Taxation of Emissions of Greenhouse Gases: The Environmental Impacts of Carbon Taxes

Abstract

In theory, carbon taxes are considered a sound instrument to curb greenhouse gas emissions. Despite its relatively scarce and recent implementation, empirical assessments of carbon taxes effectiveness are increasingly available, although they have not been surveyed yet. We fill the gap by reviewing the main studies, including indirect effects on technological development and on other pollutants (i.e. co-benefits). We also consider the supplier's response to higher expected future energy prices, surveying the principal theoretical findings and the first empirical contribution on the Green Paradox.

Keywords

Climate policy; Carbon tax, CO_2 tax; environmental effectiveness; Green paradox; Co-benefits; Porter Hypothesis; Revenue recycling.

JEL Classification

Q5; Q54; Q58; Q48; H23

Acknowledgments

We thank Nicole A. Mathys, Stefan Speck, and Philippe Thalmann for very useful comments and suggestions on an earlier version of this paper.

Introduction

The United Nations (UN) Earth Summit, held in 1992 in Rio de Janeiro, oriented the international negotiations towards the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (cf. UN Framework Convention on Climate Change). Later on, greenhouse gas emissions were regulated for a set of industrialized countries, through the Kyoto Protocol. However, recent data indicate that CO_2 emissions, the main anthropogenic greenhouse gas, are still growing at the global level, although in some countries mitigation efforts have produced significant results. There is evidence (see e.g. UNEP 2011) that it will be particularly difficult to decrease emissions enough to avoid an increase of global mean temperature above $2^{o}C$ pre-industrial temperatures in the 21^{th} century, a benchmark considered by many as necessary to avoid very costly adaptation (see e.g. EU Climate Change Expert Group 2008). Hence, more efforts are needed to curb the global level of emissions and tackle climate change. Often, carbon taxes have been advocated by economists as an effective and potentially efficient instrument for reducing greenhouse gas emissions. However, their application in the real world remains relatively seldom. Only recently, several countries have implemented taxes based on carbon or CO_2 content, with of course wide differences in the design, the tax rate and the targeted products. Presently, we are aware of 11 countries having implemented a carbon/CO_2 tax (Australia, Denmark, Finland, Ireland, Latvia, The Netherlands, Norway, Slovenia, Sweden and Switzerland). The precursors were the European Nordic countries, with Finland the first country introducing a tax explicitly targeting CO_2 in 1990.

In this paper, we concentrate on the environmental impact of carbon taxes. Of course, carbon taxes can be assessed based on other criteria, such as their impact on households, on competitiveness or on growth (see e.g. Baranzini et al.

2000). The structure of the paper is the following. Section 2 discusses the main practical characteristics of carbon taxes. Section 3 analyses the environmental performance of carbon taxes, by highlighting their impact on technology, overall emissions path and emissions of other pollutants. Section 4 summarizes and concludes.

What Kind of Emissions Taxes?

Economic instruments used in climate policies can be divided into price or quantity instruments. Emissions trading programs are quantity instruments, since the initial amount of permits corresponds to the emission target. Permit trading in organized markets or by individual negotiation determines then their price. With emissions taxes, the environmental authority administratively determines the price of emissions, then emitters adapt their behavior. Therefore, emissions trading programs determine with certainty the amount of emissions (provided that fully compliance is ensured), while the price paid by emitters is unknown a priori and it changes depending on market conditions. With emissions taxes, the cost to emitters is known and stable, while emissions are a priori unknown and change based on technological conditions (e.g. variations in abatement costs), number of emitters and general macroeconomic situation. Those uncertainties determine the economic efficiency of the instrument, as discussed in the seminal paper by Weitzman (1974) and applied in the climate policy context by Pizer (2002).

Since climate change is a global environmental problem, in theory an emissions tax has to cover each emitter and to impose a charge per unit of greenhouse gas released, which equates marginal abatement costs worldwide (for a conceptual discussion of global environmental taxes, see e.g. Thalmann, 2012). It could even be coupled with a sequestration tax credit, to take advantage of sometimes lower abatement costs in forestry. To achieve economic efficiency, the tax rate has to correspond to the marginal external costs from climate change, at the optimal abatement level (“Pigouvian” tax). Rising costs of damages from the accumulation of CO_2 concentration in the atmosphere would thus imply an increasing tax rate over time. Since efficiency is reached with this tax design, the use of the generated fiscal revenues is completely independent from the climate target and can thus be used for other purposes. However, in practice emission taxes are often conceived far away from the theoretically ideal design. Moreover, the use of generated fiscal revenues (i.e. revenue recycling) may affect the acceptability of emissions taxes. Of course, the farther away from theoretical considerations, the least the tax is efficient, cost- and environmentally-effective. In what follows, we briefly discuss the basic features defining emissions taxes in practice, i.e. the tax base, objective and tax rate, exemptions, and revenue recycling.

The tax base defines different types of emissions taxes. We are unaware neither of a tax whose base is greenhouse gas emissions nor of an international emission tax. Therefore, the emissions tax closer to the theoretical model is a carbon or CO_2 tax, applied at the national level. A carbon tax is a charge to be paid on each energy vector, proportional to the quantity of carbon emitted when it is burned. A CO_2 tax is a unit tax, specified per ton of CO_2 emitted. It can easily be translated into a carbon tax, by knowing that a ton of carbon corresponds to 3.67 tons of CO_2.

In addition to emission taxes, there are other taxes that affect emissions. In particular, an energy tax depends on the quantity of energy consumed, and is specified in some common unit (like in barrels of oil equivalent, or in British thermal units, BTU) measuring the energy content of fuel. Therefore, contrary to a carbon or CO_2 tax, an energy tax also covers nuclear and renewable energy, unless they are exempted. Moreover, since oil and gas have greater heat contents for a given amount of CO_2 emissions compared to coal, an energy tax implies a greater charge on oil and gas than a carbon tax. Other existing taxes are charged to specific energy products and have an impact on emissions, but their tax base is smaller and the tax rate is on the physical quantity of the product (e.g. on € per liter). Nordhaus (2010) proposed an international tax on fossil fuel consumption. In the same vein, although often for reasons unrelated to climate policies, several countries possess gasoline taxes and taxes on energy sales (excise duties), sometimes per unit, other ad valorem. Therefore, countries implicitly tax greenhouse gas emissions, even in the absence of explicit emissions taxes. Of course, the smaller the tax base compared to the sources of greenhouse gases, the lower the impact on emissions, for a given tax rate.

