics Unit and the Department of Economics. Debbie Axlid has corrected the language and made the papers much better, thanks!

I have received valuable financial support from Adlerbertska Forskningsfonden, STINT (Stiftelsen för internationalisering av högre utbildning och forskning), and Janneman Schmidts Stipendiefond.

Then I would like to take the opportunity to mention Tove Jendman, Rachael Blaxland, Per Martin Boström, Karolin Johansson, Mari Lundberg, and Ulrika Liss-Daniels who have been listening to me, talking about my thesis for all these years, and have made me think about other things (there is a world outside the department...). I am glad you have not gotten too tired of me yet.

Mother and father - you have supported me throughout my whole life! I am glad that you are both natural scientists, because if you had started to study the concept of opportunity costs and value of time, you might not have been so generous with time. The time you have spent caring for Linus and picking him up at the daycare center, and always been ready to help out in messy situations, has been more valuable to me than you will ever understand. My mother deserves special thanks for all the time she (and her colleagues?) spent with my mathematical problems. Thank you, Göran who also helped us out with caring for Linus. Furthermore, spending some time with my brothers Stefan and Jonas is definitely a good way of training before a seminar. Nothing indefensible is allowed to pass when having discussions with them. Thanks for being there!

Per and Linus. You are the two most important persons in my life. Nothing I write here can justify the love I feel for you. So I will just end by writing: this thesis is for you!

Introduction

This thesis consists of five self-contained articles. Still, all five papers have one important feature in common: environmental taxation. Environmental taxation is a broad and important area of research, and studying environmental taxation can be done in innumerably different ways. My work on environmental taxation ranges over several different methods and areas of economic research, and incorporates three empirical and two theoretical studies. I hope the thesis points to the importance of evaluating existing environmental taxes as well as considering new developments in the area of economic theory and its effect on environmental taxation.

In this thesis I have studied, empirically, the effect of two different specific environmental taxes, namely the tax difference between leaded and unleaded gasoline, and the sulfur tax. When studying the effect of these two taxes, different methods are called for. In paper one, *The Phase-Out of Leaded Gasoline in the EU: A Successful Failure?*, several aspects need to be taken into account: for example, the substitutability between leaded and unleaded gasoline and the introduction of catalytic converters. The effectiveness of the policies used for phasing out leaded gasoline critically hinges upon the uncertainty ex ante regarding the use of unleaded gasoline in old cars. We show that the price difference between leaded and unleaded gasoline had a significant, though small, effect on the phase out of leaded gasoline. Of more importance are catalytic converters and income. Furthermore, during the phase out period, new evidence emerged on the possibility for old cars to use unleaded gasoline, but this information was not used. Therefore, ex post, we argue that the tax difference was not as effective as it could have been if complemented with the right information; therefore we label the phase-out of leaded gasoline in the EU as a "successful failure."

When studying the effect of the sulfur tax in paper two, *The Determinants of Sulfur Emissions from Oil Consumption* in Swedish Manufacturing Industry, 1976-1995, it is not straightforward to study consumption, as in the case with the phase-out of leaded gasoline, since the target of the tax is sulfur, not oil consumption *per se*. Furthermore, the industrial oil consumption has increased over time. How then do we measure the actual effect on sulfur content? We solve this methodological problem by using structural decomposition analysis. Using this method we decompose emitted sulfur due to consumption of oil, and connect this to the sulfur tax. Hence, we are able to distinguish different factors (reduced sulfur content, substitution from oil to other energy sources, increased energy intensity, substitution from heavy to light fuel oil, structural, and production effects), of which some were affected by the sulfur tax, and some were not. Our results show that between 1985 and 1995, about 60 percent of the reduction of emitted sulfur from the manufacturing industry can be attributed to the announcement and implementation of the Swedish sulfur tax. Furthermore, two thirds of the reduction of sulfur during the whole period of 1976-1995, is captured by substitution between oil and other energy sources. The price of electricity has had a significant effect on the sulfur reduction via substitution between oil and electricity. One third of the reduction from 1976 to 1995 is explained by decreased energy intensity.

It is a well-known fact in the research area of gasoline consumption that some countries have low taxes and high consumptions and some have the reverse. This intrigued us to ask the question how come those countries with low taxes don't just increase the tax to decrease consumption, especially since the climate change is on the political agenda and transport is one of the main contributors to the depletion of the ozone layer, global warming, and acidification. A natural answer is that there is something else going on, which leads us to test the hypothesis that it might not just be that consumption affects price, but also that price affects consumption. In paper three, *Political Economy Obstacles to Fuel Taxation*, we test this assumption using the Granger non-causality test. Furthermore, we incorporate the result into a parsimonious political economy model, where we argue that consumption can be seen as a measure of lobbying. We acknowledge that using gasoline consumption as a measure of lobbying is crude, but it is possibly the simplest aggregate measure of lobbying, instead of including variables such as population density, road tolls, oil refinery capacity, number of public buses, and road expenditures, which are left for future research.

My empirical work got me interested in the assumptions behind the theory on environmental taxation and how environmental taxation is affected by changes in assumptions regarding individuals' preferences. Especially, working with transport (gasoline consumption), and given the empirical evidence that transport is habitual, made me think about how environmental taxation is affected by assumptions regarding habit formation. The theory behind environmental policy in general, and environmental taxation in particular, is large and comprehensive (for an interesting collection on seminal papers in the field see Oates, 1992), but to my knowledge habit formation has not been studied explicitly in an environmental framework before. Pollak (1970) summarizes the notion of habit formation such that *(i)* past consumption influences current preferences and hence current demand, and *(ii)* a higher level of past consumption of a good implies, *ceteris paribus*, a higher level of present consumption of that good. In papers four, *The Effect of Addic-*

tion on Environmental Taxation in a First and Second-best World, and five, *Habit Formation in Environmental Quality: Dynamic Optimal Environmental Taxation*, I model habit formation (i.e. [*i*] and [*ii*]) through a mechanism which gives us higher utility from consuming an amount of a good today if we have had a high consumption of the same good historically, which is also in line with Stigler and Becker (1977) and Becker and Murphy (1988).

Habit formation can hence be seen as a sort of learning by doing. Two common examples in the literature of habit formation (addiction) are cigarette smoking and listening to Mozart. The more we smoke and the more we listen to Mozart, the more we enjoy smoking and listening to Mozart in the future. We need to "learn" to enjoy. Still, the characters of smoking and listening to Mozart are completely different. While smoking has a negative impact on future utility (for example through health), listening to Mozart has a (possibly) positive effect on future utility. In the literature a habit such as cigarette smoking is referred to as harmful, while a habit such as listening to Mozart is referred to as beneficial. As I show in paper four, given that we have no other distortions in the economy, the conventional Pigovian tax (a tax equal to the shadow price or marginal damage of the externality) is still valid when addictive behavior is present. If we introduce time-inconsistency into the model, then the character (beneficial or harmful) of habit formation (addiction) is of crucial importance for optimal environmental taxation. Hence, a relevant question is then whether a habit like transportation is like a "cigarette" type of habit, or a "Mozart" type of habit. This is discussed further in paper four. If we introduce a restriction on future tax levels, the second-best environmental tax increases in the strength of habit formation (addiction).

For a reader not familiar with this literature it can be enlightening to discuss the connection between habit formation and addiction, especially since in paper four I use the term addiction while in paper five I use habit formation. Rational addiction is a special case of habit formation, and in paper four I formally study addiction as defined in the rational addiction literature and therefore use the term addiction, while in paper five I use the term habit formation, since in this paper my point of departure is the definition of habit formation made by Pollak (1970). Habit formation and addiction both imply complementarity of the habitual good over time. The main difference between a rational addiction model and a more general habit formation model is the timing of the complementarity. In a general habit formation model we can allow for periods of decreasing consumption of the habitual good, followed by a period or periods with increases in consumption (distant complementarity), while rational addiction implies complementarity between two subsequent periods (adjacent complementarity). These two concepts of complementarity are explored by Ryder and Heal (1973). Given the functional form of the utility function in paper five, the model still fulfils the requirements of rational addiction as defined by Becker and Murphy (1988). Since the distinction between habit formation and addiction is more of a semantic question, the reader of this thesis should not get confused by the terms used in the two papers. Addiction as defined in paper four and habit formation as defined in paper five are analytically equal, and while the terminology is of secondary importance, the crucial assumptions are about the connection of consumption choice over time.

Further, I use my acquired knowledge from paper four in paper five, but in this paper it is not the environmental bad that is habitual, it is environmental quality. More specifically, I assume that utility derived from environmental quality is given from a habit stock, dependent upon earlier environmental quality. Environmental quality is affected negatively by an environmental bad. I use optimal control theory to study the dynamic properties of such a tax. As is shown, the level and time path of the tax are affected by the assumption of habit formation: the stronger the habit, the higher the optimal quality of the environment in steady state, and the faster the transition towards the steady state tax level. Furthermore, the initial value of the habit stock is of crucial importance for the time path of the tax. An initially low habit stock corresponds to a decreasing tax over time, and an initially high habit stock corresponds to an increase in tax over time. This gives interesting results regarding the time-path of the optimal environmental tax, and points to the importance of the habit stock for the time-path of environmental taxation.

I hope that the simple models used in papers four and five applied to the environmental economics area strengthen the importance of considering psychological aspects of economics, which has been emphasized in recent economic literature (see e.g. Loewenstein, 1992, and Rabin, 1998, for extensive overviews).

References

Becker, Gary S. and Kevin M. Murphy (1988). “A Theory of Rational Addiction”, *Journal of Political Economy*, Vol. 96(4), pp. 675-700.

Loewenstein, George (1992). "The Fall and Rise of Psychological Explanations in the Economics of Intertemporal Choice", in George Loewenstein and Jon Elster, eds., *Choice over time*, New York: Russell Sage Foundation, 1992, Vol. 65(2), pp. 3-34.

Oates, Wallace E. (1992). “The Economics of the Environment”, *Journal of Political Economy*, Vol. 96(4), pp. 675-700.

Pollak, Robert A (1970). “Habit formation and dynamic demand functions”, *Journal of Political Economy*, 78 (1970), pp.745-763.

Rabin, Matthew (1998). "Psychology and Economics", *Journal of Economic Literature*, March 1998, Vol.36, Issue 1, pp. 11-47.

Ryder, Harl E. Jr. and Geoffrey M. Heal (1973). “Optimal Growth with Intertemporally Dependent Preferences”, *The Review of Economic Studies*, January, 1973, Volume 40, Issue 1, pp. 1-31.

Stigler, George J. and Gary S Becker (1977). “De Gustibus Non Est Disputandum”, *American Economic Review*, March 1977, v.67, iss. 2, pp. 76-90.

Paper 1

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The phase-out of leaded gasoline in the EU: a successful failure?

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Abstract

The objective of this paper is to analyze in both descriptive and econometric terms the phase-out of leaded gasoline consumption in the EU countries. The phase-out process is characterized by increased consumption of unleaded gasoline. We analyze the importance of price differences, share of catalytic converters, income per capita, and country characteristics in the phase-out process. Since the expected maintenance costs of using unleaded gasoline in cars without catalytic converters compared to the use of leaded gasoline differ insignificantly according to available evidence, and consumers still use leaded gasoline even though unleaded gasoline is cheaper; we interpret this as a lack of reliable information. The results indicate that countries, which have not yet phased out leaded gasoline, should do this by either banning leaded gasoline or use a larger tax differential complemented with information.

Keywords: Leaded gasoline; Unleaded gasoline; Policy instruments; Tax differential.

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Paper 2

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The Determinants of Sulfur Emissions from Oil Consumption in Swedish Manufacturing Industry, 1976-1995.

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Abstract

Using a structural decomposition analysis, we analyze the causes of reduction of emitted sulfur originating from oil consumption in the manufacturing industry in Sweden during 1976-1995. Our decomposition results provide a good point of departure for a discussion on the causes of the large reduction of emitted sulfur. The Swedish case is of interest since Sweden is one of the countries that have pursued the most ambitious policy when it comes to combating the precursors of acid rain. A large part, 59 percent between 1989 and 1995, of the reduction of emitted sulfur from the manufacturing industry can be attributed to the announcement and implementation of the Swedish sulfur tax. Two thirds of the reduction during 1976-1995 is captured by substitution between oil and other energy sources. The price of electricity has had a significant effect for the sulfur reduction via substitution between oil and electricity. Furthermore, one third of the reduction during 1976-1995 is explained by decreased energy intensity.

*We wish to thank Gardner Brown, Lennart Hjalmarsson, Olof Johansson-Stenman, Thomas Sterner, and Rick Wicks for constructive comments on the paper. We have also recieved useful comments from threee anonymous referees. We have made numerous contacts with people and organizations that have generously supplied relevant information in various forms, ranging from answers to questions of a practical character, to technical insights regarding oil consumption and combustion, the literature, and necessary data used in our decomposition analysis. For this we are grateful to Philippa Blincoe (EEA), Dr. Janusz Cofala (IIASA), Annemie Hermans (Concawe), Roland Jarsin (SPI), Nadia Kamel (Kuwait Petroleum Svenska AB), Gun Lövblad (IVL), Carrie Salama (IEA), and Christer Ågren (Internationella försurningssekretariatet, SNF). Financial support from Adlerbertska Forskningsfonden is gratefully acknowledged. The usual disclaimer applies.

Paper 3

Political Economy Obstacles to Fuel Taxation

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Abstract

Many studies have shown that fuel demand is quite elastic and that the best way to reduce fuel use (to reduce global warming) is by taxing fuel. Yet it seems almost impossible to do so, particularly in those countries with low prices and high demand. We show, by employing a Granger non-causality test using data on rich OECD countries, that the direction of causality is ambiguous. We find evidence that the causality runs from consumption to price in addition to the conventional causality from price to quantity. We believe that one of the reasons for this is that lobby groups influence the political decisions regarding taxation of gasoline consumption. Not only do low prices (low taxes) encourage high consumption but high levels of consumption also lead to considerable lobbying to defend those low prices (low taxes). Following our results we argue that it is essential to take into account the political environment as an important factor when designing environmental policy instruments such as gasoline taxes.

JEL Classification Numbers: Q41, Q48, D78.

Keywords: causality; gasoline consumption; political economy; policy instruments; taxation.

*The authors would like to thank Fredrik Carlsson, Per Fredriksson, Olof Johansson-Stenman, Christer Ljungwall, and Peter Martinsson for many useful comments. The usual disclaimer applies.

