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Curbing Carbon Emissions: Is a Carbon Tax the Most Efficient Levy?

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Key Points

The ambitious environmental objectives of the Paris Agreement imply that, in order to curb carbon emissions, all cost-effective policy options should be considered. These options include carbon taxes, probably the most popular fiscal tool for curbing emissions, and various other taxes on fossil fuels. This study uses Spanish data to assess what are the optimal taxes on oil, natural gas and coal from a welfare perspective, and compares them with a carbon tax in a general equilibrium context. The results of the analysis are as follows:

- Among their options for reducing CO2 emissions, policymakers may consider taxing coal heavily. Less punitive taxation of oil and natural gas could also form part of an optimal strategy.

- For maximum effectiveness, we found that any planned tax on oil should always be lower than the tax on natural gas, and still lower than that on coal. This counterintuitive result comes about because oil has the highest marginal economic productivity of the three fuels, though natural gas is the cleanest fossil fuel in terms of CO2 emissions. According to standard economic theory, the marginal economic productivity of any fossil fuel should be similar to international prices for it in competitive markets.

- Carbon tax has both advantages and disadvantages for policymakers. In the short run, the revenue collected would be higher from an optimal mixture of taxes on the various fossil fuels – but, in the longer term, higher taxes might be seen by taxpayers as unreasonable and could result in a loss of support for the environmental policies they are intended to underpin.

Summary for Policymakers

There is wide international consensus on the need to limit global warming to no more than 2ºC. A proof of this consensus is the agreement by 195 countries to adopt the new global climate change framework proposed in December 2015 as the Paris Agreement. This 2ºC goal might, however, be viewed as little more than aspirational, since it is only binding to the extent that nations propose to be bound by it. Nevertheless, it is a relevant landmark in climate change policy. It is important to emphasize that the reduction in emissions needed to limit global warming to no more than 2ºC is significant. Consequently, in the next few years policymakers will look to decide on a set of cost-effective policy tools to curb emissions and, hopefully, mitigate the consequences of climate change.

Carbon taxes are emerging as a common policy response to curbing greenhouse gas emissions. Intuitively, it might appear that the best way to reduce carbon emissions would be to make them more expensive through some kind of levy, such as a carbon tax. However, this intuition is not entirely correct.

This study, based on Spanish economic data, assesses what are the optimal taxes on fossil fuels to curb carbon emissions and compares them with a carbon tax. Our analysis produced some interesting results. First, for optimal efficiency in terms of reducing CO2 emissions, any tax on coal must be substantial, since this is the fossil fuel with the highest carbon emissions and lowest level of energy productivity, and it is the cheapest fossil fuel. According to standard economic theory, the price of any input, such as a fossil fuel, must equal its marginal productivity in competitive markets. In other words, the low price of coal (in calorific units) reflects a low productivity for this fuel. The opposite is true of oil. This initial result was expected. However, and according to the general equilibrium model used, we find that a lower level of taxation of oil and natural gas could also form part of an optimal strategy, especially when the environmental target chosen is conservative in terms of carbon emissions reductions. Second, again for optimal efficiency, our analysis shows that the tax on oil should be lower than the tax on natural gas, and lower still than that on coal. This is because the marginal economic productivity of oil is the highest of the three fossil fuels, though natural gas has the lowest level of carbon emissions.

Third, any carbon tax tends to converge to the optimal tax mix. This is the tax mix that minimizes the cost of the environmental policy, when the environmental target is ambitious. This study suggests that carbon taxes may be an appropriate policy instrument to consider when an aggressive environmental target is chosen. However, if the objectives in terms of CO2 emissions mitigation are more conservative, such a tax would lead to unnecessary welfare losses.

Carbon taxes can be viewed as having a short-term advantage for policymakers: revenues from the optimal tax mix are always lower than those from a carbon tax. This could create a potential dilemma for policymakers since environmental taxes may also represent a way to finance public expenses. However, and from a purely environmental policy perspective, this potential advantage may have a downside. Higher taxes might be seen by taxpayers as unreasonable and could lead to a loss of support for the environmental policies. The loss of social mandate is one of the greatest risks to the successful implementation of sound environmental climate change policies, which by its nature requires very long-term commitment and support.