Another feature determining the performance of emissions taxes is its objective, which then contributes in determining the tax rate. Since marginal climate change external costs are difficult to assess, the optimal abatement target cannot be determined and thus true Pigouvian taxes are not implemented (see Baumol and Oates 1971). Given that emissions taxes distribute abatement efforts depending on marginal abatement costs, they can be used to achieve a given abatement target at the lowest global cost (cost-effectiveness). If this is the objective, then the tax rate has to be set high enough to modify emitters' behavior so that the emissions target is reached. However, since abatement costs are not known by the environmental authority, recent legislations generally set a maximum tax rate and then let the authority modify it depending whether the emission target is achieved or not. The tax rate has then to be continuously adjusted, in particular to account for changes in the number of emitters, energy efficiency improvements, changing possibilities for fuel substitution, and availability and cost of backstop technologies. The cost-effectiveness approach has the advantage that it requires only cost minimizing firms and does not need strong assumptions such as profit maximizing and perfectly competitive firms, i.e. it applies to more realistic conditions.

Instead of cost-effectiveness, sometimes the stated objective of the emission tax is purely financial, i.e. to collect an amount of money that can then be used to finance abatement activities. This approach is of course not cost-effective, but can be more politically acceptable. Some countries proposed for instance to implement an international CO_2 tax with a relatively low rate, but whose receipt could be used to finance mitigation and adaptation measures (e.g. see the Swiss proposal at the Bali Conference).

The tax rate level is influenced by the emissions tax objective, but also by possible exemptions granted to some emitters. Of course, for a given abatement or fiscal target, more exemptions means higher tax rates for submitted emitters. Exemptions or tax rebates may be granted to some firms or sectors because of competitiveness fears, e.g. export-oriented or relatively mobile firms. Low-income households could also be exempted or submitted to a lower tax rate, although it would be administratively more cumbersome. Even though those considerations could decrease relocation of economic activities or be justified for distributive reasons, exemptions are not the most cost-effective mean to reach a given abatement target. Indeed, cost-effectiveness demands a unique carbon price to all emitters. Competitiveness or distributional concerns are thus more effectively treated by using the generated fiscal revenues or a set of complementary policies (e.g. social cushioning, carbon-motivated border tax adjustments).

From our discussion above, we observe that the management of the generated fiscal revenues is central in many aspects of carbon tax implementation. There are four main ways to use the generated fiscal revenues: earmarking to a specific activity (environmental or not); redistribution to an economic agent (household or firm); reduction of another tax (e.g. on labor or on capital); not earmarked, i.e. to the general budget. Depending on use, the generated fiscal revenues could thus increase acceptability and environmental effectiveness, decrease distributive impacts or even reduce inefficiencies in the general fiscal system.

Environmental Impacts

General Considerations

This section surveys the environmental impacts of existing emissions taxes. We are thus not presenting ex-ante studies which are used e.g. to determine the tax rate necessary to achieve a given emissions target or to simulate the impacts of a hypothetical emissions tax. In addition, we focus mainly on empirical analyses based on real data, because ex-post studies that assess the impact of emissions taxes through simulations of the "counterfactual" (the level of emissions that would have been achieved without taxes) should be considered with caution (see below). The assessment of environmental performance has to account for the induced emissions abatements in the short term, but also the more indirect longer term impact of emissions taxes, through e.g. the associated technological changes and firms' adaptation to new incentives. Moreover, it is necessary to consider three additional dimensions. First, emissions taxes reduce other pollutants, in addition to greenhouse gases. Therefore, there are supplementary benefits associated with emissions taxes ("secondary or co-benefits"). Second, since there is no worldwide emissions tax, a carbon tax implemented in a country influences trade flows or encourages activities to relocate and thus increase emissions in other regions ("geographical carbon leakage"). As a result, the net impact of the tax on global carbon emissions may be lower (see e.g. de Melo and Mathys 2010 for a detailed survey). Third, climate policy may have an impact on the extraction-path of resource-owners, eventually leading to a different timing of emissions ("inter-temporal carbon leakage", see the "Green Paradox" in section 3.4 below). In addition to those dimensions, we note that the practical features of implemented emissions taxes make it difficult to precisely assess their impact. Indeed, they are often only one instrument in a package of policy measures aimed at reducing emissions. Their implemented design is often difficult to model, since they possess several exemptions and exceptions, in particular to energy-intensive industries or to industries facing international competition. Moreover, they are often part of a general fiscal reform, which replaces other taxes on energy and reduces the share of traditional taxes (e.g. on labor and capital). Finally, the generated fiscal revenues may be used to finance abatement activities and technologies or environmental projects.

Assessment of Emissions Reductions

Supply and demand price-elasticities are central in the environmental effectiveness of emissions taxes, because they determine emitters' behavioral changes. Suppliers' response can eventually lead to "inter-temporal carbon leakage", i.e. the displacement of emissions through time. In addition, the point of imposition, the entry of new polluters, tax exemptions and the use of the generated fiscal revenues are other factors contributing to the environmental performance. As noted by Baranzini et al. (2000), there are several methodological difficulties to assess the specific features of implemented emissions taxes and to consider the different dimensions determining the empirical assessment of their environmental impacts. It is thus not surprising that the majority of studies in the literature base their conclusions on projections from scenarios, either based on top-down or bottom-up studies. The meta-analysis of Patuelli et al. (2005) reviewed specifically this literature, but related to the impact of environmental tax reforms more in general. By analyzing 61 studies comprising a total of 186 simulations, Patuelli et al. (2005) find that the studies projected an average CO_2 reduction of 9.7% due to environmental tax reforms, with studies in a short-term frame showing an impact of 6%, while those in a longer term about 13%, with notable differences depending on regions. As anticipated, those results have to be interpreted with caution, since in several studies the emissions reduction levels are chosen a priori. In addition, econometric simulations suffer of a series of other drawbacks (for a discussion, see e.g. Speck et al., 2006; Andersen, 2010. Furthermore, the scope of meta-analyses can be limited by the comparability of taxes in terms of design and size.