1 Introduction

Global warming presents one of the major challenges when it comes to sustainable development. One difficult aspect is that effects and costs are unevenly distributed over time and space. There might be very significant damages in the distant future, particularly for people living in certain areas. One (but not necessarily the only) example is people living in lowland areas such as the Seychelles or, more dramatically, Bangladesh where flooding would affect many millions. The fact that there is a considerable distance in time and space does however not negate the fact that there is a clear connection between our use of fossil fuels and any ecosystem effects from increased ambient levels of carbon in the atmosphere.

One of the major sources of human-induced global warming is the use of fossil fuels in the transport sector. In the absence of a major breakthrough for non-fossil fuels, global warming must be dealt with by reduced consumption and as an economist it is natural to believe that this is most efficiently achieved by a higher user price. The US, with less than 5% of the World population, accounts for over 25% of crude oil consumption and more than two thirds of that consumption is by the transport sector. Many studies have shown that fuel demand is quite elastic in the long run and it is argued that the most efficient way to reduce fuel use (to reduce global warming) is by taxing fuel; see e.g. Dahl and Sterner (1991a and b) for an extensive overview.[1] The same tax would coincidentally reduce many other traffic-related externalities (but

[1] Johansson and Schipper (1997) have looked in greater detail at the breakdown between responses in terms of kilometers driven and number and types of vehicles. In the transport economics literature, there has been more detailed work on the choice of travel mode, the complementarity of or substitutability between different modes of traffic in a city, and so forth. All of these have concluded that gasoline demand does have some degree of elasticity with respect to price.

would however not generally be the most efficient way of dealing with these local externalities (European Commission COM(95)691, 1995).[2] Although fuel prices have been drastically increased in many countries, it is still difficult to increase gasoline taxes, particularly in those countries with low prices and high demand. The US consumer price of gasoline is about 30% of the European price and consumption of gasoline is about four times higher per capita than in Europe.[3] The US is in no way alone in having cheap fuel, but due to its size it is a good example. Other similar countries are Canada, Australia and many Third World oil-exporters such as Mexico, Nigeria or Saudi Arabia. Together these countries account for a dominant share of the global fuel consumption and the politics of fuel taxation (or other instruments intended to reduce fuel use) in these countries will thus be decisive for the implementation of global climate policies.

The former French foreign minister Jean-François Poncet was once quoted as having said: *"It's hard to take seriously that a nation has deep problems if they can be fixed with a 50-cent-a-gallon gasoline tax."*[4] This statement captures the difference in political culture and perception of the problem across the Atlantic. It does however probably underestimate the underlying economic and political difficulties. The purpose of this paper is to cast light on these difficulties of raising gasoline taxes by looking at the direction of causality in the relationship between gasoline taxes and gasoline demand. The conventional wisdom of studies on fuel demand is that higher taxes imply higher consumer prices, which

[2] Trading of carbon rights would in many respects have the same effect as carbon taxes: (fossil) fuels would become more expensive.

[3] The average price in the US 1999 was 0.3 $/l while the average price in the major European economies (Germany, France, UK and Italy) was 0.99 $/l (with purchasing power conversion of currencies). US gas consumption was 1,300 l/cap/yr compared to an average of 320 in the same group of major EU countries.

[4] Quoted in the Washington Post March 27, 1992.

imply lower demand. There is no doubt that this very intuitive result is, broadly speaking, true. Still, the measurement of the elasticities is complicated by the existence of long lags and other problems.[5] We want to point to an additional problem that affects both the estimation of elasticities and their interpretation and application in a policy context. Suppose that a high consumption level makes people adamant in resisting tax increases, and at lower consumption levels people encourage them – or at least find it easier to tolerate them. Part of what previously was estimated as demand elasticity would then in fact be confounded with a political tax response mechanism. In this paper we have chosen a parsimonious approach to the political economy of gasoline taxation. We use Granger non-causality tests to examine the strength of the forces that lead to low taxes in high consumption countries, and then proceed by testing our hypothesis in a simple political model of gasoline taxation.

This paper is organized as follows: First, obstacles to fuel taxation are discussed, followed by a discussion of causality tests. We then carry out a test for causality and use the result to formulate a simple political taxation model by including consumption as a proxy for lobby strength. Finally, the results are interpreted and concluding remarks are made.

2 Obstacles to Higher Fuel Taxes

As long as energy is a normal good (or factor of production) its demand will decrease as price increases. This in itself is sufficient to create the

[5] The econometric studies that concentrate on long-run relationships using panel and cross-sectional country data tend to find price elasticities in the range of –0.8 and sometimes even greater than –1, while more short run studies find considerably lower values. Studies that attempt to capture the long run by using dynamic models with lag structure on time series data typically find intermediate values (Baltagi and Griffin, 1983). In comparison our data reflects a price elasticity of –1 (observe that this is the price elastictity for price one period lagged), estimated by a fixed effects model.

negative correlation that we normally identify as a demand elasticity. In this article we want to highlight factors that might provide an additional connection but with the opposite direction of causality; factors through which high (low) fuel consumption leads to low (high) taxes. In high-consumption countries the consumers own vehicles and property and have a lifestyle that hinges on high uses of fuel, and there is thus a perceived[6] risk of large losses from fuel taxes. A large number of businesses – from car producers to gas stations, from amusement and shopping centers to oil companies, etc., have interests in a society in which gas remains cheap. The employees of these institutions have the same interest to the extent that their job is dependent on the profit of their employer. Oil companies are generally recognized as a powerful lobby, and naturally oppose fuel taxes. The political representatives of all these people thus have a lot of popularity to gain from making the case against fuel taxes.

At the same time the people who would gain from higher taxes are either few or diffuse and unorganized. To many laymen the very idea of any tax being "too low" may seem paradoxical. Some training in economics and general equilibrium thinking are necessary to realize that there is, at least notionally, an optimum level of each tax. Tax rates above the optimum damage the economy, but so do tax rates below it – since they lead to sub-optimal levels of either public spending, budget deficits or taxation of other commodities. There are economic agents who directly gain from a fuel tax: On the one hand there are providers of alternative modes of transport who might gain from higher fuel taxes - conceivably those employed by, or with interests in, public transport, bicycles, etc. On the other hand, the general public may in principle

[6] We say perceived loss since fuel taxes might well be a gain if general equilibrium effects are taken into account.

gain from a better tax system and the resulting improvement in the allocation within the economy, but this is a very abstract concept and not likely to attract much support.[7]

One other important factor that deserves to be mentioned is population density. Few international studies of gasoline demand include this variable and it generally does not perform well statistically. One of the reasons for this is that the readily available measures of population density are defined over a whole nation's territory, while the most important determinant may be local densities within the relevant range of daily travel. Such a variable is however very hard to construct since it is partly endogenous. It is well known that most US cities have population densities that in fact are much lower than those in Europe. Cities with population densities around 10 persons/ha like Detroit[8] are not in the same situation as European cities like London or Paris with population densities in the 50-75 persons/ha range, not to mention many Asian cities with 100-500 persons/ha. It is not surprising that fuel consumption in the dispersed US cities, which often lack intensive public transport, is four times as high as in typical European cities. While a large share of the difference is due to habits and vehicle characteristics that would adapt to changed fuel prices within 5-10 years, another large share is due to differences in urban architecture that would take considerably longer and be more painful to change. Therefore we focus, in this paper, on

[7] Ironically, even the oil companies might benefit. In some high-tax countries like Norway, Sweden, Italy and Japan, the high taxes are combined with high pre-tax prices of gasoline. This seems odd (higher taxes should squeeze the margins of the oil companies) but a possible political explanation lies in an implicit acceptation of higher profits in exchange for high taxes. It is as if the environmental authorities are so keen on conservation that they accept high markups or other cartel behaviors from the fuel companies. Similarly one might imagine the oil companies not complaining too much about high taxes as long as their profit margins are not attacked. Thus, the politicians would in some sense be "sharing" the high rents caused by conservation with the fuel companies.

[8] Thomas Brinkhoff: City Population, http://www.citypopulation.de.

the lobby aspect of the possible “reversed” direction of causality.

2.1 The Economics of Lobbying

The main thrust of economic literature on policy making assumes an optimizing framework in which the government seeks to maximize social welfare while economists provide neutral, technical support to the calculations. True policies are however not necessarily designed to maximize welfare or GDP. In fact, such policies might even be rare outside the textbooks. Instead, real policies are presumably best seen as the result of a struggle between conflicting interests. Those who have a considerable stake in a particular policy may be willing to put considerable resources into lobbying. The gain to this group may in aggregate be small compared to the total loss to society from non-optimal policies, but the latter costs are borne by a much larger group of diverse people who find it difficult to organize themselves to further their interests.

There is growing literature that builds both on the realization of the fact that the entities threatened to be regulated can simply expend resources to influence policy decisions, and on the closely related notion that policy makers have interests of their own. One of the seminal articles in this area shows that economic interest groups can be successful by investing lobbying funds to influence the political process in their favor, and lobbying groups essentially seek to get advantageous trade policies passed, that tilt the relative prices in their favor (Grossman and Helpman, 1994). Another important contribution is Becker (1983) who sees competition among rival lobbies as a way of selecting efficient policy instruments.

Fredriksson (1997, 1998, 2001) is one of the authors who analyze lobbying in the area of environmental policymaking. Policymaking is not just the result of a neutral effort by the state to promote welfare; it also reflects the self-interest of some groups, and typically the most powerful, well established and concentrated groups will tend to have an advantage over other groups. Small numbers of polluters typically have more opportunity to band together as lobbyists than the much more numerous, dispersed and unorganized victims of pollution (Damania and Fredriksson 2000). One should however neither underestimate the capacity for NGOs to capture and represent the interests of these victims, nor forget the fact that there may be many "polluters" who are also unorganized and relatively powerless.

A large proportion of the articles on lobbying are concerned with the effect of lobbying on the political system or on trade related issues. The number of articles on taxation is more limited.[9] Interesting exceptions include Doi et al. (2002) who study the choice between using increased tax revenues to either reduce the public debt or increase spending. Fredriksson and Gaston (1999) look at the role of trade unions as lobbyists and show that they can be in favor of eco-taxes for purely selfish labor-market reasons. Svendsen (1999) analyzes the distinct interests and preferences of environmentalists and of different categories of business (electricity producing and electricity consuming). All the strongest lobby groups in this study were found to prefer grandfathered permits to taxes.

In models of vote-maximization such as Hettich and Winer (1988), assumptions such that successful politicians will avoid over-taxing their voters are made. However, the state needs money and something has to be taxed, whether it is income, wealth, property or certain consumption

[9] A search of the literature (through the database "Econlit") turns up 143 "hits" for lobbying and voting, 90 for lobbying and trade but only 18 for lobbying and tax. The numbers of articles on energy, transport and lobbying was even smaller.

goods. Clearly, consumers may resist any tax, and fuel taxes are likely to be resisted more if those who bear the greatest share have more political power than other groups. The political attitudes towards both mobility and environmental pollution may be decisive, and the costs and benefits depend, among other factors, on population density. Goel and Nelson (1998) is the only study, to our knowledge, that empirically studies the determination of fuel taxes within a vote-maximization framework. They find, consistent with Hettich and Winer (1988), that *nominal rates tend to be adjusted to inflation, and higher real (pre-tax) prices of gasoline lead to lower taxes.* Both these factors suggest that politicians "tend to seize the opportunity" to raise taxes whenever it is relatively easy – in these cases because the tax is masked either by the rise of other prices or by the fall in gas prices themselves. Their results also indicate that the presence of significant oil industries leads to lower gas taxes,that higher highway tolls are associated with lower taxes, that higher population densities appear to have resulted in higher taxes before 1981 and in lower taxes thereafter, and that higher compliance with environmental standards implies higher taxes. In the Empirical Results section below, we estimate a simple political model of gasoline taxation following from the work of Hettich and Winer (1988) and Goel and Nelson (1998).

3 Models of Causality in the Market for Transport Fuel

A full-scale model of the demand and supply of transport fuels is fairly large and difficult to estimate for a number of reasons. There are long time lags involved on both the supply and demand side. Energy demand and supply both require heavy capital with a long lifetime and with fairly fixed technology once it is in place. This creates inertia and long processes of adaptation to changing market conditions. Furthermore, there are complex patterns of joint production among the petroleum products and substitutability between these and other energy carriers. To build a model of energy taxation that takes lobbying properly into account requires a great deal of institutional knowledge of each specific country and time period. Both of these sets of models need to deal with highly imperfect competition and considerable power (economic and political) among the suppliers and perhaps among some of the consumers too. To build a joint model is beyond the scope of the present paper, in which we are merely paving the way for such future work by providing a measure of the relative strength of the different forces at play. We will however carry out causality tests – or more formally, Granger tests of non-causality – to ascertain the existence of a "political" effect of consumption levels on taxes.

One may see this as a simple means of testing our hypothesis on a strongly reduced form of the ideal model. There is a large body of literature that tests for causality among economic variables. A number of articles, such as Hooker (1996), Chang et al. (2001), Asafu-Adjaye (2000) and Stern (1993) test the directions of causality between energy variables (consumption or price levels) and a series of macroeconomic variables such as income, growth, employment or inflation. All these studies show that the energy variables can cause changes in the macroeconomic variables.

4 Data

For practical reasons (space and data availability) we have chosen the most parsimonious model, and data that is reasonable given our purpose. We have restricted our sample to 22 rich OECD countries, as classified by the World Bank,[10] and have used data on price and tax (weighted price/tax of unleaded and leaded gasoline), total gasoline consumption (IEA, 1994, 1997, 1998, and 2000) and GDP (World Development Indicators, 2002) for 1978-2000 (when testing for causality we exclude 1978-1981 from the data due to the oil crisis). Prices, taxes and GDP series are adjusted for purchasing power.