Introduction

There is wide international consensus on the need to limit global warming to no more than 2ºC. Proof of this consensus is that 195 countries adopted a binding deal on global climate change in December 2015, known as the Paris Agreement. This agreement reveals an increasing global pragmatism in terms of reducing greenhouse emissions as soon as possible. The 2ºC goal could be seen as merely aspirational, since it is only binding to the extent that nations propose to be bound by it. In particular, each country must define a national target on emissions, the 'nationally determined contributions.' Countries agreed to report transparently and regularly on their emissions and their efforts to achieve this target.

However, it is important to emphasize that the reduction in emissions needed to limit global warming to no more than 2ºC is, nonetheless, quite significant. To illustrate this, the 2ºC scenario defined by the International Energy Agency (2016) considers a reduction of "CO2 emissions (including emissions from fuel combustion, and process and feedstock emissions in industry) by almost 60 percent by 2050 (compared with 2013)." In the same vein, in its 2030 Energy Strategy, the European Union sets a 40 percent reduction in carbon emissions compared with 1990 levels. Consequently, in the next few years governments will look to identify a set of cost-effective policy tools to curb emissions and also mitigate the consequences of climate change.

It is not easy to quantify the impact of environmental taxes on carbon emissions. The final impact of a specific tax on emissions will depend ultimately on the structure of the economy in question, the preferences of households, technological conditions for production of goods and services, international prices of energy and, also, the flexibility to switch among different fuels. In this context, the objective of this study is to understand the impacts of different fossil fuel taxes on carbon emissions in the long run, using a general equilibrium model. This study does not focus on the optimal level of emissions, but on the optimal tax mix required to curb emissions, given an environmental target.

We must stress that the focus of our study is fossil fuel taxes. Policymakers have a range of available policy responses to curb carbon emissions. Aldy and Stavins (2012), for example, studied the advantages and disadvantages of different environmental policy tools such as carbon taxes, cap-and-trade, emission reduction credits, clean energy standards and fossil fuel subsidy reductions. In addition, policymakers in their study could choose to adapt or to live with the consequences of climate change. In practice, it is likely that some combination of mitigation and adaptation policies would provide the most cost-effective policy response, particularly at the national level, given each country's differing social-economic circumstances, state of development and resource endowments.

In our study we used a general equilibrium model calibrated for the Spanish economy. In this model, a government, in order to achieve its environmental target, can tax carbon emissions or the consumption of oil, coal and natural gas. We focus on the long-run impacts of these taxes on the economy and on CO2 emissions. In this context, we identify the optimal mix of taxes on oil, coal and natural gas in order to curb emissions and to achieve a specific carbon emissions reduction target. We find that the optimal tax mix is the one that minimizes the potential negative impacts on social welfare that may result from the environmental target for carbon reduction. We compare the outcome of this optimal tax mix in terms of social welfare and tax revenues with the outcome of a standard carbon tax. We find this optimal tax mix has a different tax rate for each fossil fuel.

From a methodological point of view, a limitation of our study is that renewables technologies and nuclear are not taken into consideration. These two forms of energy make it possible to keep the consumption of energy constant while reducing the use of fossil fuels. In other words, it could be the case that there would be no need to curb the consumption of fossil fuel through taxes, if it was found that renewable sources could displace these polluting technologies. However, from a technical point of view, renewable sources can replace fossil fuels only up to a certain point. In the electricity sector it is possible to shift partially from using coal or natural gas as a fuel to renewable sources. But, given the limitations of current renewable technologies, fossil fuel fired generation plants will remain critical. This is because they can provide the ancillary services required to ensure secure and resilient power systems that deliver reliable electricity services in the presence of the intermittency that results from the large-scale deployment of renewable generation. Perhaps in the future, technological development such as access to cost-effective, large-scale batteries, or more innovative markets and business models, will provide a means to more effectively manage the problem of intermittency connected with natural resources such as the sun, wind or water. In addition, a shift to renewable energy is much more difficult in the transportation sector, at least based on current technology. These developments could make the case for taxes on fossil fuels or carbon emissions less important. However, tax instruments are proven and effective policy tools that are likely to continue to have a significant role to play in environmental policy.