Only a few studies use an empirical approach based on real data. Among them, Lin and Li (2011) deal with methodological issues, and in particular with endogeneity[1]. They use a difference-in-difference approach to compare the emissions per capita of Denmark, Finland, Sweden, the Netherlands and Norway, before and after the introduction of a carbon tax. As a control group, they used similar European economies, but which have not implemented carbon taxes. They find a significant effect of carbon taxation for Finland only, whose impact corresponds to a reduction of 1.7% in the growth rate of CO_2 per capita, compared with the case in which the countries would have followed an emissions path without carbon tax, as in the control group. According to Lin and Li (2011), the non-statistically significant result for the other countries is mainly due to the important tax exemptions to energy-intensive sectors. This analysis is partly

corroborated by Bruvoll and Larsen (2004), who analyze the impact of carbon taxes on CO_2 emissions in Norway, over the period 1990-1999. Norway is a country with relatively high carbon tax rates in some specific sectors (e.g. US$ 51/t CO_2 for gasoline in 1999), but several activities are submitted to lower rates or exempted (e.g. cement production). The authors use a multisectoral model to compare emissions with (based on real data) and without carbon taxes (“the counterfactual”). They find that carbon taxes reduce emissions by 2.3%, mainly through an increase in energy efficiency and change in energy mix, while impact on scale is negligible. Given the relative high tax rates, the authors maintain that the impact would have been much greater, if emissions in sectors expected to be great contributors to emissions were not exempted. For the same country, Godal and Holtsmark (2001) show that the exempted sectors would face an average decline in operating profits from 17% to 22% if the privileged CO_2 exemption regime would end. The Norwegian failure to extend the tax base to the exempted industries show that increasing the level of existing taxes on emissions may be politically more feasible than including additional emission sources. If the goal is to achieve an emission abatement target cost-effectively, the lesson may thus be to start with low taxes and a broad taxation base rather than high taxes on some sectors and complete exemptions on others (Godal and Holtsmark 2001). Of course, for the tax to be environmentally effective, all the submitted sectors have to be sensitive to energy prices. Indeed, in a study on a panel of (mainly) energy-intensive industries in Denmark, Norway and Sweden, Enevoldsen et al. (2007) show that with the exception of natural gas and electricity (whose long-term elasticity is between −0.10 and −0.28 in the three countries), all energy inputs are to a significant extent sensitive to energy/carbon taxes (elasticity between −0.42 and −0.62). Given the low tax-elasticity of electricity, the authors encourage policymakers to target the electricity mix and to reduce the relative carbon content. Moreover, cross-price elasticities show some evidence of substitution between coal or oil and electricity. Considering broader input aggregates, Enevoldsen et al. (2007) find that the energy input has a tax-elasticity in the range of –0.35 to –0.44 for the three countries. This implies that energy/carbon taxes not only affect the energy mix, but also decrease energy consumption. In addition, the study finds positive cross-price elasticity between labor and energy, which means that energy/carbon taxes induces a switch from energy-intensive to labor-intensive sectors (cf. e.g. EEA 2011a).
Concerning the impact of existing product taxes on emissions, there is a huge but more general literature on price elasticity of gasoline consumption (vs. emissions). A number of surveys provide summaries of results on gasoline demand elasticities, such as Graham and Glaister (2002). These traditional literature surveys are complemented by meta-analyses. Brons et al. (2008) perform a meta-analysis on a dataset composed by 312 elasticity estimates from 43 primary studies. The estimates of the short run price elasticity of gasoline demand fall between –1.36 and –0.37 and are in general lower in absolute value than the long run estimates, which fall between –2.04 and –0.12. The mean price elasticity of gasoline demand is –0.34 in the short run and –0.84 in the long run. Brons et al. (2008) also identify the characteristics driving different results. They show in particular that USA, Canada and Australia display a lower price elasticity; that price elasticity increases over time; and that time-series studies and models with dynamic specification report lower elasticity estimates (in absolute value) than the general sample. Generally, price elasticities are lower than the corresponding values of income elasticities both in the short and in the long run (see Graham and Glaister, 2002; Sterner 2007). Applied to emissions taxes, this would imply that the (real) tax rate would have to grow faster than income, to offset the increase in consumption due to an income growth (but this could lead to a “Green Paradox”, see below). Compared to other policy instruments, Austin and Dinan (2005) show that fuel taxes are superior to standards, because they allow for both short-term (e.g. driving less) and long-term adjustments (e.g. replacing the vehicles fleet) (see also Sterner 2007). More recent works address specifically the impact of taxes on gasoline consumption and, in some cases, on emissions. Results of this literature point out that carbon taxes could have a specific impact on emissions. For instance, Davis and Kilian (2011) use a range of econometric techniques to assess the potential impact that a carbon tax could have in the United States, by estimating the impact of past variations in gasoline tax. They note that the resulting reductions in carbon emissions may not grow proportionately as linear econometric models predict and that tax elasticity is much larger than price elasticity, maybe because the price variations due to the tax are perceived as more permanent by consumers. According to their preferred model, a 10 cent increase in gasoline tax would imply a short–term reduction in US carbon emissions of about 0.5%. The fact that consumers’ reaction depends on the source of price variation is a consistent finding in the literature. For instance, Baranzini and Weber (2012) find that in Switzerland an increase in the existing mineral oil tax decreased gasoline demand by about 3.5%. Therefore, this study shows that an increase in the tax has two distinct impacts, both of which decrease demand: first, the price increase itself, then, an additional reaction by consumers, who know that this price increase is not a natural variation resulting from market forces. Ghalwash (2007) obtains differentiated impacts, but his results on different types of goods are somewhat ambiguous. Li et al. (2012) find a much larger effect of tax increase with respect to price increase and point to an interesting explanation: because gasoline

tax changes are subject to public debates and attract a great deal of attention from the media, this could contribute to reinforce consumers' reaction. Scott (2012) finally finds consumers to be twice as responsive to tax-driven price changes as to market-driven price changes. In an experimental framework, Goeschl and Perino (2012) show however that taxes can crowd out agent's intrinsic motivation. Nevertheless, it should be noted that in their framework tax revenues are neither allocated to more abatement efforts nor redistributed.

Environmental Impacts of Technological Development

The literature reviewed by EEA (2011b) shows that price-based policy instruments have in general a positive impact on eco-innovation, although this effect is not universal. A carbon tax is expected to stimulate the production of clean technology, because it modifies the price differential between the use of high-carbon and low-carbon technologies. This literature sometimes refers to the "Porter Hypothesis", from Porter (1991) and Porter and van der Linde (1995), in which the authors outline the hypothesis that stricter environmental regulations could help a country more than harming it, by fostering technological innovation and provoking a first-mover advantage (strong version). In our context, we do not consider the impact on international competitiveness of a carbon tax, as this topic is beyond the scope of this paper (for a survey, see e.g. Zhang and Baranzini 2004). However, we do consider in this Section induced technological innovation, and hence we consider the weak (Hicksian) form of the Porter hypothesis (cf. Jaffe and Palmer 1997)[2].