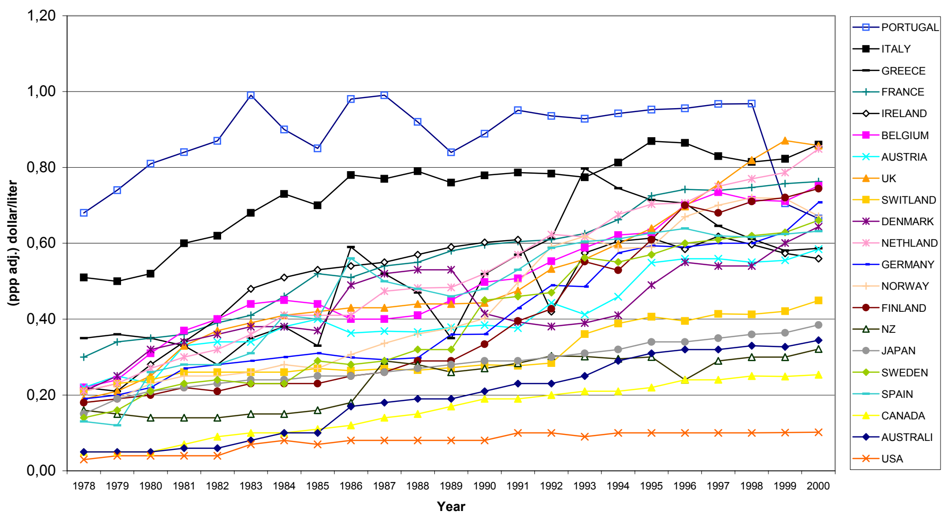

Figure 1. Tax on gasoline - development over time.

The development of gasoline taxes over time can be seen in Figure 1.[11] Almost all of them increased, except in Portugal where the tax varied, although at very high levels (the highest in the sample, which of course

[10] World Development Indicators (2002) in this category include Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom and USA, of which we exclude Iceland due to lack of data, and Luxembourg due to its special character (Luxembourg has a large inflow of cars coming from adjacent countries to fill up with cheaper gasoline).

[11] The countries are listed in descending order according to initial tax in 1978. The initial taxes for the respective countries were: USA 0.03, Australia 0.05, Canada 0.05, Spain 0.13, Sweden 0.14, Japan 0.15, NZ 0.16, Finland 0.18, Norway 0.18, Germany 0.19, Netherlands 0.19, Denmark 0.21, Switzerland 0.21, UK 0.21, Austria 0.22, Belgium 0.22, Ireland 0.22, France 0.30, Greece 0.35, Italy 0.51, and Portugal 0.68.

is partly due to the purchasing power conversion). Italy is another high tax country, while the US had the lowest gasoline tax over time together with Canada and Australia. The corresponding consumption pattern (gasoline consumption as a share of GDP) decreased over time for all countries except Portugal and Greece (their consumptions as a share of GDP were fairly stable). Hence, the trend is an increasing gasoline tax over time, but the levels differ significantly among countries. We present the data on consumer prices and consumption levels in Figure 2 (summary statistics are provided in Table A1 of the Appendix).

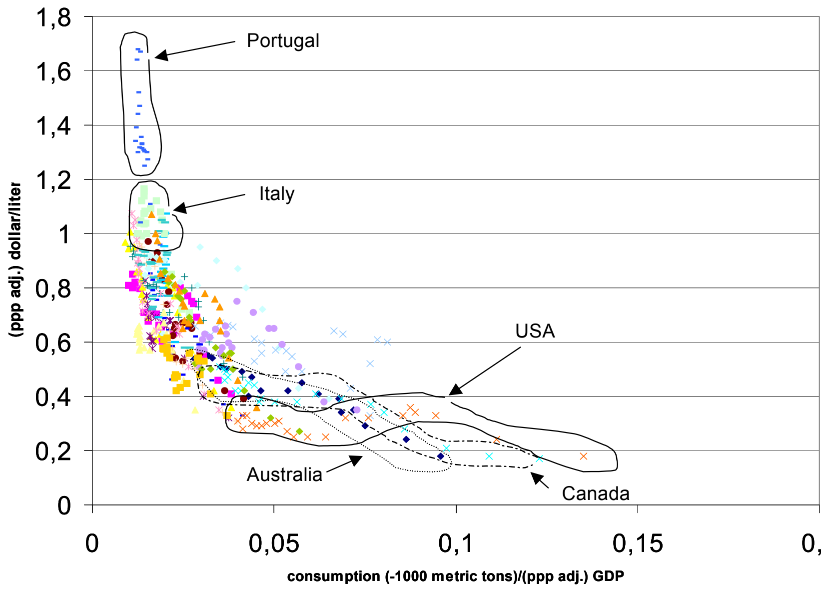

Figure 2. Consumption as share of GDP and price of gasoline (1978-1999).

One attractive feature of Figure 2 is that it shows explicitly the connection - but also the distinction - between the cross-sectional and temporal dimensions of our data. For all the countries in our data set there is a general movement in our figure towards lower consumption intensities and higher prices. This is of course captured by the negative price elasticities in the time series data. A large part of the variation is however between countries, which implies that panel data analyses may give higher price elasticities (which is reflected in our data by a price elasticity of around minus one).

5 Empirical Results

5.1 Granger Causality for Gasoline Consumption

The Granger non-causality tests are based on the simple notion that cause precedes effect. The reason the tests are referred to as non-causality tests is that non-causality is the only hypothesis possible to test in an econometric framework (see Bishop, 1979; Kennedy, 1992; and Greene, 1993). This is also the reason that we refer to *Granger-causing*, rather than just causing.

The Granger non-causality tests are based upon Granger's (1969) original idea that a necessary condition for causality is that the *lagged* parameter of the independent variable must be able to predict the current dependent variable – measured by the significance of the parameter and whether adjusted R^2 increases when including the lagged value of the independent variable. The original Granger non-causality test was developed for time-series data. In this paper we use panel data, which complicates our econometric analysis (discussed further below). We estimate for the original Granger non-causality test Model (1) and (2), where i=country and t=year.

Q as dependent variable:

$$Q_{i,t} = \alpha_i + \beta_1 Q_{i,t-1} + \varepsilon_{i,t} \tag{1a}$$

$$Q_{i,t} = \alpha_i + \beta_1 Q_{i,t-1} + \beta_2 P_{i,t-1} + \varepsilon_{i,t} \tag{1b}$$

P as dependent variable:

$$P_{i,t} = \alpha_i + \beta_3 P_{i,t-1} + \varepsilon_{i,t} \tag{2a}$$

$$P_{i,t} = \alpha_i + \beta_3 P_{i,t-1} + \beta_4 Q_{i,t-1} + \varepsilon_{i,t} \tag{2b}$$

In Models (1) and (2) we analyze the causal relationship between the price of gasoline (P) and the specific consumption of gasoline (Q). The specific consumption of gasoline Q is defined as gasoline consumption divided by income, $Q = G/Y$. In most models of the market for transport fuel, demand is assumed to be a function of price and income, $G = f(Y, P)$. The models of Granger causality we are dealing with here are however difficult to estimate in a model with two right hand side variables, since the symmetry is then lost. Fortunately, we know from a very large number of studies that have been carried out, that the long-run income elasticities of gasoline demand are close to unity.[12] We have therefore assumed, for the sake of this test, that they are unitary, in which case the function $Q = G/Y = f(P)$ can serve as a reduced form of the true function $G = f(Y, P)$. Our model is thus one of demand intensity rather than of fuel demand *per se*, but if the assumption of unitary income elasticity is accepted then there is no important distinction between the two. All of the variables mentioned are in logarithms and the models are thus constant elasticity models.[13]

A necessary condition for Q (P) to cause P (Q) is that lagged values of the independent variable Q (P) must be able to predict P (Q), i.e. that the parameters are significantly different from zero. From the tests we can conclude that *(i)* price Granger causes consumption, *(ii)*

[12] See Dahl and Sterner (1991a and b) and Sterner and Franzén (1994).

[13] This is the most conventional assumption in fuel demand models as shown by the surveys mentioned above.

consumption Granger causes price, *(iii)* there is no causal relationship, or that *(iv)* a bidirectional relationship exists.

When estimating a dynamic panel (i.e. we have a lagged dependent variable on the right hand side), the estimators and significances are biased upwards (Verbeek, 2000). One way of dealing with such a problem is to estimate an instrumental variable for the lagged dependent variable. Following this, we have estimated two instrumental variables: one for lagged price, and one for lagged consumption.[14] Using this approach we "save" observations compared to estimating the instrumental variable as a function of the dependent variable two periods lagged.[15] The instrumental variable estimation yields consistent estimates, even though the estimates are not efficient (Baltagi, 2001). Using the instrumental variables, we estimate a fixed effects model.[16] We disregard the years 1978-1981, due to the special characteristics of that period (the oil crisis). The presented estimations do appear to have some autocorrelation, but given the purpose of this simple model (to get an indication of whether or not causality could run in the direction from consumption to price), we refrain from using more sophisticated econometric methods.[17] The development in recent literature on panel data using techniques from time series analysis is fairly limited. Problems concerning unit

[14] The instrumental variable for lagged price is estimated as a function of general taxes, specific taxes on services and goods, CPI, and a time trend. The instrumental variable for lagged consumption is estimated as a function of total amount of passenger cars, income and a time trend. (The tax data is collected from OECD, Revenue Statistics, Ed. 1999; and passenger cars from World Road Statistics 2000).

[15] Still, if the lagged dependent variable (one period) is estimated as a function of the dependent variable (two periods), then the estimates are roughly the same as when using the instrumental variables described in Footnote 14. Using the lagged dependent variable (two periods) as an instrumental variable yields a price elasticity equal to -0.92 for long run gasoline demand.

[16] Individual country intercepts are not presented in this article, but are available from authors upon request.

[17] The estimated autocorrelations of order one e(i,t) were: Model 1a): 0.47, 1b) 0.53; 2a) 0.71; 2b) 0.74. Values close to zero imply low autocorrelation.

roots, spurious regressions and cointegration could arise in panel data estimations, especially when data is available for long time series. Still, literature and tests for these problems are scarce (Verbeek, 2000). For a thorough overview of dynamic data models, see Baltagi (2001). The results are as follows (t-values are displayed in parentheses).

Price Granger causes Consumption:

$$Q_{i,t} = \alpha_i + \underset{(7.29)}{0.57} Q^{iv}_{i,t-1}$$

$$Q_{i,t} = \alpha_i + \underset{(6.01)}{0.48} Q^{iv}_{i,t-1} - \underset{-6.07}{0.52} P_{i,t-1}$$

Consumption Granger causes Price:

$$P_{i,t} = \alpha_i + \underset{(4.67)}{0.33} P^{iv}_{i,t-1}$$

$$P_{i,t} = \alpha_i + \underset{(2.24)}{0.14} P^{iv}_{i,t-1} - \underset{-8.08}{0.26} Q_{i,t-1}$$

Our results show that the conventional model cannot be rejected (that price causes consumption). There is however also evidence of the "reverse" causality, shown by the significant parameter on consumption. Furthermore, as can be seen we find an increase in adjusted R^2 in both models. The results thus point to a bidirectional relationship between gasoline price and gasoline consumption.

5.2 Political Model of Gasoline Consumption

Since we have found indications that gasoline consumption Granger causes the price of gasoline and since taxes are the most obvious component of the price for this type of effect, it is natural to continue by investigating whether gasoline consumption is a determinant of gasoline taxation. Furthermore, given our descriptive and empirical evidence, we argue that consumption of gasoline could be used as a lobby indicator. Following the work by Hettich and Winer (1988) and Goel and Nelson (1998), we test the hypothesis that the tax on gasoline is dependent on the price of gasoline (net of tax), and add consumption of gasoline as a crude measure of lobbying (we also include a time trend). The Granger non-causality test indicates that price affects consumption, but also that consumption affects price. Following this, tax is not just a function of consumption, but consumption is also affected by taxation i.e. we have an endogeneity problem when including gasoline consumption as an explanatory variable for gasoline taxation. Therefore, we use the same approach as in the preceding section to estimate an instrumental variable for consumption (gasoline consumption is estimated as a function of number of passenger cars). Another way to deal with this would be to expand the analysis of lobby groups and the determinants of gasoline taxation by including population density, road tolls, oil refinery capacity, number of public buses, road expenditures and other variables that probably better reflect the power of lobby groups and political economy. This is left for future research.

The model is estimated as a panel with fixed effects, with ppp adjusted prices and taxes, which means that we do not include the possibility of “money illusion” (the specific country effects are available from the authors upon request). The model to be estimated is (all the variables mentioned are in logarithms, except years):

$$Tax_{i,t} = \alpha_i + \beta_5 (net\ price)_{i,t} + \beta_6 (gasoline\ consumption)_{i,t} + \beta_7 (year) + \varepsilon_{i,t}.$$

Note that the consumption variable is consumption per capita.

Our results are as follows:

$$Tax_{i,t} = \alpha_i - \underset{(-1.48)}{0.73}(net\ price)_{i,t} - \underset{(-7.82)}{0.97}(gasoline\ consumption)_{i,t} + \underset{(24.57)}{0.62}(year).$$

The estimation results[18] show that net price has a negative effect on tax. This lends support to the hypothesis that policy makers raise taxes "opportunistically" in moments when prices (net or World Market) fall, and that they tend to appease protests against high fuel prices by lowering taxes when net prices rise. Of particular interest for this paper is the fact that consumption of gasoline has a negative significant effect on gasoline tax for all countries, i.e. the higher the consumption, the lower the gasoline tax. Since we are interpreting consumption as a proxy for lobbying, this again lends some support to the notion that higher (lower) levels of consumption lead to more lobbying in favor of lower (higher) taxes, and thus, to some extent the policies become self-reinforcing since higher (lower) consumption leads to lower (higher) taxes, lower (higher) prices and higher (lower) consumption.

6 Interpretation and Discussion

The US (together with Australia and Canada) has a very high consumption (relative consumption intensity) per capita together with low fuel prices. This suggests that the most efficient strategy for improving fuel efficiency, and at least for reducing carbon emissions, would be to increase fuel prices in these countries. Yet after all these studies, a number of attempts to increase gas taxes in the US and oil taxes at a general level in the EU, have failed. One should also note that a country such as the US indeed experienced very significant reductions in fuel inten-

[18] Adjusted R-square=0.94, and the estimated autocorrelation of order one e(i,t)=0.74.

sity during the observed period. The reason is that the fuel efficiency of US vehicles were influenced by many factors. In addition to actual local prices, there are the "expected prices" which were very significant, at least during the oil crises of the 1970s. International prices may also have affected the development of more energy efficient engine technology, and finally, some quite severe regulatory measures and other policy instruments such as the CAFÉ standards and the fines for manufacturers, have also helped reduce fuel use by the US vehicle stock.