There are other studies, with different methodological approaches or objectives, which discuss the use of taxes to achieve environmental goals. See Appendix 1 for a review of literature on this subject.

A Brief Description of the Methodological Approach

In our analysis, the economy is represented though a dynamic general equilibrium model with the characteristics of a small open economy. This is represented by a household, three competitive firms and the government. They engage actively in an external sector by trading a final representative good, foreign bonds and three primary energy inputs (oil, natural gas and coal). The government taxes fossil fuel, and transfers the revenues from these taxes to the representative household by means of a lump sum transfer. The idea behind this mechanism is to minimize the impact of taxes on households' disposable income. In addition, the government runs a balanced fiscal budget. This model is an adaptation of the neoclassical growth model for the Spanish economy proposed by Blazquez et al. (2017).

In order to simplify the model and to focus on the best tax mix, it is important to stress that CO2 emissions do not impact the households' welfare or economic activity. In this model, the level of carbon emissions is not relevant for the household or the firm. They only take account of economic variables such as private consumption, investment or profits. Obviously, governments set environmental targets due to social preferences, but in our model we assume that this government sets a target of carbon emissions according to exogenous criteria.

Empirical Results and Discussion

This section analyses what are the optimal taxes on oil, natural gas and coal to reduce carbon emissions and then compares the outcome of the taxes identified with the outcome from a standard carbon tax. We define the optimal tax mix as the combination of tax rates on fossil fuels that minimizes the negative impact on households' welfare while achieving a specific CO2 emissions target. As is standard, welfare losses are defined in terms of the increase in private consumption needed to keep social welfare constant. Accordingly, a 1 percent decrease in social welfare implies that if private consumption is raised by 1 percent the household would have zero welfare losses.

This study assumes that the economy is in a stable state. The steady state or long-run equilibrium is defined as a set of the variables that satisfies the optimality conditions of all the economic agents. Once the economy reaches this point, in the absence of any disturbance, it will stay at that point. This implies that we focus on the long-term impacts of different taxes, rather than the short-term transitionary effects.

Our analysis ignores the potential impacts of energy policies on the demand for fossil fuels and their prices because we analyze a small economy and also since its impact on global demand for fossil fuels is negligible. In the case of regional or even global taxes, global demand for fossil fuel would be affected, producing a negative impact on international prices. In addition, we did not take account of the depletion of fossil fuel reservoirs in the long run and the potential impact of that on prices of fossil fuels. New technologies in exploration and production constantly raise estimates for proven reserves of fossil fuels. According to the BP Statistical Review of World Energy 2016, global proven reserves of oil increased from 683 billion barrels (bn bbls) in 1980 to 1,698 bn bbls in 2015. In the same period, proven reserves of natural gas multiplied by a factor of three. In the case of coal, current reserves represent enough for more than 100 years of consumption. However, other studies such as Hoel and Kverndokk (1996) and Strand (2010) point out that fossil fuels are exhaustible resources and, therefore, energy policy must take this into consideration together with environmental concerns.

As an initial step, we define the baseline scenario as the steady state equilibrium of the economy without taxes. This steady state equilibrium is related to a specific level of CO2 emissions and households' welfare. In this context, the environmental target is defined as a reduction in CO2 emissions compared with levels associated with the baseline scenario.

As is usual in such models, the optimal tax mix is obtained numerically. However, and despite the fact that there is no analytical solution, we find that the optimal tax mix satisfies the following two mathematical conditions represented in the following expressions:

$$\frac{Marginal\ productivity\ of\ oil}{Marginal\ productivity\ of\ coal} = \frac{International\ price\ of\ oil\ (1 + tax\ rate\ on\ oil\ )}{International\ price\ of\ coal\ (1 + tax\ rate\ on\ coal\ )} = \frac{Emissions\ from\ oil}{Emissions\ from\ coal} \quad (1)$$

$$\frac{Marginal\ productivity\ of\ natural\ gas}{Marginal\ productivity\ of\ coal} = \frac{International\ price\ of\ gas\ (1 + tax\ rate\ on\ gas\ )}{International\ price\ of\ coal\ (1 + tax\ rate\ on\ coal\ )} = \frac{Emissions\ from\ natural\ gas}{Emissions\ from\ coal} \quad (2)$$