Studies assessing empirically the technological impact of emissions taxes or environmental regulations often use patents as a proxy for technological change in a particular sector (cf. EEA 2011), whereas they measure total factor productivity to identify an effect affecting the whole economy, as those proxies seem to have a good fit with respect to the unobservable technological improvement.

Commins et al. (2011) analyze the impact of energy taxes (and the European Union Emissions Trading System, from 2005 on) on a panel of European firms over the period 1996 to 2007. Despite a large inter-sectoral variation, the results show that energy taxes lead to an average net increase in total factor productivity. They conclude saying that "this finding supports the Porter Hypothesis. Regulation spurs innovation". Of course, not only emissions taxes are expected to spur technological innovation. For instance, analyzing seven European countries over the period 1989-2004, Noailly (2010) shows that more demanding standards increase patents in energy efficiency in the building sector, whereas higher energy prices do not. The author gives two explanations for the latter result. First, real energy prices are generally very low over the observed period. Second, the building sector faces an important principal-agent problem, perhaps leading to lower sensitivity to economic incentives. Similarly, Jaffe and Palmer (1997) find that in the US increasing environmental compliance expenditures leads to higher total R&D expenditures, with a lag. However, they do not find a direct impact on domestic successful patent applications. This result was already obtained by Jaffe and Stavins (1994), who assess the technology diffusion in energy-efficiency technologies following a change in energy prices, based on US data from 1979 to 1988. The authors extrapolate their result to the case of energy taxes, which would lead to an increase in energy prices. Newell, Jaffe and Stavins (1999) find a similar result with a large set of US data from the 60s to the 90s: changes in energy prices (as well as in efficiency standards) induce technological innovation in product characteristics.

Using US data from 1970 to 1994, Popp (2002) computes an energy-price elasticity of technology, the latter defined as the share of energy patents applications relative to all applications. Controlling for the stock of knowledge using patent citations, he finds an elasticity of 0.06 in the short-term.

Applying a similar approach, using European data (EU15) from 1996 to 2007, Costantini and Mazzanti (2012) find a positive link between environmental and energy policy (measured through tax revenues) and the export dynamics of high-technological firms (the result partly applies also to medium-low-tech firms). The effect on exports, not technology itself, is relatively large, with elasticities ranging from 0.024 to 0.038, depending on the type of taxation, and does not apply to green sectors only.

Several studies (Arimura et al. 2007, Johnstone and Labonne 2006, Darnall et al. (2007) and Lanoie et al. 2011) used a business' self-reporting database including 4'200 facilities distributed among seven OECD countries (Canada, France, Germany, Hungary, Japan Norway and USA). Lanoie et al. (2011) test the three versions of the Porter hypothesis and show that perceiving high environmental policy stringency has a positive effect on environmental R&D expenditure, but no impact on total R&D. Keeping stringency constant, the authors try to identify some instrument-specific effects (e.g. of taxes), and report that only medium and high performance standards have a positive effect.

The issue of policy stringency is further analyzed by Brunnermeier and Cohen (2003) on a sample of 146 industries over the period 1983-1992. They obtain that pollution abatement expenditures (a proxy for policy stringency) do affect patents, but that monitoring and enforcement (measured as the number of inspections) do not. Hence, it seems that the announcement of policy tightening suffices to induce technological change (signal effect).

However, the impact of environmental policy on technological innovation and diffusion should also be assessed outside the country implementing the climate policy. Recent theoretical literature discusses the conditions under which trade spills over technological change and impacts carbon emissions, see for instance Di Maria and van der Werf (2010), Golombek and Hoel (2004) or Acemoglu et al. (2012). Lanjouw and Mody (1996), first outline the link between environmental regulation in a given country (proxied by pollution control expenditures) and innovation in another. Based on a qualitative study, the authors analyze German, Japanese and US patents from the 70’s to the end of the 80’s, coupled with observations from a series of low- and middle-income countries. Among developed countries, the authors find that most domestic policies stimulate patent production also in the two other countries, although the strongest impact is within the country. Moreover, they find that developing countries enjoy the inventions of developed countries and concentrate their efforts mainly on adaptive innovation, i.e. adapting existing technologies and patenting for local markets (but not for exports). In the same vein, Barker et al. (2007b) apply an ex-post dynamic econometric analysis using cointegration techniques and find that the Environmental Tax Reforms implemented in some European countries (Denmark, Finland, Germany, The Netherlands, Sweden and the UK) lead to a very small geographical carbon leakage to EU’s non-ETR countries, because technological innovations cross borders to non-ETR EU countries, the latter thus enjoying positive spillovers. Di Maria and van der Werf (2010) posit even the basis for a net halo, i.e. negative carbon leakage. However, the result of Barker et al. (2007b), Lanjouw and Mody (1996) and the others needs to be confirmed by additional empirical evidence. For instance, Popp (2006), in a study on patent reactions to NO_x and SO_2 policies in Germany, Japan and the US over 1979 to 2003, cannot find a direct link between domestic environmental regulation and patenting in foreign countries, i.e. inventions respond to domestic but not to foreign policy. Follower countries do not seem to enjoy technology transfers by applying the innovations developed by the forerunners, but they rather develop their own. However, Popp (2006) does find an indirect impact represented by a transfer of knowledge, measured by cross-country patent citations. Hence, latecomers still enjoy some spillovers, but knowledge- instead of technology-related.

A final remark concerns the rebound effect associated to technological change, i.e. technologies can favor clean energy (and thus a decline in emissions), but also reduce the real cost of energy services per unit, thus leading to an increase in emissions. Hence, the net effect of eco-innovation could be theoretically ambiguous. Since aggregate empirical estimations are assessing the total change in emissions resulting from emissions taxes or technology changes, the rebound effect is implicitly accounted for in the final result. On the contrary, the rebound effect has to be explicitly modeled in simulation studies or general equilibrium models. The importance of the rebound effect is subject to debate. Some authors like Brännlund et al. (2007) find that in Sweden an increase in energy efficiency of 20% augments CO_2 emissions by approximately 5%. In this case, technological change is thus increasing emissions. By considering capital costs explicitly, other studies like Mizobuchi (2008) find for Japan a lower rebound effect of 27%, which means that actual emissions reductions due to technological change are 73% of the engineering potential. The macroeconomic simulation of Barker et al. (2007a) for the UK economy leads to a similar result, with a rebound effect of approximately 15%. In these cases, technological improvements have thus a net abatement impact on emissions, in line with Lin and Li (2011).