It is, however, still true that US gas consumption is high and it is natural and quite well known that there is quite a vociferous popular opinion against fuel taxes. We have mentioned a number of factors that are probably important in this context: the overall negative attitude to "big government" and taxation, the existence of strong automobile and oil industry lobbies and the low population densities of many regions making long distance commuting common even at the "local" level. The fact that public transport is less common is related to this low density and serves as both a cause and an effect of the dominance of the private car. This is self-reinforcing since the small number of people traveling by and working in public transport leads to weak lobbies and opinions in favor of public transport. Since the private automobile is such a necessity and public transport sometimes is unavailable, it is likely that the US is one of the countries where fuel taxation is somewhat regressive[19] which of course makes many politicians wary about the issue.

In countries such as Italy and Portugal however, the balance of inter-

[19] According to Poterba (1991) it is regressive in the US although this has been criticized by Chernick and Reschovsky (1997) who show that there is almost no regressivity even in the US if expenditure rather than income data are used. In addition, a full analysis should consider the fact that it is frequently the poor who are more affected by the pollution such as smog since they tend to have less means of self-protection (medical expenditures and screening, choice of domicile in areas with cleaner air, etc.).

ests may be rather different. For example, there is little oil production in Italy itself. A reasonable strategy to keep oil imports down is to conserve energy by raising its price. The fact that this strategy happens to derail some of the resource rent from foreign producers to the national treasury can hardly be a problem. Most motorists have smaller vehicles and live closer to their jobs compared to the US. They have had high fuel prices for a very long time and have adapted accordingly,and therefore have not much to lose from even higher taxes. Furthermore, the owners, employees and subcontractors of Fiat should know that the market share of the small Fiats depends positively on high fuel prices. The employees of the public transport sector benefit as well. In Italy, income taxes have proven notoriously difficult to collect, and this is perhaps the real, pragmatic reason for high gasoline taxes. Gasoline has to be controlled anyhow (since it is flammable, etc.) making gas taxes an easy and important source of tax revenue for the state. Thus implicitly, anyone who feels that the state needs its revenues - either because they appreciate the state's services or maybe because they are employed by the state - may feel some degree of understanding if not sympathy for the fuel taxes.

The tradition of earmarking gas taxes is also quite distinct in different countries and probably influences the support for or opposition against a tax. In the US most fuel taxes are in fact earmarked for highway construction. This may appear odd to economists used to preaching the virtues of not earmarking, but has general political support in the US. In the UK efforts to "hypothecate" the petrol taxes are regularly vilified, and in France too, the principal of the unified budget has dominated political and economic thinking[20] and the ministry of finance regularly

[20] See Hayward (1983), Dunn(1981) and Nivola and Crandall (1995).

uses transport related taxes for other purposes. In the US when Nixon sought to impound some highway funds in 1972, the states challenged this in a lawsuit and won.[21] Two years later Congress enacted legislation forbidding such impoundments.

It is common that countries with important auto manufacturing firms like the USA, Germany, France, Italy, Sweden and the UK have low or zero excise taxes on motor vehicles, while countries like Denmark, Finland, Greece, Ireland, and Portugal that lack such industries have very sizeable excise taxes (e.g. a 100% or more tax in Denmark and Finland). We find a similar, strong variation in yearly registration fees. One of the strongest lobbying groups is the auto industry, and of course in countries where registration fees are low and the number of vehicle owners is large they are even stronger. In the countries lacking a vehicle industry and where prohibitive vehicle taxes restrict the number of vehicle owners, the lobby is weaker. Presumably this means that the demand for public transport is higher, and that also has consequences.

The empirical evidence shows the relevance of looking into the political features of gasoline pricing in more detail than has previously been done. Naturally, there is simultaneity in the determination of price and consumption of any good, and the parsimonious approach chosen in this paper does not do this fact sufficient justice. Acknowledging the shortcomings of our model and the Granger-test, we still argue that by using non-causality tests, we have provided new evidence of the rationale and importance of studying the political environment in the taxation of gasoline.

The conventional wisdom of the hundreds of studies on fuel demand is that demand is driven by prices which in turn are driven by politically

[21] State Highway Commission of Missouri v. Volpe (1973).

decided taxes together with international oil prices, both of which can be treated as exogenous. Our results have a number of consequences both for the way we ought to model fuel demand and for the political economy of instrument design in the area of vehicle fuels. Our empirical results indicate that standard demand theory is not sufficient for insightful policy making.

What conclusions are we to draw from this that might also apply in more general terms to a number of other areas of environmental and energy policy? Clearly the fuel market has both a demand side and a supply side. The supply side is technically and politically complicated as we have mentioned, and on top of this we are now arguing that there is most likely a politically and endogenously determined tax rate. The ideal would perhaps be to model this as a joint political-economical supply and demand model, which may be a goal for future research. Our results suggests that the cross-sectional studies, which provide the highest price elasticity estimates, might be somewhat overstated. The conclusion of this would not be that demand is inelastic, but just that it might be a little less elastic than some of the cross-sectional data suggests. Furthermore, taking the endogeneity of the tax rate into account would help reconcile the cross-sectional evidence with the time series evidence mentioned earlier.

Unfortunately, our results also imply that we are beginning to understand the difficulties of implementing higher gasoline taxes in those countries where they are most needed – the countries with high consumptions. However, small tax increases in these countries have two positive effects: First, through the demand side, even though they are small they cause some demand side response. Second, they may actually weaken the resistance to future increases in tax by starting to build some form of constituency supporting higher prices, and by weakening those who are very heavily dependent on low fuel prices.

References

[1] Asafu-Adjaye, J. (2000). "The Relationship between Energy Consumption, Energy Prices and Economic Growth: Time Series Evidence from Asian Developing Countries", *Energy Economics*, December, v. 22, iss. 6, pp. 615-25.

[2] Baltagi, Badi H. (2001). *Econometric Analysis of Panel Data*, Wiley, Chichester, England.

[3] Baltagi, Badi H. and Griffin, James M. (1983). "Gasoline Demand in the OECD: An Application of Pooling and Testing Procedures", *European Economic Review*, 22 (2) pp. 117-137.

[4] Becker, Gary S. (1983). "A Theory of Competition among Pressure Groups for Political Influence", *Quarterly Journal of Economics*, August 1983, vol.98(3), pp.371-400.

[5] Bishop, Robert V. (1979). "The Construction and Use of Causality Tests", *Agricultural Economics Research*, 31(4).

[6] Chang, T, W. Fang and L. Wen (2001). "Energy Consumption, Employment, Output, and Temporal Causality: Evidence from Taiwan Based on Cointegration and Error-Correction Modelling Techniques", *Applied Economics*, June, v. 33, iss. 8, pp. 1045-56.

[7] Chernick, H. and A. Reschovsky (1997). "Who Pays the Gasoline Tax?", *National Tax Journal*, June, v. 50, iss. 2, pp. 233-59.

[8] Dahl, Carol and Thomas Sterner. (1991a). "A Survey of Econometric Gasoline Demand Elasticities", *International Journal of Energy Systems*.

[9] Dahl, Carol and Thomas Sterner. (1991b). "Analyzing Gasoline De-

mand Elasticities: A Survey", *Energy Economics*, 13(3), July, pp 203-10.

[10] Damania, R. and Per G. Fredriksson (2000). "On the Formation of Industry Lobby Groups", *Journal of Economic Behavior and Organization*, April, v. 41, iss. 4, pp. 315-35.

[11] Doi, T., T. Ihori, and H. Kondo (2002). "Government Deficits, Political Inefficiency, and Fiscal Reconstruction in Japan", *Annals of Economics and Finance*, May 2002, v. 3, iss. 1, pp. 169-83.

[12] Dunn, James A. Jr. (1993). "The Politics of Motor Fuel Taxes and Infrastructure Funds in France and the United States", *Policy Studies Journal*, Summer vol.21.

[13] European Commission COM(95)691 (1995). *Towards Fair and Efficient Pricing in Transport. Policy Options for Internalising the External Costs of Transport in the European Union.*

[14] Fredriksson, Per G. (1997). "The Political Economy of Pollution Taxes in a Small Open Economy", *Journal of Environmental Economics and Management*, 33(1), May 1997, pages 44-58.

[15] Fredriksson, Per G. (1998). "Environmental Policy Choice: Pollution Abatement Subsidies", *Resource and Energy Economics*; 20(1), March 1998, pages 51-63.

[16] Fredriksson, Per G. (2001). "How Pollution Taxes May Increase Pollution and Reduce Net Revenues", *Public Choice*, April, v. 107, iss. 1-2, pp.65-85.

[17] Fredriksson, Per G. and N. Gaston (1999). "The 'Greening' of Trade Unions and the Demand for Eco-taxes", *European Journal of Political Economy*, November v. 15, iss. 4, pp.663-86.

[18] Goel, R. and M. Nelson (1999). "The Political Economy of Motor Fuel Taxation", *The Energy Journal*, 20(1), pp. 3—59.

[19] Granger, C.W.J. (1969). "Investigating Causal Relations by Econometric Models and Cross-Spectral Methods", *Econometrica*, August 1969, Vol.37(3), pp.424-438.

[20] Greene, William H. (1993). *Econometric Analysis* (2nd edition), Prentice-Hall, Englewood Cliffs, New Jersey, USA

[21] Grossman, M.G. and E. Helpman (1994). "Protection for Sale", *American Economic Review*, Vol.84(4), pp. 833—850.

[22] Hayward, J. E. S. (1983). *Governing Finance: The One and Indivisible Republic*, 2nd edition, London: Weidenfeld and Nicolson.

[23] Hettich W. and Winer S.L. (1988). "Economic and Political Foundations of Tax Structure", *American Economic Review*, Vol.78(4), pp. 701—712.

[24] Hooker, M. (1996). "What Happened to the Oil Price-Macroeconomy Relationship?", *Journal of Monetary Economics*, October v. 38, iss. 2, pp. 195-213.

[25] International Energy Agency (1994). *Oil and Gas Information 1994*, Organization for Economic Cooperation and Development, Paris, France.

[26] International Energy Agency (1997). *Oil Information 1997*, Organization for Economic Cooperation and Development, Paris, France.

[27] International Energy Agency (1998). *Oil Information 1970-1997* (Diskette Service Documentation), Organization for Economic Cooperation and Development, Paris, France.

[28] International Energy Agency (2000). *International Energy Prices and Taxes*, Organization for Economic Cooperation and Development, Paris, France.

[29] Johansson, Olof and Lee Schipper (1997). "Measuring the Long-Run Fuel Demand of Cars: Separate Estimations of Vehicle Stock,

Mean Fuel Intensity, and Mean Annual Driving Distance", *Journal of Transport Economics and Policy*, 31(3), September 1997, pages 277-92.

[30] Kennedy, Peter (1992). *A Guide to Econometrics* (3rd edition), MIT Press, Cambridge, USA.

[31] Nivola, P.S. and R.W. Crandall (1995). *The Extra Mile – Rethinking Energy Policy for Automotive Transportation*, Washington D.C.: The Brookings Institute.

[32] Poterba, J. M. (1991). "Is the Gasoline Tax Regressive?" in Bradford, D., ed., *Tax Policy and the Environment 5*, NBER (National Bureau of Economic Research), MIT Press, pp.145—64.

[33] Stern, D. (1993). "Energy and Economic Growth in the USA.: A Multivariate Approach", *Energy Economics*, April, v. 15, iss. 2, pp. 137-50.

[34] Sterner, T and M. Franzén (1994). "Long-run Demand Elasticities for Gasoline", with M Franzén, in *Global Warming and Energy Elasticities*, ed by Terry Barker, Nick Johnstone and Paul Ekins, Routledge.

[35] Svendsen, G. (1999). "U.S. Interest Groups Prefer Emission Trading: A New Perspective", *Public Choice*, October, v. 101, iss. 1-2, pp. 109-28.

[36] Verbeek, M. (2000). *A Guide to Modern Econometrics*, John Wiley & Sons, Ltd. England, 2000.

[37] World Development Indicators (2002). CD-ROM, World Bank, Washington D.C., 2002.

7 Appendix

Table A1. Summary statistics.

	Mean	Std.Dev.	Skewness	Kurtosis	Minimum	Maximum
Data used in testing for casuality (Years 1982-1999)						
Price* (ppp adj.) dollar/litre	0.73	0.25	0.80	4.44	0.25	1.68
Consumption of gasoline (-000 metric tons)	23510.9	64240.5	4.12	18.52	810	348715
GDP (ppp adj. Dollars, 10^{11})	7.27	13.35	3.54	16.68	0.1	84.27
Number of observations						357
Data used in "political model" (Years 1978-1999)						
Tax* (ppp adj.) dollar/litre	0.44	0.22	0.41	2.60	0.04	0.99
Net price* (ppp adj.) dollar/litre	0.28	0.10	2.12	9.18	0.15	0.79
Number of observations	388					

*All prices and taxes are weighted using the consumption shares for leaded and unleaded gasoline.

Paper 4

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.

JEL classification: D62, D91, H21.

Keywords: Optimal taxation; environment; addiction; time-inconsistency; second-best.

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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:

$$t^1a^1 + n^1 = m^1 + y^1 \quad (5)$$

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

$$t^2a^2 + n^2 = m^2 + y^2 \quad (6)$$

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.

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

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):

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

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

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

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

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.

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

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.

References

[1] Becker, Gary S. and Kevin M. Murphy (1988). "A Theory of Rational Addiction", *Journal of Political Economy*, Vol. 96(4), pp. 675-700.

[2] Becker, Gary S., Michael Grossman, and Kevin M. Murphy (1991). "Rational Addiction and the Effect of Price on Consumption", *The American Economic Review*, May 1991, Vol. 81(2), pp. 237-241.

[3] Becker, Gary S., Michael Grossman, and Kevin M. Murphy (1994). "An Empirical Analysis of Cigarette Addiction", *American Economic Review*, June 1994, Vol. 84(3), pp. 396-418.

[4] Boyer, Marcel (1983). "Rational Demand and Expenditure Patterns under Habitformation", *Journal of Economic Theory*, 1983, Vol. 31, pp. 27-53.

[5] Carrasco, Raquel, J Maria Labeago Azcona, and J David López Salido (2002). "Consumption and Habits: Evidence from Panel Data", *Centre for Economic Policy Research*, Discussion Paper No.3520, November 2002.

[6] Chaloupka, Frank (1991). "Rational Addiction and Cigarette Smoking", *The Journal of Political Economy*, August 1991, Vol. 99(4), pp. 722-742.