The economic interpretation of these equations is that the ratio of marginal productivity between two fuels equals the ratio of domestic prices and, in addition, the ratio of marginal productivity also equals the ratio of marginal levels of emissions. In other words, a policymaker, in order to achieve the optimal tax mix, might want to consider, simultaneously, carbon emissions, the international prices of fossil fuels and the level of marginal productivity. According to standard economic theory, the price of any input, such as fossil fuels, must be equal to its marginal productivity in a competitive market. In other words, coal has the lowest price (in calorific units) and it reflects the lowest marginal productivity. The opposite is true of oil, which is the fuel with the highest price.

These equations imply that, first, the higher the level of CO2 emissions the larger the necessary tax rate and, second, the higher the level of international prices the lower the necessary tax rate. This is because international prices mirror marginal productivities of fuels and, as such more, expensive fossil fuels are also more productive and as a consequence they should have lower taxes.

Given the long-term international price of fossil fuels and the level of emissions, the optimal tax mix is the following: tax rate on oil<tax rate on natural gas<tax rate on coal. This means that, to be optimally effective, the tax rate on coal should be the highest because it is the fossil fuel with both the highest level of emissions and the highest marginal productivity. However, the most interesting result of the study is that, for maximum effectiveness, the tax rate on oil should always be the lowest, because of its high marginal productivity and despite natural gas being the cleanest fossil fuel.

For the sake of completeness, the following equations show the relationship between the ratio of marginal productivities of two fossil fuels and the ratio of their domestic prices, in the case of a carbon tax:

$$\frac{Marginal\ productivity\ of\ oil}{Marginal\ \ productivity\ of\ coal} =$$

$$\frac{International\ price\ of\ oil\ \ + carbon\ tax * emissions\ from\ oil}{International\ price\ of\ coal + carbon\ tax * emissions\ from\ coal} \quad (3)$$

$$\frac{Marginal\ productivity\ of\ \ gas}{Marginal\ \ productivity\ of\ coal} =$$

$$\frac{International\ price\ of\ oil + carbon\ tax * emissions\ from\ gas}{International\ price\ of\ coal + carbon\ tax * emissions\ from\ coal} \quad (4)$$

Figure 1 shows that the welfare losses from a carbon tax are larger than those from the optimal tax mix. In other words, the results suggest that, for any environmental carbon target, the optimal tax mix is always better, in terms of social welfare, than a carbon tax. Both policies tend to converge as the environmental target becomes more ambitious, resulting in almost the same welfare losses when the CO2 target reaches 80 percent. In addition, Figure 1 also shows that the abatement cost of CO2, in terms of welfare losses, is not linear, and the more ambitious the target the more it increases.

In our model, revenue from taxes on fossil fuels are directly transferred to households via a lump sum transfer. In this context, it is possible to imagine that higher taxes imply, at the same time, higher transfers to the household and as such there would be no impact on welfare or output. However, this is not the case in the great majority of instances. This negative relationship between carbon reduction and welfare occurs because taxes can distort the optimal allocation of resources, having a negative impact on macroeconomic activity. However, for very small