Counterproductive Carbon Taxes? The Green Paradox

Reminiscent of exhaustible resource theory, and starting in particular from Sinclair (1992), new theoretical contributions introduce more explicitly the supply-side of the market in the assessment of the environmental effectiveness of carbon taxes. Sinn (2008) shows that more stringent climate policy could not only lead to a geographical dislocation of emissions, but also to their temporal displacement (“temporal carbon leakage”). Indeed, if future climate policies are expected to be more stringent than those currently in place, wealth-maximizing resource suppliers can anticipate a depression in their revenues and thus anticipate the extraction of those resources. If this effect is so strong so that the net effect on damages is positive, a climate policy could even exacerbate the climate issue. This is the so-called “Green Paradox”.

Following Gerlagh (2010), there are two version of the Green Paradox. The weak version is a short term phenomenon and is represented by the case when, following a climate policy, resource-owners anticipate the timing of extraction, thus increasing current emissions. However, given the long-lasting effects of emissions in the atmosphere, climate policies have to consider cumulative emissions and their damages. If emissions increase today, but they decrease sufficiently tomorrow, climate change is then less severe and we face a weak Green Paradox (see Gerlagh 2010; Habermacher and Kirchgässner 2011). A strong Green Paradox implies instead that the climate policy modifies the anticipations of resource-owners such that the resulting cumulative extraction corresponds to larger environmental damages.

Gerlagh (2010) does not analyze an explicit climate policy, but refers to a backstop technology. Under some conditions, he finds a weak and a strong Paradox. However, when relaxing the assumptions regarding the perfect substitutability between limited resources and the backstop technology and introducing an increasing marginal cost in the backstop technology, Gerlagh (2010) does not obtain a Green Paradox (see also Hoel 2010). Sinn (2008) notes that time-invariant unit taxes on carbon extraction would lead to a flattening of the carbon supply, thus avoiding a temporal carbon leakage. However, since resource-owners countries are likely to be against this policy, Sinn (2008) proposes instead a world-wide system of emission trading, in which oil-importing countries would act as a monopsony, thus constraining the suppliers' inter-temporal maximization. Habermacher and Kirchgässner (2011) expand Sinn's (2008) model by introducing additional climate measures such as alternative carbon taxes and peculiarities such as backstop technologies, global fuel demand cartels, and carbon capture and storage systems. Their model reverses the outcome, since with both competitive or monopolistic resource suppliers (cf. e.g. OPEC), the net present value of cumulative emissions decreases with a carbon tax once taking into account future carbon measures, i.e. there is no evidence of a strong Green Paradox. Fischer and Salant (2012) obtain a similar result, but find evidence in favor of the weak version, i.e. in their model there is inter-temporal carbon leakage due to climate policies. Interestingly, they note that a relatively more stringent policy is likely to lead to lower inter-temporal carbon leakage, i.e. the simulations accounting for rent adjustment converge to those that omit the possibility of carbon leakage. That is why Fischer and Salant (2012) advocate for ambitious policy reducing inter-temporal carbon leakage.

Using a Pareto optimality approach as in Sinn (2008), and not a utilitarian approach as often done in the literature, Spinesi (2012) shows that increasing subsidy to R&D expenditures in the field of fossil fuels could also avoid both the weak and the strong Green Paradox. Indeed, greater subsidies could counter the reduction in resource-owners' profits due to an increasingly strong climate policy (in this case a higher carbon tax). This result is valid both with perfect and imperfect competition in the suppliers market, similarly to Habermacher and Kirchgässner (2011). However, subsidizing fossil fuel production could raise distributive issues since it could create additional rents for monopolistic firms. Moreover, other contributions on the optimal path of emissions suggest exactly the opposite, i.e. coupling carbon taxes with (temporary) research subsidies in the clean sectors.

Empirical assessments of the Green Paradox are extremely rare as we are aware of one study only, in addition not specific to climate policy. Di Maria et al. (2012) find a substantial drop in price of coal deliveries to US (coal-fired) power plants between a program announcement capping SO_2 emissions in 1991, and its implementation in 1995, especially for high-sulfur coal. This finding is in line with theory, since we expect coal producers to increase their supply prior to introduction of the cap. However, the evidence on the Green Paradox itself, which focuses on the emissions trajectory, is rather mixed. Indeed, the price drop is not transferred to an overall change in quantities or on the quality of coal (i.e. the sulfur intensity). Plants seem to start early adapting to the new regulation by reducing the sulfur content ahead of schedule. Only those not constrained by long-term contracts take advantage of lower spot prices, in line with theory. Hence, this paper concludes that a Green Paradox does not automatically rise in anticipation of a tighter regulation. We recall that the theoretical background predicts that supplier's response may lead to a Green Paradox, under given circumstances, but that proper policy design matters. Following Di Maria et al. (2012), we emphasize two factors against the rise of a Green Paradox. First, coal demand from power plants appears to be quite inelastic. Actually, it seems that long-term contracts play an important role and that a short implementation lag (4 years in this case) leads to a prolonged period of coal sales but not all plants can take advantage of such window of opportunity, due to capacity constraints and other sources of short-term inflexibility. Second, overlapping environmental regulations may limit the risk of a Green Paradox. The lesson applicable to climate policy is that it is possible to avoid a Green Paradox by introducing as soon as possible stricter regulations in view of the 2020's new Kyoto agreement abatement goal. In any case, announcing the objectives early and postponing policies later is the worst solution.

Summarizing, the intuition of the Green Paradox extends our knowledge of the impacts of climate policies, in particular allowing resource supply to be endogenously determined. However, the theoretical literature on the Green Paradox does not suggest that policymakers should not implement climate policies to avoid counterproductive effects. On the contrary, the literature indicates that the strong version can be avoided if policymakers carry on their climate policies taking into account the reaction of resource-owners. Moreover, this reaction is generally modeled also in the case of reduced competition, a theoretical framework that characterizes the market of many natural resources, e.g. oil. Empirical assessments of the Green Paradox are currently very rare, also because the largest part of the theoretical literature is very recent, but also because of challenging empirical issues related to endogeneity and information on policy expectations.