[7] Frederick, Shane, George Loewenstein, and Ted O'Donoghue (2002). "Time Discounting and Time Preference: A Critical Review", *Journal of Economic Literature*, June 2002, Vol. XL, pp. 351-401.

[8] Gorman, W.M (1967). "Tastes, habits and choices", *International*

Economic Review, June 1967, Vol. 8(2), pp.218-222.

[9] Griffiths, Mark (1997). "Exercise addiction: A case study", *Addiction Research*, May 1997, Vol. 5(2), pp.161-168.

[10] Griffiths, Mark (2000). "Does Internet and computer 'addiction' exist? Some case study evidence", *CyberPsychology and Behaviour*, April 2000, Vol. 3(2), pp.211-218.

[11] Gruber, Jonathan and Botond Köszegi (2001). "Is Addiction 'Rational'? Theory and Evidence", *Quarterly Journal of Economics*, November 2001, Vol. 116(4), pp. 1261-1303.

[12] Gruber, Jonathan and Botond Köszegi (2002). "A Theory of Government Regulation of Addictive Bads: Optimal Tax Levels and Tax Incidence for Cigarette Excise Taxation", *National Bureau of Economic Research*, Working paper 8777, February 2002.

[13] Gärling, Tommy, Daniel Eek, Peter Loukopoulos, Satoshi Fujii, Olof Johansson-Stenman, Ryuichi Kitamura, Ram Pendyala, and Bertil Vilhelmson (2002a). "A Conceptual Analysis of the Impact of Travel Demand Management on Private Car Use", *Transport Policy*, Volume 9(1), January 2002, pp. 59-70.

[14] Gärling, Tommy, Anita Gärling, and Peter Loukopoulos (2002b). "Forecasting Psychological Consequences of Car-Use Reduction: A Challenge to an Environmental Psychology of Transportation", *Applied Psychology*, January 2002, Vol. 51(1).

[15] Laibson, D. (1997). "Golden Eggs and Hyperbolic Discounting", *Quarterly Journal of Economics*, Vol. 112, pp. 443-477.

[16] Loewenstein, George (1992). *"The Fall and Rise of Psychological Explanations in the Economics of Intertemporal Choice"*, in George Loewenstein and Jon Elster, eds., Choice over time. New York: Russell Sage Foundation, 1992, Vol. 65(2), pp. 3-34.

[17] McIlwraith, R.D. (1998). "I'm addicted to television: The personality, imagination, and TV watching patterns of self identified TV addicts", *Journal of Broadcasting and Electronic Media*, Summer 1998, Vol. 42(3), pp.371-386

[18] O'Donoghue, Ted and Matthew Rabin (1999). "Doing it Now or Later", *American Economic Review*, March 1999, pp. 103-124.

[19] Orphanides, Athanasios, David Zervos (1998). "Myopia and Addictive Behaviour", The Economic Journal, January 1998, Vol. 108, pp.75-91.

[20] Perry, Marty J. and John F. Barry (1998). "The gay male client in sex addiction treatment", *Sexual addiction and compulsivity*, 1998, Vol. 5(2), pp.119-131.

[21] Pigou, A.C. (1946). *The Economics of Welfare*, 4th edition, London, Macmillan

[22] Phelps, E. S. and Robert A. Pollak (1968). "On Second-Best National Saving and Game-Equilibrium Growth", *Review of Economic Studies*, April 1968, Vol. 35(2), pp. 185-199.

[23] Phlips, Louis (1983). *Applied Consumption Analysis.* Advanced Textbooks in Economics, vol.5. Revised Edition. Amsterdam, North-Holland, 1983.

[24] Pollak, Robert A (1968). "Consistent Planning", *Review of Economic Studies*, April 1968, 35(2), pp.201-08.

[25] Pollak, Robert A (1970). "Habit formation and dynamic demand functions", *Journal of Political Economy*, 78 (1970), pp.745-763.

[26] Pollak, Robert A (1976). "Habit formation and long-run utility functions", *Journal of Economic Theory*, 13(1976), pp.272-297.

[27] Rabin, Matthew (1998). "Psychology and Economics", *Journal of Economic Literature*, March 1998, Vol.36, Issue 1, pp. 11-47.

[28] Reser, Joseph P. (1980). "Automobile addiction: Real or imagined?", *Man Environment Systems*, Sep-Nov 1980, Vol. 10(5), pp.279-287.

[29] Rorlich, Jay B. (1981). "The dynamics of work addiction", *Israel Journal of Psychiatry and Related Sciences*, 1981, Vol. 18(2), pp.147-156.

[30] Ryder, Harl E. Jr. and Geoffrey M. Heal (1973). "Optimal Growth with Intertemporally Dependent Preferences", *The Review of Economic Studies*, January, 1973, Volume 40, Issue 1, pp. 1-31.

[31] Stigler, George J. and Gary S Becker (1977). "De Gustibus Non Est Disputandum", *American Economic Review*, March 1977, v.67, iss. 2, pp. 76-90.

[32] Strotz, Robert (1956). "Myopia and Inconsistency in Dynamic Utility Maximization", *Review of Economic Studies*, 1956, 23(3), pp.165-80.

[33] Vanderheyden, P.A. (1999). "Religious addiction: The subtle destruction of the soul", *Pastoral Psychology*, March 1999, Vol. 47(4), pp.293-302.

Paper 5

Habit Formation in Environmental Quality: Dynamic Optimal Environmental Taxation

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Abstract

In this article we propose a model in which individuals experience habit formation in environmental quality. Further, a consumption good causes a negative external effect on the environment. A benevolent social planner maximize utility given the negative effect of the consumption good on the environment, taking into account that there is habit formation in environmental quality. Given a simple model we show that the level and time path of the corresponding optimal environmental tax is affected by the assumption of habit formation; more specifically the stronger the habit, the higher the optimal level of environmental quality in steady state, and the faster the transition towards the steady state tax level. Furthermore the initial value of the habit stock is of crucial importance for the time path of the tax. Also, we solve for, and analyze, dynamics and the existence and characteristics of equilibria in the model and discuss how the characteristics of habit formation affect steady state.

JEL classification: C61, D90

Keywords: Habit formation; environment; intertemporal choice; transitional dynamics.

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1 Introduction

It is not a controversial statement that the state of the environment (environmental quality) affects utility, but how and through which mechanisms, are subject to more discussion. Could it be that the utility derived from environmental quality is not only dependent on the current state of environmental quality, but rather on the difference between the current state of the environment and some experience of past states of environmental quality? If this is true, the question arises about how we should model the "experience of past states of environmental quality." We propose that one way to model this is to treat the "experience of past states of environmental quality" as a habit stock. Hence, the link between the utility derived from the current state of the environment and past states is habit formation. This implies that environment is a habitual "good." The definition of a habitual good, which we use throughout the paper, is summarized succinctly by Pollak (1970). The author defines a habit such that *(i)* past consumption influences current preferences and hence, current demand and *(ii)* a higher level of past consumption of a good implies, *ceteris paribus*, a higher level of present consumption of that good. The incorporation of habit formation in an environmental framework has not been well investigated, and in this article we aim at shedding some light on whether or not it is of importance to account for habit formation when dealing with environmental problems.

Our contribution to the literature is firstly that we model habit formation in a good that is of a public good character (environmental quality), and secondly that we analyze how this assumption affects an optimal environmental tax, the time-path of such a tax, and environmental quality in steady state. As is shown, the level and time path of the tax are affected by the assumption of habit formation: the stronger the habit, the higher the optimal quality of environment in steady state, and the faster the transition towards the steady state tax level. Furthermore, the initial value of the habit stock is of crucial importance for the time path of the tax. An initially low habit stock corresponds to a decreasing tax over time, and an initially high habit stock corresponds to an increase in tax over time.

Given that we have habit formation in environmental quality, we have intertemporally dependent preferences by assumption, and this is nothing new *per se*. A significant share of the literature on growth, for example, has over time dealt with optimal growth paths under different forms of utility functionals. Kurz (1968) develops a model of economic growth incorporating wealth effects. This is analogous with many of the growth models incorporating environment or pollution as an argument in the utility function (see for example Beltratti, 1996; Gradus and Smulders, 1993; and Smulders, 1995). The formal structure of such models is similar to the structure of the model proposed in this paper. The main difference between these models and the one presented in this article is the explicit modeling of habit formation, i.e. we include two parameters that reflects the degree of habit formation and focus on their effect on optimal environmental taxation. Also, there is a difference in the motivation behind the models. In this paper we argue that the utility derived from environmental quality is dependent not primarily on the current state of environmental quality, but rather on the differences of the current state of environmental quality compared to past states or levels of environmental quality. An individual builds up a habit stock that is positively dependent on past levels of environmental quality, and then the individual compares the current state of environmental quality to this habit stock. A deterioration of environmental quality gives a negative effect on the utility, while an increase in level of environmental quality gives a positive effect on the utility. It seems to be a reasonable assumption that people are not solely concerned about the current level of environmental quality; but rather compare it to historical levels. Think about a grandfather who tells his grandson what it was like when he was a child and was able to swim in the lake. The knowledge of the state of the environment deteriorates over time, since when the grandson becomes a grandfather he will have no knowledge of how it was to swim in the lake. We model this as deterioration of the habit stock, which is thoroughly explained in the Model section below.

In traditional economic modeling, preferences are assumed to be separable over time. Psychological findings continuously indicate that this is not true, and have been incorporated in several articles over the years (see for example Loewenstein and Elster, 1992; and Rabin, 1998, for extensive overviews). The literature on non-separable utility over time can be divided into two parts (Chaloupka, 1991). The first part is 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., 1994), which gives an explanation for the existence of addiction in an economic framework. In Phlips (1983), this distinction of research on changing preferences is referred to as "purely semantic." Phlips shows that rational addiction can be seen as a special case of a more general habit formation model.

The model in this paper is based on both the rational addiction model developed by Stigler and Becker (1977) and Becker and Murphy (1988), and the model developed by Pollak (1970) in which utility is not dependent on the consumption level *per se*, but rather on the change between past consumption and current consumption levels. The main difference between this paper and Becker and Murphy (1988) and Pollak (1970) is that we include a public good that displays habit formation (environmental quality), and not a private consumption good.[1] Furthermore, the mentioned public good is affected by a negative external effect.

The paper is organized in the following way. First we develop the model. Second, we solve for the problem of the social planner, where we characterize the equilibrium, discuss dynamics and solve for the steady state, and subsequently we solve for the decentralized problem. We graphically illustrate and analytically derive the optimal tax path and discuss the effect of habit formation before ending with concluding remarks.

2 The Model

We assume that the intertemporal utility of an individual depends on consumption of two different goods and environmental quality. The two consumption goods are substitutes, but one of the goods gives rise to a negative external effect on environmental quality (from now on we refer to this good as *the environmental bad*). The environmental quality is of a public good character, and so individuals do not take into account that their consumption of the environmental bad has a negative effect on the environment. We assume that a social planner implements a tax to correct for this behavior. Hence, the choice of the social planner is to maximize utility given the negative effect of the environmental bad, taking into account that there is habit formation in environmental

[1] Several studies take into account that different private goods (most studied is probably the consumption of cigarettes) display habit formation (see e.g. Chaloupka, 1991; and Becker et al., 1994).

quality.

To formalize the discussion above, the total discounted utility is given by a quadratic utility function:

$$\int_{t=0}^{\infty} (aN(t) + bX(t) + cZ(t) + dS(t) + AN(t)^2 + BX(t)^2 + CZ(t)^2 + DS(t)^2 + 2EX(t)N(t) + 2GN(t)S(t) + 2FX(t)S(t) + 2HZ(t)X(t) + 2IN(t)Z(t) + 2JZ(t)S(t))e^{-\rho t}dt. \quad (1)$$

a, b, c, d, A, B, C, D, E, F, G, H, I, and J are constant parameters, and $N(t)$, $X(t)$, $Z(t)$, and $S(t)$ are variables that change over time. The variables are defined as follows:

$N(t)$ = Environment which displays habit formation.

$X(t)$ = The "dirty" consumption good (the environmental bad).

$Z(t)$ = The "clean" consumption good.

$S(t)$ = The habit stock related to the environment.

Without loosing the key features of the model, the following assumptions are made regarding the variables:

$$N(t) = n - \gamma X(t) \quad (2)$$

$$Z(t) = y - X(t) \quad (3)$$

$$\dot{S}(t) = \beta N(t) - \delta S(t). \tag{4}$$

Environmental quality (2) is defined as a flow variable, i.e. we do not consider environmental quality as a stock. This is because we want to be able to focus on the effect of habit formation, and therefore want to use the simplest possible model. The environment is affected negatively by consumption of the good X, with a parameter $0 < \gamma < 1$, that illustrates how bad the good is for the environment. We have a goods market equilibrium condition: (3). We assume an exogenously given income equal to y in each period and normalized prices to one, and assume that it is neither possible to save nor borrow. $\dot{S}$ is the change in S over time, and the habit stock increases with βN, $(0 < \beta < 1)$, where β is a "habit formation coefficient" and depreciates over time with a depreciation rate equal to δ $(0 < \delta < 1)$. This way of modelling the habit stock follows Becker and Murphy (1988), but is also a variation of the discrete model of Pollak (1970). Due to tractability of the analysis we leave out time when referring to a variable, hence $X = X(t)$, except when we want to make a specific point where the time dimension is of importance.

It should be noted that the choice of a quadratic utility function is made mainly for analytical convenience, and could be comparable to a linearization around a steady state (since taking derivatives of a quadratic function yields linear relationships between the variables).

We assume further that individuals do not take into account the negative effect of consuming X on environmental quality, i.e. the environment has a public good character. Subsequently the individual treats environmental quality as given ($\bar{N}(t)$) (and consequently take the habit stock as given). The corresponding utility function for an individual (a representative agent) is given by:

$$\int_{t=0}^{\infty}(a\bar{N}(t)+bX(t)+cZ(t)+dS(t)+A\bar{N}(t)^2+ BX(t)^2+CZ(t)^2+DS(t)^2+2EX(t)\bar{N}(t)+2G\bar{N}(t)S(t)+ 2FX(t)S(t)+2HZ(t)X(t)+2I\bar{N}(t)Z(t)+2JZ(t)S(t))e^{-\rho t}dt \quad (5)$$

The goods market equilibrium condition for the individual is given by:

$$Z(t) = y + v - \tau X(t) \quad (6)$$

Where $\tau = 1 + r$, is a tax on good X. Further, we assume that the tax revenue is returned to the individual via a lump sum tax, v.