The Co-benefits of Emissions Taxes and Carbon Policies

In addition to greenhouse gases, climate policies may have an impact on other pollutants. In theory, those impacts can be positive or negative. For instance, a policy targeting CO_2 abatement can decrease SO_2 emissions, by leading to a switch from oil to natural gas. That is, CO_2 and SO_2 are in this case complements and spillovers are positive. However, the same policy may lead to a higher combustion temperature of natural gas, creating more emissions of NO_X. That is, CO_2 and NO_X are in this case substitutes, but spillovers can be either positive or negative, depending on the output effect, e.g. if less natural gas is used overall (Holland 2011). However, there is a general consensus that positive spillovers substantially overweigh negative externalities. That is why the literature talks about co-benefits, secondary or ancillary benefits. We use the IPCC's (2007) definition of co-benefits, illustrating the importance of an integrated approach that considers additional benefits as important as direct benefits.

OECD (2002) presents a long list of beneficial effects induced by emission abating policies. It includes lower mortality and morbidity from lower local air pollution, better visibility, higher crop yields, less damages to structures due to less acid rain, reduced urban congestion, noise and accidents. Indoor pollution matters mainly for developing countries (OECD 2009). According to OECD (2002), ecological benefits should also be included, because tropical forests are important for the conservation of flora and fauna.

Most of these benefits are local and arise in the short-term, which could contribute to increase the acceptability of climate policies (cf. OECD 2002). Pittel and Rübbelke (2008) show with a simple game-theoretical setting that international negotiations would be favored if the player's pay-off would include co-benefits, reducing the free-riding problem. Moreover, there is some evidence outlying that co-benefits are likely to be higher in emerging economies than in developed countries. That is, Pittel and Rübbelke (2008) show that accounting for exclusive and immediate local benefits increases the pay-offs of a developing country's cooperative attitude.

An important issue in this literature is represented by the valuation of co-benefits in monetary terms, in particular because many studies focus on the health impacts of reduced air pollution, which typically represent the largest component of co-benefits. But the value of statistical life is a controversial approach, with considerable political sensitivity (cf. OECD 2002, 2009).

An additional methodological issue is the determination of the baseline scenario, i.e. the case wherein the climate policy is not implemented. For instance, projected changes in standards for air pollutants have to be considered (OECD 2002). Moreover, simulations should consider both the opportunity cost of investing in another policy targeting local pollutants instead of a carbon policy, as well as the reduced administrative burden deriving from the co-benefits of a single policy on different fields of regulation (OECD 2009). Furthermore, model calibration is not neutral. For instance, the determination of the social discount rate is very likely to affect the final results, as well as other underlying assumptions. For example, a non-linear relation between air pollution and health makes more sense than a linear assumption (OECD 2009).

Due to all these issues, estimations of co-benefits are not very consistent across studies. According to OECD (2002), they range from 30% to 100% of abatement costs, with lower estimates in more recent studies. Furthermore, empirical estimates are likely to underestimate the effect of co-benefits, since it is particularly demanding to take into account all spillovers. Therefore, studies generally focus on the main co-benefits only.

Ekins (1996) surveys the estimated co-benefits for a series of developed countries (US, UK, Germany, Norway and European countries in general) and finds a very large range of values from US$21 per ton of carbon up to US$794, with an average co-benefits per ton of carbon of US$273. OECD (2002) reviews 13 studies and finds that estimates depend on the scope of the analysis (i.e. how many co-benefits and how many sectors are analyzed) and on the country. When results are monetized, they range from US$3 to US$452 per ton of carbon. More recently, OECD (2009) surveyed 9 studies focusing on different cases in terms of country of interest, horizon, pollutants, co-benefits and model assumptions. When results are monetized, they range from about US$14 to $58 per ton of carbon.

Nemet et al. (2010) review 37 studies on air-quality-related co-benefits providing 48 monetary estimates, 28 relative to developed countries and 20 for developing countries. Although comparability between studies with different architecture is not always ensured, Nemet et al. (2010) confirm that recent analysis tends to be more conservative and that in general estimates for developing countries are higher than for developed countries. The median (mean) for developed countries is

US$31 (US$44) per ton of CO_2 and US$43 (US$81) for developing countries. A possible explanation for higher co-benefits in developing countries is their higher levels of air pollution and thus larger health benefits from abatement, assuming a non-linear relation between pollution and health effects.
Groosman et al. (2011) analyze the transport and electric power sectors in the US, ending up with estimates for co-benefits over the period 2010-2030 ranging from US$1 to US$77 per ton of CO_2. Estimates are sensitive to modeling assumptions and years, with co-benefits at the end of the period being many times larger than in 2010. The authors present 4 scenarios, modifying the underlying assumptions and in particular mortality response to pollution exposure, capped SO_2 emissions, and the social discount rate. Interestingly, the authors find that marginal co-benefits exceed marginal abatement cost for 2 scenarios over 4. Omission of co-benefits would thus substantially under-estimate the benefits of a climate policy using e.g. carbon taxes.

Summary and Conclusions

Carbon taxes political acceptability is a major concern, which may explain why in practice only few countries have implemented them. Major issues range from distributive consequences, to administrative burden and competitive impacts. In this paper, we discuss specifically the concern regarding their environmental effectiveness. In the literature, the environmental performance is often evaluated through ex ante simulations based on disputable assumptions. In this paper, after reviewing the main characteristics of carbon taxes, we discuss their environmental impacts mainly based on empirical estimations using real data. We highlight several factors determining emissions, such as technological innovation, the complementary decrease of other pollutants (co-benefits) and the reaction of suppliers (the Green Paradox). We stress that climate policy should be considered from an integrated perspective and that the full potential of carbon taxes can be assessed only with a comprehensive approach which includes all aspects related to the implementation of this instrument. When carbon taxes are evaluated in this multifaceted way, rationales for implementation tend to increase rather than decline.

References

Acemoglu, D., Aghion, P., Bursztyn, L. & Hemous, D. (2012): “The Environment and Directed Technical Change”, American Economic Review, 102(1): 131-66
Ambec, S., Cohen, M.A., Elgie, S. & Lanoie, P. (2013), “The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness?”, Review of Environmental Economics and Policy, 0(0):1-22
Andersen, M.S. (2010): “Europe’s Experience with Carbon-Energy Taxation”, S.A.P.I.E.N.S. Available at: http://sapiens.revues.org/1072
Antweiler, W., Copeland B.R. & Taylor, M.S. (2001): “Is Free Trade Good for the Environment?”, American Economic Review, 91(4):877-908
Arimura, T., Hibiki, A. & Johnstone, N. (2007): “An Empirical Study of Environmental R&D: What Encourages Facilities to Be Environmentally Innovative?” in Johnstone, N. (Ed.) (2007): Corporate Behavior and Environmental Policy, Edward Elgar/OECD
Austin & Dinan (2005): “Clearing the air: The costs and consequences of higher CAFE standards and increased gasoline taxes”, Journal of Environmental Economics and Management, 50: 562-582
Baranzini, A., Goldemberg, J. & Speck, S. (2000): “A Future for Carbon Taxes”, Ecological Economics, 395-412.
Baranzini, A. & Weber, S. (2012): “Elasticities of Gasoline and Fuel Demands in Switzerland”, Geneva School of Business Administration Working Paper. Available at SSRN: http://ssrn.com/abstract=1984584
Barker, T., Ekins, P. & Foxon, T. (2007a): “The Macro-Economic Rebound Effect and the UK Economy”, Energy Policy, 35: 4935-4946.
Barker, T., Junankar, S., Pollitt, H. & Summerton, P. (2007b): “Carbon Leakage from Unilateral Environmental Tax Reforms in Europe, 1995-2005”, Energy Policy, 35: 6281-6292.
Baumol, W.J. & Oates, W.E. (1971): “The Use of Standards and Prices for Protection of the Environment”, The Swedish Journal of Economics, 73: 42-54.
Brännlund et al. (2007): “Increased Energy Efficiency and the Rebound Effect: Effects on Consumption and Emissions”, Energy Economics, 29: 1-17.

Brons, M., Nijkamp, P., Pels, E. & Rietveld, P. (2008): "A Meta-Analysis of the Price Elasticity of Gasoline Demand. A SUR Approach", Energy Economics, 30(5): 2105–2122.
Brunnermeier, S.B. & Cohen, M.A. (2003): "Determinants of Environmental Innovation in US Manufacturing Industries", Journal of Environmental Economics and Management, 45: 278-293
Bruvoll, A. & Larsen, B.M. (2004): "Greenhouse Gas Emissions in Norway: Do Carbon Taxes Work?", Energy Policy, 32: 493-505.
Commins, N., Lyons, S., Schiffbauer, M. & Tol, R.S.J (2011): "Climate Policy and Corporate Behaviour", The Energy Journal, 32(4): 51-68.
Costantini, V. & Mazzanti, M. (2012), "On the Green and Innovative Side of Trade Competitiveness? The Impact of Environmental Policies and Innovation on EU Exports", Research Policy, 41: 132-153
Darnall, N.G., Jolley, J. & Ytterhus, B. (2007): "Understanding the Relationship between a Facility's Environmental and Financial Performance" in Johnstone, N. (Ed.) (2007): Corporate Behavior and Environmental Policy, Edward Elgar/OECD
Davis, L.W. & Kilian, L. (2011): "Estimating the Effect of a Gasoline Tax on Carbon Emissions", Journal of Applied Econometrics, 26(7): 1187–1214.
De Melo, J. & Mathys, N.A. (2010): "Trade and Climate Change: The Challenges Ahead", CEPR Discussion Papers 8032
Di Maria, C., Lange, I. & Van der Werf (2012), "Should we be worried about the Green Paradox? Announcement Effects of the Acid Rain Program", CESifo Working Paper Series No. 3829
Di Maria, C. and Van der Werf, E. (2010): "Carbon Leakage Revisited: Unilateral Climate Policy with Directed Technical Change", Environmental Resource Economics, 39: 55-74
EEA (2011a): "Environmental Tax Reform in Europe: Implications for Income Distribution", EEA Technical Report 16.
EEA (2011b): "Environmental Tax Reform in Europe: Opportunities for Eco-Innovation", EEA Technical Report 17.
Ekins, P. (1996): "How Large a Carbon Tax is Justified by the Secondary Benefits of CO2 Abatement?", Resource and Energy Economics, 18: 161-187.
Enevoldsen et al. (2007): "Decoupling of industrial energy consumption and CO2-emissions in energy intensive industries in Scandinavia", Energy Economics, 29: 665-692.
EU Climate Change Expert Group (2008): The 2°C target. Information reference document.
Fischer, C. & Salant, S.W. (2012): "Alternative Climate Policies and Intertemporal Emissions Leakage: Quantifying the Green Paradox", Resources for the Future Discussion Paper No. 12-16.
Gerlagh, R. (2010): "Too Much Oil", Working Papers 2010.14, Fondazione Eni Enrico Mattei.
Ghalwash, T. (2007): "Energy Taxes as a Signaling Device: An Empirical Analysis of Consumer Preferences", Energy Policy, 35(1): 29-38.
Godal, O. & Holtsmark, B. (2001): "Greenhouse Gas Taxation and the Distribution of Costs and Benefits: the Case of Norway", Energy Policy, 29: 653-662.
Goeschl, T. & Perino, G. (2012): "Instrument Choice and Motivation: Evidence from a Climate Change Experiment", Environmental & Resource Economics, 52: 195-212.
Golombek, R. & Hoel, M. (2004): "Unilateral emission reductions and cross-country technology spillover", The B.E. Journals in Economic Analysis & Policy, 0(2): 3.
Graham D.J. & Glaister, S. (2002): "The Demand for Automobile Fuel. A Survey of Elasticities", Journal of Transport Economics and Policy, 36(1): 1–25.
Groosman, B., Muller, N. & O'Neilly-Toy, E. (2011): "The Ancillary Benefits from Climate Policy in the United States", Environmental & Resource Economics, 50: 586-603.
Habermacher, F. & Kirchgässner, G. (2011): "Climate Effects of Carbon Taxes, Taking into Account Possible Other Future Climate Measures", CESifo Working Paper Series 3404.
Hoel, M. (2010): "Climate Change and Carbon Tax Expectations", CESifo Working Paper Series 2966.
Holland, S.P. (2011): "Spillovers from Climate Policy to Other Pollutants", in: NBER (2011): "The Design and Implementation of U.S. Climate Policy".
IPCC (2007): "Climate Change 2007: Synthesis Report", Contribution of Working Groups I, II, III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
Jaffe, A.B., Newell, R.G. & Stavins, R.N. (2005): "A Tale of Two Market Failures: Technology and Environmental Policy", Ecological economics, 54: 164-174
Jaffe, A.B & Palmer, K. (1997): "Environmental Regulation and Innovation: A Panel Data Study", The Review of