Given the definition of the utility function the following must hold: $A = \frac{1}{2}u_{NN}$, $B = \frac{1}{2}u_{XX}$, $C = \frac{1}{2}u_{ZZ}$, $D = \frac{1}{2}u_{SS}$, $E = \frac{1}{2}u_{NX}$, $F = \frac{1}{2}u_{NS}$, $G = \frac{1}{2}u_{NX}$, $H = \frac{1}{2}u_{ZX}$, $I = \frac{1}{2}u_{NZ}$, and $J = \frac{1}{2}u_{ZS}$. To make the model as stringent as possible, we make some assumptions on the utility function and parameters, which hold throughout the paper: $u_X > 0$, $u_N > 0$, $u_Z > 0$, $u_S > 0$, $d = -a$, $A = \frac{1}{2}u_{NN} < 0$, $B = \frac{1}{2}u_{XX} < 0$, $C = \frac{1}{2}u_{ZZ} < 0$, $D = \frac{1}{2}u_{SS} < 0$, $E = \frac{1}{2}u_{NX} = 0$, $F = \frac{1}{2}u_{NS} = 0, H = \frac{1}{2}u_{ZX} = 0$, $I = \frac{1}{2}u_{NZ} = 0$, $J = \frac{1}{2}u_{ZS} = 0$, $G = \frac{1}{2}u_{NS} > 0$.

Special attention should be given to the assumptions $u_S > 0$, $d = -a$, and $G = \frac{1}{2}u_{NS} > 0$. The first of these three assumptions is an assumption that indicates that we have a *beneficial* habit.[2] This term is

[2] As can be shown, the choice of a benefical good puts a restriction on the relative size of A in relation to D (A must be smaller in magnitude than D), but since this doesn't alter the results or intuition of the results, we do not develop the restriction further in the paper. The calculations can be obtained from the author upon request.

used in the rational addiction literature, and refers to an addiction/habit that does not have any negative effects on the individual through the stock effect (not to be mixed up with the negative effect on environmental quality assumed in this paper). The opposite of a beneficial addiction is a *harmful* addiction, where the most cited example is smoking. The instant effect of smoking is positive, but the habit stock effect is negative. The second assumption indicates that individuals get utility not from environmental quality per se, but rather from a reference level which is dependent on earlier consumption. This follows the approach by Pollak (1970). The third assumption is necessary (but not sufficient, as is shown below) for a higher level of past environmental quality to imply, *ceteris paribus*, a higher level of present environmental quality, i.e. an increase in past levels of environmental quality increases the marginal utility of present level of environmental quality. Furthermore we assume that $N, Z, X > 0$.

We can now restate the utility functions given the assumptions of the parameters:

$$\int_{t=0}^{\infty}(a(N-S)+bX+cZ+AN^2+BX^2+CZ^2+DS^2+2GNS)e^{-\rho t}dt \quad (7)$$

$$\int_{t=0}^{\infty}(a(\bar{N}-S)+bX+cZ+A\bar{N}^2+BX^2+CZ^2+DS^2+2G\bar{N}S)e^{-\rho t}dt. \quad (8)$$

Now the basic set up of the model is finished, and what we are going to do next is solve the optimization problem of the social planner. This exercise aims at finding and characterizing the optimal paths of the model. We then turn to the question of optimal environmental taxation (the decentralized problem).

3 The Problem of the Social Planner

The problem for the social planner is to maximize (1) subject to (2), (3), and (4).

Given one state (S) and one control variable (X), we are clearly able to study transitional dynamics. To identify a possible optimal path we use the Maximum Principle of Pontryagin (introduced by Pontryagin, Boltyanskii, Gamkrelidze and Mishchenko (1964)). The subsequent presentation of and solution to the maximization problem follows Sierstad and Sydsaeter (1987), and Sydsaeter, Strom and Berck (2000) closely. The current value Hamiltonian for our problem is stated as follows (where we have substituted in for restrictions [2] and [3]):

$$\begin{aligned}H^c = a((n-\gamma X)-S)+bX+c(y-X)+A(n-\gamma X)^2+BX^2+\\ C(y-X)^2+DS^2+2G(n-\gamma X)S+\lambda(\beta(n-\gamma X)-\delta S), \quad (9)\end{aligned}$$

where λ is the current value shadow price. The analysis of optimality hinges upon the following conditions:

Mangasarian's Sufficient Conditions. Infinite Horizon.

Suppose that an admissible pair $(S^*(t), X^*(t))$ satisfies the following conditions for all $t \geq t_0$:

(1) $X^*(t)$ maximizes $H^c(t, S^*(t), X(t), \lambda(t))$

(2) $\dot{\lambda}(t) - \rho\lambda(t) = -\partial H^c(t, S^*(t), X^*(t), \lambda(t))/\partial S.$

(3) $H^c(t, S(t), X(t), \lambda(t))$ is concave w.r.t $(S(t), X(t))$.

(4) $\lim_{t\to\infty} [\lambda(t)e^{-\rho t}(S(t) - S^*(t))] \geq 0$ for all admissible $S(t)$.

Then $(S^*(t), X^*(t))$ is optimal.

Conditions (1) and (2) represent the Maximum Principle of Pontryagin, and are *necessary conditions* for optimality to hold. Conditions (3) and (4) are *sufficient conditions* for optimality, but we acknowledge that we could still find optimal solutions even if (3) and (4) do not hold (for a further discussion see Sierstad and Sydsaeter, 1977). We also impose the transversality condition $\lim_{t\to\infty} S(t) > 0$ (following from $N > 0$). It can be shown that the current value Hamiltonian is concave w.r.t habit stock and the consumption good X (Condition [3]) iff $D(B + C + A\gamma^2) > G^2\gamma^2$. Given Condition (1), an interior maximum of H^c requires that $\frac{\partial H^c}{\partial X} = 0$. Hence,

$$\frac{\partial H^c}{\partial X} = b - c + 2BX - 2C(y - X) - a\gamma - 2GS\gamma - 2A\gamma(n - \gamma X) - \beta\gamma\lambda = 0, \tag{10}$$

and solving for λ and X we find that

$$\lambda = \frac{b - c + 2BX - 2C(y - X) - a\gamma - 2GS\gamma - 2A\gamma(n - \gamma X)}{\beta\gamma} \tag{11}$$

$$X = \frac{-b + c + 2Cy + a\gamma + 2A\gamma n + 2GS\gamma + \beta\gamma\lambda}{2(B + C + A\gamma^2)}. \tag{12}$$

Hence λ is a decreasing function in X (note that $A, B, C < 0$). Using Condition (2), we can solve for $\dot{\lambda}$:

$$\frac{\partial H^c}{\partial S} = -a + 2DS + 2G(n - \gamma X) - \delta\lambda = \rho\lambda - \dot{\lambda} \Longrightarrow$$

$$\dot{\lambda} = (\rho + \delta)\lambda + a - 2DS - 2G(n - \gamma X). \tag{13}$$

If we take the time derivative of X given from Equation (12), we get:

$$\dot{X} = \frac{2G\dot{S}\gamma + \beta\gamma\dot{\lambda}}{2(B + C + A\gamma^2)}. \tag{14}$$

Since we know $\dot{\lambda}$ from Equation (13), λ from Equation (11), and $\dot{S}$ from Equation (4), we can substitute in for $\dot{\lambda}$, λ, and $\dot{S}$ in Equation (14), which means that $\dot{X}$ can be written as a function of X and S. Accordingly, the dynamic system can be summarized by two differential equations, $\dot{S}$ and $\dot{X}$. More specifically, the system that we are interested in solving is:

$$\begin{cases} \dot{X} = KS + (\delta + \rho)X + M \\ \dot{S} = \beta n - \beta\gamma X - \delta S, \end{cases} \tag{15}$$

where

$K = \frac{-2D\beta\gamma - 2G\gamma(2\delta+\rho)}{2(B+C+A\gamma^2)}$

$M = \frac{-a\gamma(\delta+\rho-\beta) - 2An\gamma(\delta+\rho) + b(\delta+\rho) - c(\delta+\rho) - 2Cy(\delta+\rho)}{2(B+C+A\gamma^2)}$.

The general solution to this system is given by:

$S(t) = S^* + R_1 e^{\mu_1 t} + R_2 e^{\mu_2 t}$

$X(t) = X^* + R_3 e^{\mu_1 t} + R_4 e^{\mu_2 t}$,

where R_i =constants, and μ_i =eigenvalues given from the system, and * refers to steady state values of S and X.

We now define the matrix Ω as

$$\Omega = \begin{bmatrix} (\delta + \rho) & (K) \\ (-\beta\gamma) & (-\delta) \end{bmatrix}.$$

The determinant is then equal to $\det \Omega = K\beta\gamma - \delta^2 - \delta\rho$.

The *trace* of Ω ($tr\Omega$) is equal to ρ, and the eigenvalues of the determinant Ω are

$\mu_{1,2} = \frac{1}{2}(\rho \pm \sqrt{\rho^2 + 4(-K\beta\gamma + \delta^2 + \delta\rho)})$.

If the determinant is negative, we know that we have two real, distinct, non-zero roots, while if the determinant is positive we can either have two real, distinct, non-zero roots ($\frac{(tr\Omega)^2 - 4\det\Omega}{4} > 0$), or we have that the eigenvalues are complex conjugates ($\frac{(tr\Omega)^2 - 4\det\Omega}{4} < 0$). As we proceed (see Section 3.2) we are able to show that $\det\Omega < 0$, given our assumption of habit formation, which in our case corresponds to a positive and a negative root, i.e.:

$\mu_1 = \frac{1}{2}(\rho - \sqrt{\rho^2 + 4(-K\beta\gamma + \delta^2 + \delta\rho)}) < 0$ and

$\mu_2 = \frac{1}{2}(\rho + \sqrt{\rho^2 + 4(-K\beta\gamma + \delta^2 + \delta\rho)}) > 0$.

3.1 Solution of the Model

Now we proceed with the solution to the system. Since $\mu_2 > 0$, we know that $R_2, R_4 = 0$ for $S(t)$ to tend asymptotically to S^*. Hence, the general solution of the system is reduced to

$$S(t) = S^* + R_1 e^{\mu_1 t}$$
$$X(t) = X^* + R_3 e^{\mu_1 t}.$$

To determine R_1 and R_3 we assume that we are in period $t = 0$. Then the initial value of $S(0) = S^* + R_1$, and hence $R_1 = S(0) - S^*$. Correspondingly $R_3 = X(0) - X^*$.

The solution of the system is then equal to:

$S(t) = S^* + (S(0) - S^*)e^{\frac{1}{2}(\rho - \sqrt{\rho^2 + 4(-K\beta\gamma + \delta^2 + \delta\rho)})t}$

$X(t) = X^* + (X(0) - X^*)e^{\frac{1}{2}(\rho - \sqrt{\rho^2 + 4(-K\beta\gamma + \delta^2 + \delta\rho)})t}$.

This means that if $S(0) < S^*$ ($S(0) > S^*$), then S grows (falls) over time towards S^*, and the same logic holds for X.

3.2 Phase-diagrams and Transitional Dynamics

A convenient property of the differential equations derived in Section 3 (15), is that they do not explicitly depend on time, and can therefore be used to illustrate the dynamics of the system. To be more specific: we have an autonomous system when time does not enter explicitly into a system of equations. This means that the time-derivatives do not change over time, but the solutions for S and X respectively *do* depend on time. Also, given some uniquely defined initial condition $(S(0), X(0))$, there is a corresponding solution curve (path or trajectory), $(S(t), X(t))$, that is unique for the given initial condition. As t varies over time, the system moves along a trajectory that depends only on the coordinates (S, X), and not on the time of arrival at that point (Shone, 1997). In a phase-diagram, the direction along the trajectory as time increases is illustrated by arrows. Shone lists three important properties for trajectories of autonomous systems which are important to bear in mind:

1. There is no more than one trajectory through any point in the phase plane.

2. A trajectory that starts at a point which is not a fixed point will only reach a fixed point in an infinite time period.

3. No trajectory can cross itself unless it is a closed curve. If it is a closed curve then the solution is a periodic one.

A fixed point, which in the economic literature is referred to as a steady state, is defined as a point where neither $S(t)$ nor $X(t)$ changes over time. To find the steady states for our model we need to solve for $\dot{S}(t) = 0$, and $\dot{X}(t) = 0$.

We have analytically solved for the dynamics in the model through the determinant and the eigenvalues, but for a further discussion it is illuminating to illustrate the discussion graphically using a phase-diagram. A phase-diagram is used to find out what happens if we deviate from the curves $\dot{S}(t) = 0$ and $\dot{X}(t) = 0$. If we are on the $\dot{S} = 0$ curve, S is constant. Then what happens to $\dot{S}$, and hence to S, if we go to the right (increasing X) or left (decreasing X) of the $\dot{S} = 0$ line? The same applies for the $\dot{X} = 0$ curve, for which we want to find out what happens to $\dot{X}$ if we are below (decreasing S) or above (increasing S) the $\dot{X}$ curve. Firstly we need to solve for $\dot{S}(t) = 0$, and $\dot{X}(t) = 0$.

If $\dot{S}(t) = 0$, then S is given by:

$$S = \frac{\beta(n - \gamma X)}{\delta}. \tag{16}$$

If $\dot{X}(t) = 0$, then S is given by:

$$S = \frac{M}{K} + \frac{\delta + \rho}{K} X. \tag{17}$$

Before we proceed, let us think about these two equations for a short moment. The second equation is crucial, since in this expression we define N (it is a function of X) either to be a complement or a substitute to S or to be unrelated over time. Given the quadratic utility function, we by assumption have a linear relationship between the habit stock and environmental quality. The relationship is either positive (past levels of environmental quality have a positive effect on the present level of environmental quality), negative (past levels of environmental quality have a negative effect on the present level of environmental quality), or the coefficient is equal to zero (past levels of environmental quality has no effect on the present level of environmental quality - independence). From the definition of habit formation (given by Pollak, 1970), we must have a negative relationship between the habit stock and the environmental bad (since this corresponds to a positive relationship between the habit stock and environmental quality), otherwise a higher level of past environmental quality would not imply a higher level of present environmental quality. Hence, for an increase in current level of environmental quality to increase future levels of environmental quality indicates, not only that $G > 0$, but also that we should have a positive relationship between the habit stock and consumption of the habitual good.[3] Since N depends negatively on the consumption of X it follows that to have habit formation we are going to make the crucial assumption that

$$\frac{\delta + \rho}{K} < 0.$$

[3]It should be noted that this is closely linked to the concept of adjacent complementarity. The distinction between adjacent and distant complementarity was developed by Ryder and Heal (1973). These two concepts are not trivial, but to quote the authors:

> "...a person with distant complementarity who expects to receive a heavy supper would tend to eat a substantial breakfast and a light lunch. A person with adjacent complementarity would tend to eat a light breakfast and a substantial lunch in the same circumstances." (Ryder and Heal, 1973, page 5).