Economics and Statistics, 79: 610-619.
Jaffe, A.B. & Stavins, R.N. (1994): "Energy-Efficiency Investments and Public Policy", The Energy Journal, 15: 43-65.
Johnstone, N. & Labonne, J. (2006): "Environmental Policy, Management and Research and Development" in Elmskov, J. ed. (2006): OECD Economic Studies, OECD
Krysiak, F.C. (2011): "Environmental Regulation, Technological Diversity, and the Dynamics of Technological Change", Journal of Economic Dynamics and Control, 35: 528-544
Lanjouw, J. O. & Mody, A. (1996): "Innovation and the International Diffusion of Environmentally Responsive Technology", Research Policy, 549-571
Lanoie, P., Laurent-Lucchetti, J., Johnstone, N. & Ambec, S. (2010): "Environmental Policy, Innovation and Performance: New Insights on the Porter Hypothesis", Journal of Economics & Management Strategy, 20(3): 803-842
Li, S., Linn, J. & Muehlegger, E. (2012): "Gasoline Taxes and Consumer Behavior", Working Paper Series rwp12-006, Harvard University, John F. Kennedy School of Government.
Lin, B. & Li, X. (2011): "The Effect of Carbon Tax on Per Capita CO2 Emissions", Energy Policy, 39: 5137-5146.
Mizobuchi, K. (2008): "An Empirical Study on the Rebound Effect Considering Capital Costs", Energy Economics, 30: 2486-2516.
Nemet, G. F., Holloway, T. & Meier, P. (2010): "Implications of Incorporating Air-Quality Co-Benefits into Climate Change Policymaking", Environmental Research Letters, 5(1), 014007
Newell, R.G., Jaffe, A.B. & Stavins, R.N. (1999): "The Induced Innovation Hypothesis and Energy-Saving Technological Change", Quarterly Journal of Economics, 114 : 941-975
Noailly, J. (2010): "Improving the Energy-Efficiency of Buildings: The Impact of Environmental Policy on Technological Innovation", Fondazione Eni Enrico Mattei Working Papers 106.
Nordhaus, W.D. (2010): "Carbon Taxes to Move Toward Fiscal Sustainability", The Economists' Voice, Berkeley Electronic Press, 7(3).
OECD (2002): "Ancillary Benefits and Costs of GHG Mitigation: Policy Conclusions", Working Party on Global and Structural Policies 13.
OECD (2009): "Co-Benefits of Climate Change Mitigation Policies: Literature Review and New Results", OECD Economic Department Working Paper 34.
Patuelli, R., Nijkamp, P. & Pels, E. (2005): "Environmental Tax Reform and the Double Dividend: A Meta-Analytical Performance Assessment", Ecological Economics, 55: 564-583.
Pittel, K. & Rübbelke, D.T.G. (2008): "Climate Policy and Ancillary Benefits: A Survey and Integration into Modelling of International Negotiations on Climate Change", Ecological Economics, 68: 210-220.
Pizer, W.A. (2002): "Combining price and quantity controls to mitigate global climate change." Journal of Public Economics, 85: 409-434.
Popp, D. (2002): "Induced Innovation and Energy Prices", The American Economic Review, 92(1): 160-180
Popp, D. (2006): "International Innovation and Diffusion of Air Pollution Control Technologies: the Effect of NOx and SO2 regulation in the US, Japan and Germany", Journal of Environmental Economics and Management, 51:46-71
Porter, M.E (1991): "America's Green Strategy", Scientific American, 264: 168
Porter, M.E & van der Linde, C. (1995): "Toward a New Conception of the Environment-Competitiveness Relationship", Journal of Economic Perspectives, American Economic Association, 9: 97-118.
Scott, K.R. (2012): "Rational Habits in Gasoline Demand", Energy Economics, forthcoming.
Sinclair, P.J.N. (1992): "High Does Nothing and Rising is Worse: Carbon Taxes Should Keep Declining to Cut Harmful Emissions", The Manchester School of Economics and Social Studies, 60: 41-52
Sinn, H-W. (2008): "Public Policies Against Global Warming: a Supply Side Approach", International Tax and Public Finance, 15: 360-394.
Speck, S., Andersen, M.S., Nielsen, H.O., Ryelund, A. & Smith, C. (2006): "The Use of Economic Instruments in Nordic and Baltic Environmental Policy 2001-2005", Nordic Council of Ministers Report.
Spinesi, L. (2012): "Global Warming and Endogenous Technological Change: Revisiting the Green Paradox", Environmental & Resource Economics, 51:545-559.
Sterner, T. (2007): "Fuel Taxes: An Important Instrument for Climate Policy", Energy Policy, 35:3194-3202.
Thalmann, P. (2012): "Global environmental taxes", in Milne, J.E. & Andersen, M.S. (eds), Handbook of Research on Environmental Taxation, Edward Elgar Publishing, 456-476.
UNEP (2011): "Bridging the Emissions Gap", UNEP Synthesis Report

Weitzman, M.L. (1974): “Prices vs. Quantities.” Review of Economic Studies, 41: 50-65.
Zhang, Z. & Baranzini, A. (2004): “What Do We Know About Carbon Taxes? An Inquiry into their Impacts on Competitiveness and Distribution of Income”, Energy Policy, 32: 507-518.

[1]Endogeneity may lead to biased results and has thus to be accounted for. In our context, the main source of endogeneity is the reverse causality between policy and emissions. Estimations of the impacts of a climate policy on emissions have to consider that higher levels of emissions may lead to more stringent policies.
[2] For a short introduction to the general Porter hypothesis' theoretical bases, including the narrow and strong version, see e.g. Jaffe et al. (2005), Krysiak (2011), Lanoie et al. (2011) and Costantini and Mazzanti (2012). For another survey including empirical studies, see Ambec et al. (2013).

Taxation of Emissions of Greenhouse Gases: The Environmental Impacts of Carbon Taxes

Dr. Andrea Baranzini	Geneva School of Business Administration (HEG-Ge), University of Applied Sciences of Western Switzerland (HES-SO), Carouge – Geneva, Switzerland
Stefano Carattini	Geneva School of Business Administration (HEG-Ge), University of Applied Sciences of Western Switzerland (HES-SO), Route de Drize 7, 1227 Carouge– Geneva, Switzerland

DOI:	10.1007/SpringerReference_327527
URL:	http://www.springerreference.com/index/chapterdbid/327527
Part of:	Global Environmental Change
Editor:	Dr. Bill Freedman
PDF created on:	March, 01, 2013 08:54