In our model we assume a quadratic utility function, which implies that the habitual good and the habit stock can only have a strictly positive, strictly negative or unrelated relationship. But since we assume habit formation we must have a positive relationship, and hence by definition we have adjacent complementarity. Further, this implies that we disregard the possibility of distant complementarity. A more general habit formation model could allow for periods of decreasing consumption, following a period of increased consumption in the good that is habitual, but this is not possible in this setting given the functional form of the utility function.

From this we can conclude that $K < 0$, and hence that the $\det \Omega < 0$, since $\det \Omega = K\beta\gamma - \delta^2 - \delta\rho$. Given the assumption of a positive relationship between N and S we disregard the possibility of a high rate of time preference, since this would make $K > 0$, and possibly the $\det \Omega > 0$ (which could result in an unstable equilibrium).

The corresponding phase diagram is presented in Figure 1.

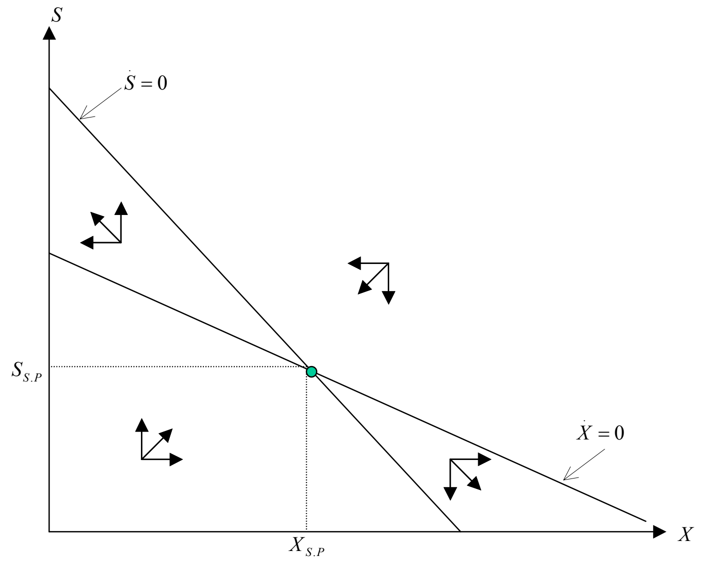

Figure 1. Phase-diagram in S and X-space.

The phase-diagram graphically illustrates the dynamics of the system derived in Section 3.1. Following the maximum principle, not all possible trajectories of the system are optimal. In Figure 2 below we have taken two examples of different $S(0)$: one high and one low. If we assume that the initial value of S is high, then the optimal trajectory hinges upon the choice of the control variable X at $t = 0$. Path I illustrates an optimal choice of $X(0)$, according to the maximum principle. The same argumentation can be made for the case when we assume a low initial value of $S(0)$. Choosing a high $X(0)$ would in this case result in the optimal path such as II. Also, the optimal paths fulfill the sufficient condition for optimality to hold (Theorem 1, Condition 4), i.e. $\lim_{t\to\infty} [\lambda(t)e^{-\rho t}(S(t) - S^*(t))] \geq 0$ for all admissible $S(t)$.

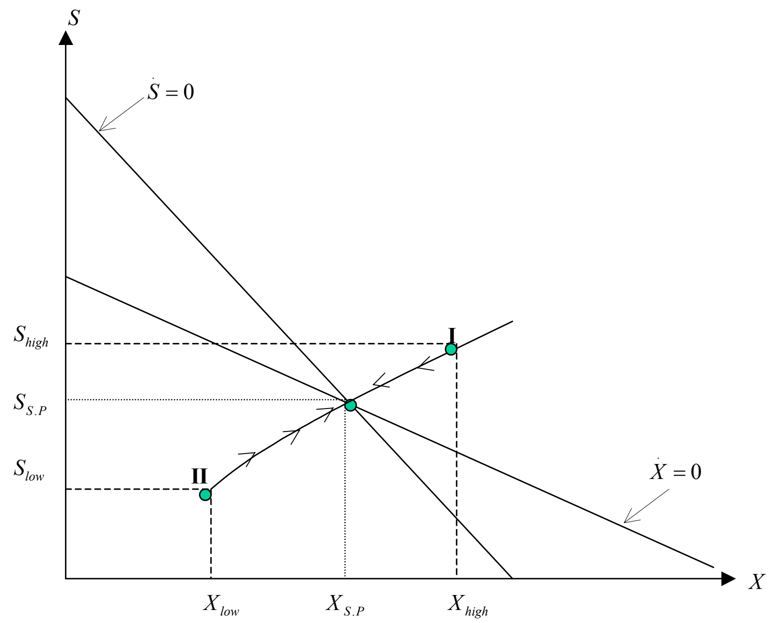

Figure 2. Optimal trajectories given initial condition on the habit stock.

It is worth noting that if we relax the assumption that $X > 0$, and assume that $X \geqslant 0$, we could have a boundary solution where the $\dot{S} = 0 - curve$ cuts the $S - axis$. Hence, the optimal consumption of the environmental bad is equal to zero. The optimality of such a solution hinges upon whether the welfare over time is higher on such a path compared to a path towards the steady state discussed earlier. This is not a trivial comparison and is left for future research (for a discussion on comparisons of multiple steady states, see for example Deissenberg, Feichtinger, Semmler, and Wirl, 2001). We disregard this solution in this study, but acknowledge that such a solution could still exist, and would depend partly on the substitutability between goods X and Z. For example, in the case of gasoline where leaded and unleaded gasoline have been shown to be almost perfect substitutes, we could imagine that this solution would be preferred to a solution with consumption of both leaded and unleaded gasoline. A solution where the $\dot{X} = 0 - curve$ cuts the $X - axis$ ($S = 0$) is impossible, since it violates the transversality condition $\lim_{t \to \infty} S(t) > 0$.

This rather elementary exercise points at the importance of the initial value of S, the habit stock of past environmental quality.

3.3 Steady State Consumption and Comparative Statics

Given what we have found so far we can solve for the optimal steady state consumption of X. In steady state we know that (16) must equal (17), and solving for X yields the following steady state consumption of X:

$$X^*_{S.P} = \frac{\frac{\beta n}{\delta} - \frac{M}{K}}{\frac{\delta + \rho}{K} + \frac{\beta \gamma}{\delta}}. \tag{18}$$

Solving correspondingly for S, N, and Z is straightforward:
$\dot{S}(t) = \beta N(t) - \delta S(t) = 0$ in steady state $\Rightarrow S(t) = \frac{\beta N(t)}{\delta} \Rightarrow$

$$S^*_{S.P} = \frac{\beta}{\delta} \left(n - \gamma \frac{\frac{\beta n}{\delta} - \frac{M}{K}}{\frac{\delta + \rho}{K} + \frac{\beta \gamma}{\delta}} \right),$$

$N(t) = n - \gamma X(t) \Rightarrow$

$$N^*_{S.P} = n - \gamma \frac{\frac{\beta n}{\delta} - \frac{M}{K}}{\frac{\delta + \rho}{K} + \frac{\beta \gamma}{\delta}},$$

$Z(t) = y - X(t) \Rightarrow$

$$Z^*_{S.P} = y - \frac{\frac{\beta n}{\delta} - \frac{M}{K}}{\frac{\delta+\rho}{K} + \frac{\beta\gamma}{\delta}}.$$

Since the focus of this paper is on habit formation, we would like to investigate the effect on steady state X ($X^*_{S.P}$) given a change in either G or β. We start by examining the effect of an increase/decrease in G (an increase in past levels of environmental quality increases the marginal utility of the present level of environmental quality) on optimal consumption of X.

Substituting in for M and K in $X^*_{S.P}$ yields the following expression:

$X^*_{S.P} =$
$\frac{2Dn\beta^2\gamma+2Gn\beta\gamma(2\delta+\rho)-b(\delta^2+\delta\rho)+c(\delta^2+\delta\rho)+2Cy(\delta^2+\delta\rho)+a\gamma\delta(-\beta+\delta+\rho)+2An\gamma(\delta^2+\delta\rho)}{2(D\beta^2\gamma^2+(B+C+A\gamma^2)(\delta^2+\delta\rho)+G\beta\gamma^2(2\delta+\rho))} =$
$\frac{\Theta}{2\Psi}$,

where $\Theta = 2Dn\beta^2\gamma + 2Gn\beta\gamma(2\delta+\rho) - b(\delta^2+\delta\rho) + c(\delta^2+\delta\rho) + 2Cy(\delta^2+\delta\rho) + a\gamma\delta(-\beta+\delta+\rho) + 2An\gamma(\delta^2+\delta\rho)$ and

$\Psi = D\beta^2\gamma^2 + (B+C+A\gamma^2)(\delta^2+\delta\rho) + G\beta\gamma^2(2\delta+\rho)$.

Also $\Theta, \Psi < 0$ (following from the sign of the determinant). Then we can write the derivative of $X^*_{S.P}$ with respect to G as:

$\frac{\partial X^*_{S.P}}{\delta G} = \frac{-\beta\gamma^2(2\delta+\rho)\Theta}{2\Psi^2} + \frac{4n\beta\gamma\delta+2n\beta\gamma\rho}{2\Psi}$.

We know that $\frac{-\beta\gamma^2(2\delta+\rho)\Theta}{2\Psi^2} > 0$, and $\frac{4n\beta\gamma\delta+2n\beta\gamma\rho}{2\Psi} < 0$. Hence, if $\frac{-\beta\gamma^2(2\delta+\rho)\Theta}{2\Psi^2} + \frac{4n\beta\gamma\delta+2n\beta\gamma\rho}{2\Psi} > 0$, then $\frac{\partial X^*_{S.P}}{\delta G} > 0$.

If we assume that $\frac{-\beta\gamma^2(2\delta+\rho)\Theta}{2\Psi^2} + \frac{4n\beta\gamma\delta+2n\beta\gamma\rho}{2\Psi} > 0$, then after some simplifications it follows that

$\frac{\Theta}{2\Psi}(= X^*_{S.P}) > \frac{n}{\gamma}$. But since this implies that $N < 0$ (remember that $N = n - \gamma X$), this cannot be true. Hence,

$\frac{\partial X^*_{S.P}}{\delta G} = \frac{-\beta\gamma^2(2\delta+\rho)\Theta}{2\Psi^2} + \frac{4n\beta\gamma\delta+2n\beta\gamma\rho}{2\Psi} < 0$.

The more habitual environmental quality the lower the optimal steady state consumption of the environmental bad (X). This is what we expect.

We now turn to the habit formation coefficient β. Using the same approach as above, we can write $\frac{\partial X^*_{S.P}}{\delta\beta}$ as:

$\frac{\partial X^*_{S.P}}{\delta\beta} = -\frac{(2D\beta\gamma^2+G\gamma^2(2\delta+\rho))\Theta}{2\Psi^2} + \frac{4Dn\beta\gamma-a\gamma\delta+2Gn\gamma(2\delta+\rho)}{2\Psi}$.

Hence $\frac{\partial X^*_{S.P}}{\delta\beta} \gtrless 0$ dependent on if

$-\frac{(2D\beta\gamma^2+G\gamma^2(2\delta+\rho))\Theta}{2\Psi^2} + \frac{4Dn\beta\gamma-a\gamma\delta+2Gn\gamma(2\delta+\rho)}{2\Psi} \gtrless 0.$

Going through some simplifications yields the following restrictions:

$\frac{\partial X^*_{S.P}}{\delta\beta} > 0 \textit{ iff } \frac{\Theta}{2\Psi} > \frac{n}{\gamma} - \frac{a\delta}{2\gamma(2D\beta+G(2\delta+\rho))}$ and

$\frac{\partial X^*_{S.P}}{\delta\beta} < 0 \textit{ iff } \frac{\Theta}{2\Psi} < \frac{n}{\gamma} - \frac{a\delta}{2\gamma(2D\beta+G(2\delta+\rho))}$.

Hence, if $2D\beta + G(2\delta+\rho) < 0$ then $\frac{\partial X^*_{S.P}}{\delta\beta} < 0$ (given the same argumentation as for $\frac{\partial X^*_{S.P}}{\delta G}$).[4]

If $2D\beta + G(2\delta+\rho) > 0$ then $\begin{cases} \text{if } X^*_{S.P} \text{ large } (N \text{ small}) \ \frac{\partial X^*_{S.P}}{\delta\beta} > 0 \\ \text{if } X^*_{S.P} \text{ small } (N \text{ large}) \ \frac{\partial X^*_{S.P}}{\delta\beta} < 0. \end{cases}$

We can conclude that the sign of $\frac{\partial X^*_{S.P}}{\delta\beta}$ hinges upon several parameters, and their relative size. But, if we face a situation where we have a large optimal steady state consumption of X, and $2D\beta+G(2\delta+\rho) > 0$, then a larger habit formation coefficient (i.e. that we increase the habit stock more for every given level of N) would indicate that the optimal level of steady state X increases. When $2D\beta + G(2\delta+\rho) < 0$ or $2D\beta + G(2\delta+\rho) > 0$ in combination with a small steady state consumption level of X, an increase in the habit formation coefficient would indicate a reduction of the optimal steady state consumption of X.

[4] From the positive relationship between N and S we know that $D\beta+G(2\delta+\rho) > 0$, but we do not know the sign of $2D\beta + G(2\delta+\rho)$.

4 The Decentralized Problem

4.1 The Problem of the Individual

Now we turn to the maximization problem of the individual. The individual consumption of X is *independent of time*, due to the assumption that individuals do not take into account that their consumption of X affects environmental quality, and hence affects the habit stock. The individual chooses to consume the exact same amount of X in every period. This is interesting from an analytical point of view since it allows us to exactly determine the start value of X and S, and given the initial conditions, the social planner needs to find the optimal path towards steady state, i.e. the optimal path of the environmental tax. The tax is equal to the Pigovian tax[5] (see e.g. Gruber and Köszegi, 2001; and Löfgren, 2002), but it is of interest to examine how it optimally should evolve over time.

The corresponding maximization problem for the individual is written as (note that the individual does not take into account the negative effect of the consumption of X on the environment and therefore we can treat the individual problem as a static problem):[6]

$$U^{ind} = a(\bar{N} - S) + bX + cZ + dS + A\bar{N}^2 + BX^2 + CZ^2 + DS^2 + 2G\bar{N}S.$$

Taking the derivative of U^{ind} with respect to X yields the following steady state consumption of X for the individual, when no tax is imposed:

[5] The tax is equal to the shadow price or marginal damage of the externality (Pigou, 1946).

[6] For the chosen parameters, the utility function can be shown to be concave with respect to X, as we would require.

$$X_{ind} = \frac{-b + c + 2C(v + y)}{2(B + C)}.$$

When we impose a tax ($\tau = 1 + r$) on the consumption of good X, the first order condition for the individual corresponds to

$$X_{ind} = \frac{-b + c\tau + 2C\tau(v + y)}{2(B + C\tau^2)}$$

and hence consumption of X strictly decreases in τ.[7]

4.2 Optimal Taxation

Again our problem can be illustrated by a phase-diagram. Given that the individual consumption of X is lower than the optimal consumption of X, we know that environmental quality is worse than optimal. But we can only speculate whether or not the initial value of S is lower or higher than the optimal S. The initial value on the habit stock crucially depends on time, i.e. how long time individuals have consumed the environmental bad. What we do know is that we have a problem of optimal environmental taxation including two different dynamics and three different initial taxes (see Figure 3 below). Hence, to illustrate what the implementation of an optimal tax would look like, we refer to three different levels on the initial habit stock (i, ii, and iii). These three levels all have different implications on the time-path of the optimal tax.

[7] The derivative of X_{ind} with respect to τ, $\frac{\partial X_{ind}}{\partial \tau} = \frac{B(c+2C(v+y))-C\tau(-2b+\tau(c+2C(v+y))}{2(B+C\tau^2)^2}$. If we assume an interior solution then $B < C\tau^2$ must hold, and then the derivative can be shown to be negative. Hence, X strictly decreases in τ (assuming an interior solution).

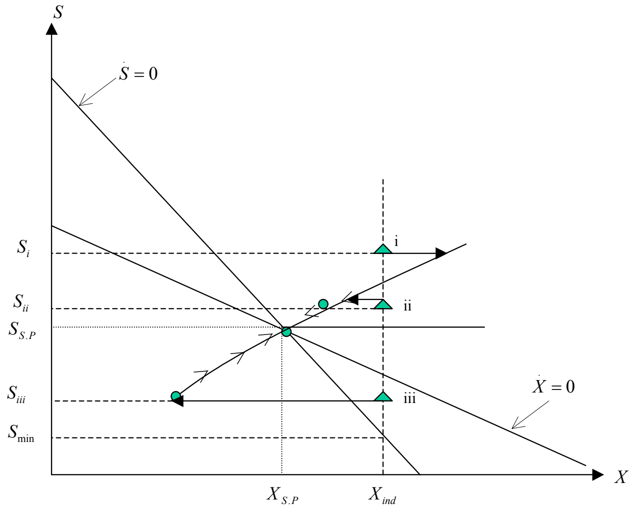

Figure 3. Optimal environmental tax path given initial conditions on the habit stock.

The arrows in Figure 3 represent the shift in consumption going from the individual's maximization problem to the social planner's maximization problem. From a visual inspection of Figure 3 we can conclude that the more the habit stock degenerates over time, the more likely the social planner is to face a situation such as (iii). Since we have shown that the consumption of X for the individual strictly decreases in tax, we find that given a habit stock *lower* than the optimal habit stock, the optimal response from a social planner would be to implement a tax (corresponding to a decrease in X), and then decrease the tax level over time (increase X) until steady state is reached. For a given habit stock *higher* than the optimal habit stock, the optimal response from a social planner would be either of two options: (a) situation (ii) corresponds to implementing a tax (decrease in X), and then increase the tax level over time (decrease X) until steady state is reached, or (b), situation (i) corresponds to implementing a *subsidy* initially, and then an increasing tax (level) until steady state is reached. Note that the habit stock can only be degenerated to $S_{\min}$ and that this point would correspond to an individual steady state, where both the habit stock and consumption of X are constant. Hence, following from Figure 3 we know that $\tau(0) > \tau^*$ if $S(0) < S^*$, and $\tau(0) < \tau^*$ if $S(0) > S^*$, and could even be a subsidy ($\tau(0) < 1$). Furthermore, $\dot{\tau} < 0$ if $S(0) < S^*$, and $\dot{\tau} > 0$ if $S(0) > S^*$.

We now formalize our discussion on the time-path of an optimal environmental tax. For optimality to hold, the social planner should set the tax so that the optimal path of X is equal to the individual's choice of X at every point in time.

The optimal path of X is given by $X(t) = X^* + (X(0) - X^*)e^{\mu_1 t}$,where $\mu_1 = \frac{1}{2}(\rho - \sqrt{\rho^2 + 4(-K\beta\gamma + \delta^2 + \delta\rho)})$. The social planner should set the optimal environmental tax so that $X_{ind} = X^* + (X(0) - X^*)e^{\mu_1 t} \Rightarrow$ $\frac{-b+c\tau+2C\tau(v+y)}{2(B+C\tau^2)} = X^* + (X(0) - X^*)e^{\mu_1 t}$. Solving for τ yields the following optimal tax path:

$$\begin{aligned}\tau(t) = {} & \frac{1}{2(2Ce^{\mu_1 t}(X^0 - X^*) + 2CX^*)} \\ & [c + 2C(y+v) - ((-c - 2C(y+v))^2 \\ & -4(b + 2BX^* + 2Be^{\mu_1 t}(X^0 - X^*))(2CX^* + 2Ce^{\mu_1 t}(X^0 - X^*)))^{\frac{1}{2}}]\end{aligned} \tag{19}$$

We have already shown the effect of G (remember that $G = \frac{1}{2}u_{NX}$, which should be interpreted as: an increase in past levels of environmental quality increases the marginal utility of the present level of environmental quality) on steady state consumption of X. It was shown that $\frac{\partial X^*}{\partial G} < 0$. This indicates that the optimal tax path is affected by G in a non-trivial way (both through X^* and μ_1). It is straightforward to show that $\frac{\partial \mu_1}{\partial G} > 0$, which can be interpreted as an effect on the transition speed towards the steady state tax. The larger the G, the larger (i.e. the less negative) is μ_1, the longer time it takes for the tax to approach the steady state tax (compared in levels). The same holds for the habit formation coefficient, β.

From Equation (19) we note the following:

The steady state tax ($t \to \infty$) and initial tax ($t = 0$) have the same "form":

$\tau(0) = \frac{1}{4CX(0)}[c + 2C(y + v) -$
$\sqrt{(-c - 2C(y + v))^2 - 8(b + 2BX(0))(CX(0))}]$

and

$\tau^* = \frac{1}{4CX^*}[c + 2C(y + v) -$
$\sqrt{(-c - 2C(y + v))^2 - 8(b + 2BX^*)(CX^*)}]$.

Hence, we find that the initial tax and steady state tax depends on habit formation through the optimal choice of X at time $t = 0$ (there is only one optimal choice of X given the initial value on the habit stock) and through steady state consumption of X.

It can also be shown that the optimal environmental tax in *steady state* is equal to the optimal environmental tax in a static case, i.e. disregarding the dynamic property of the habit stock.

5 Concluding Remarks

Habit formation has not, to our knowledge, been studied in an environmental framework before, and in this paper, using a simple model, we show that habit formation crucially affects optimal environmental taxation in a dynamic setting.

Even if we know that an environmental bad should be taxed using a tax equal to the Pigovian tax, it is of interest to study how such a tax evolves over time, and also how optimal consumption levels are affected by the assumption of habit formation. We show that when individuals experience habit formation in environmental quality, the time-path of the optimal tax critically hinges upon the initial value of the habit stock. There are three alternative paths: one corresponding to an increasing tax over time and two corresponding to a decreasing tax over time, with the initial tax being either a tax or a subsidy. The initial value of the habit stock depends on how long individuals have consumed the environmental bad. The longer the time, the lower the corresponding habit stock. Furthermore, habit formation affects the optimal tax path both in level and transition speed towards steady state levels. The transition speed towards the steady state levels is affected negatively by an increase in habit formation, while the level of the optimal tax is affected non-trivially by changes in habit formation. Also, the optimal consumption of the environmental bad decreases in habit formation through G. Hence, the stronger the habit, the higher the optimal level of environmental quality.

It should also be noted that the dynamics are highly dependent on two factors: firstly the concavity of the utility function with respect to the habit stock, and secondly how strong the habit formation is. The more diminishing the utility with respect to the habit stock, and the stronger the habit, the more likely that the model is unstable. We disregard the case of such strong habits and very concave utility function with respect to the habit stock, but acknowledge the explanatory power it has for addiction.

An evident extension of this paper is to incorporate habit formation in a growth-environment framework. In an article by Shieh et al. (2000), addiction and growth are studied, and the authors find that addiction has an effect on the steady state growth rate (the effect depends on the properties of the addiction), but the authors do not specifically consider environment, nor taxation. Another area for future research is to empirically test for the character of habit formation in environmental quality, i.e. what determines the reference point, and how persistent the habit is.

References

[1] Becker, Gary S. and Kevin M. Murphy (1988). "A Theory of Rational Addiction", *Journal of Political Economy*, 96, no 4, pp. 675-700.

[2] Becker, Gary S., Michael Grossman, and Kevin M. Murphy (1994). "An Empirical Analysis of Cigarette Addiction", *American Economic Review*, June 1994, v. 84, iss. 3, pp. 396-418.

[3] Beltratti, Andrea (1996). *Models of Economic Growth with Environmental Assets*, Kluwer Academic Publishers, Dordrecht.

[4] Boyer, Marcel (1983). "Rational Demand and Expenditure Patterns under Habit formation", *Journal of Economic Theory*, 1983, Volume 31, pp. 27-53.

[5] Chaloupka, Frank (1991). "Rational Addiction and Cigarette Smoking", *The Journal of Political Economy*, August 1991, Volume 99, Issue 4, pp. 722-742.

[6] Deissenberg C., G. Feichtinger, W. Semmler, F. Wirl (2001). "History dependence and global dynamics in models with multiple equilibria", *Working paper No 12 Center for Empirical Macroeconomics*, Department of Economics, University of Bielefeld, Germany, 2001.

[7] Gorman, W.M (1967). "Tastes habits and choices", *International Economic Review*, June 1967, Vol. 8(2), pp.218-222.

[8] Gradus, R. and Sjak Smulders (1993). "The Trade-off Between En-

vironmental Care and Long-term Growth - Pollution in Three Prototype Growth Models", *Journal of Economics*, Vol. 58(1), pp.25-51.

[9] Gruber, Jonathan and Botond Köszegi (2001). "Is Addiction 'Rational'? Theory and Evidence", *Quarterly Journal of Economics*, November 2001, Vol. 116(4), pp. 1261-1303.

[10] Kurz, Mordecai (1968). "Optimal Economic Growth and Wealth Effects", *International Economic Review*, October 1968, Vol. 9(3), pp.348-357.

[11] Loewenstein, George, and Jon Elster (1992). "The Fall and Rise of Psychological Explanations in the Economics of Intertemporal Choice", in George Loewenstein and Jon Elster, eds., *Choice over time.* New York: Russell Sage Foundation, 1992, 65(2), pp. 3-34.

[12] Löfgren, Åsa (2002). "The Effect of Addiction on Environmental Taxation in a First and Second-best World", part of thesis.

[13] Phlips, Louis (1983). *Applied Consumption Analysis.* Advanced Textbooks in Economics, vol.5. Revised Edition. Amsterdam, North-Holland, 1983.

[14] Pigou, A.C. (1946). *The Economics of Welfare*, 4th edition, London, Macmillan

[15] Pollak, Robert A (1970). "Habit formation and dynamic demand functions", *Journal of Political Economy*, 78 (1970), pp.745-763.

[16] Pollak, Robert A (1976). "Habit Formation and Long-Run Utility Functions", *Journal of Economic Theory*, 13(1976), pp.272-297.

[17] Pontrayagin, L., V. Boltyanskii, R. Gamkrelidze, and E. Mishchenko (1964). *The Mathematical Theory of Optimal Processes*, Pergamin Press. Translated by D.E. Brown.

[18] Rabin, Matthew (1998). "Psychology and Economics", *Journal of*

Economic Literature, March 1998, Vol.36, Issue 1, pp. 11-47.

[19] Ryder, Harl E. Jr. and Geoffrey M. Heal (1973). "Optimal Growth with Intertemporally Dependent Preferences", *The Review of Economic Studies*, January, 1973, Volume 40, Issue 1, pp. 1-31.

[20] Shieh, Jhy-yuan, Ching-chong Lai, and Wen-ya Chang (2000). "Addictive Behavior and Endogenous Growth", *Journal of Economics*, Vol. 72(3), pp.263-273.

[21] Shone, Ronald (1997). *Economic Dynamics*. Cambridge University Press. Cambridge, United Kingdom, 1997.

[22] Sierstad, Atle and Knut Sydsaeter (1977). "Sufficient Conditions in Optimal Control Theory", *International Economic Review*, June 1977, Vol.18(2), pp. 367-391.

[23] Sierstad, Atle and Knut Sydsaeter (1987). *Optimal Control Theory with Economic Applications*, Vol. 24 of Advanced Textbooks in Economics, North Holland, Elsevier Science Publisher.

[24] Smulders, Sjak (1995). "Environmental Policy and Sustainable Economic Growth", *De Economist*, Vol. 143(2), pp.163-195.

[25] Stigler, George J. and Gary S Becker (1977). "De Gustibus Non Est Disputandum", *American Economic Review*, March 1977, v.67, iss. 2, pp. 76-90.

[26] Sydsaeter, Knut, Arne Strom, and Peter Beck (2000). *Economists' Mathematical Manual*, Springer-Verlag Berlin-Heidelberg, Germany, 2000.