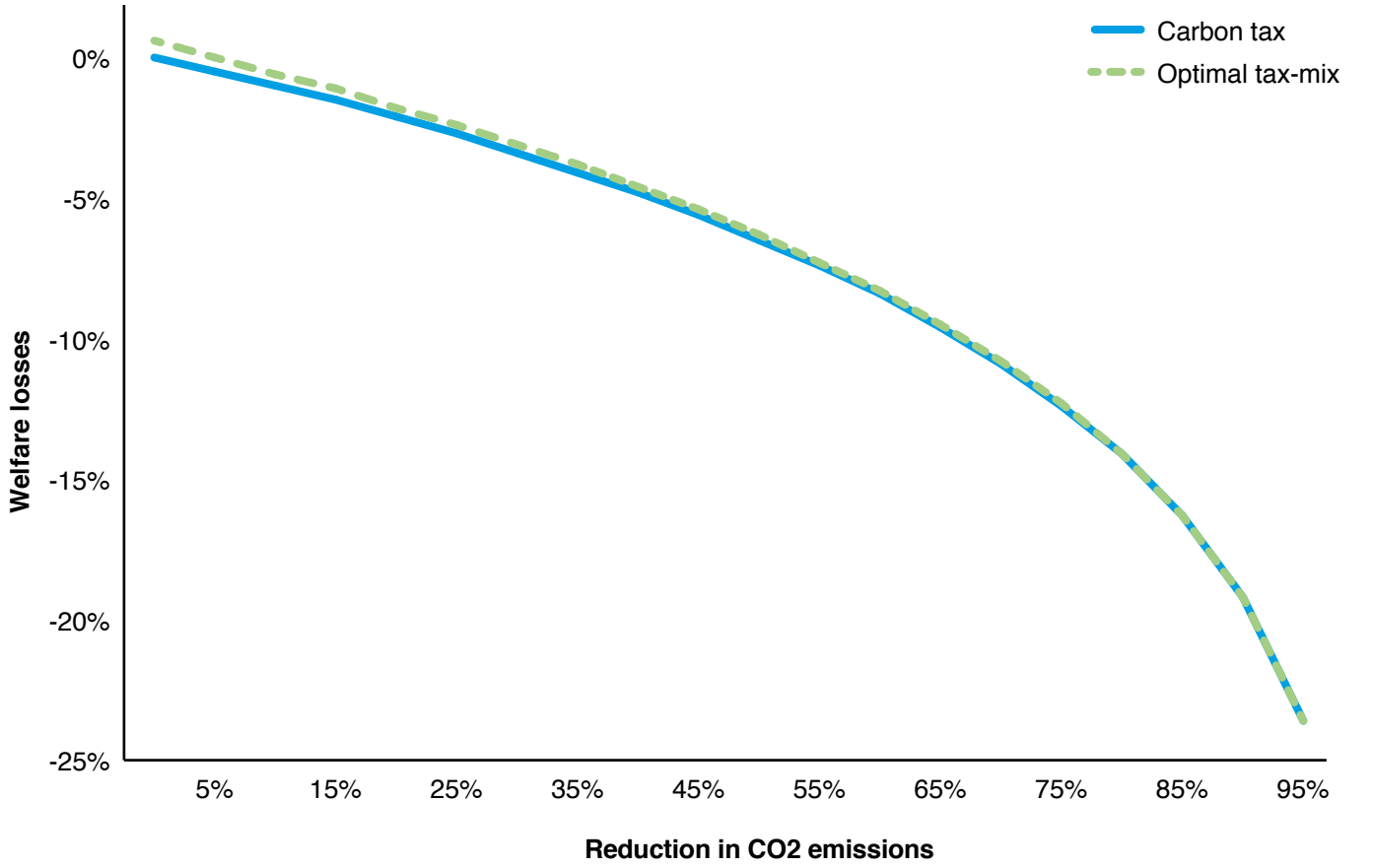

Figure 1. Welfare losses and carbon emissions.
Source: KAPSARC.

reductions of carbon emissions (below 5 percent) the optimal tax mix leads to a minimal increase in households' welfare.

To understand why in our analysis the carbon tax is not an optimal tax, it is important to note that international prices of fossil fuels provide information to economic agents in two different ways. First, they give information on the economic value of one unit of calorific energy. According to economic theory, a more expensive fossil fuel should, at the same time, be more productive. Second, fuel prices also provide information on the economic value of one unit of carbon emissions. The optimal tax mix modifies domestic prices by means of taxes to guarantee that there is no divergence between the 'economic value' of one calorific unit (productivity) and the economic value of one unit of CO2 emissions. Nevertheless, the carbon tax totally focuses on emissions and does not take into consideration the international price of fossil fuels. Only when the environmental target chosen is very ambitious does the carbon tax tend to converge with the optimal tax mix. A useful insight for policymakers might be that carbon taxes should only be implemented to achieve large reductions in CO2 emissions, because they are not an adequate policy tool for mild environmental targets. This result is probably unexpected for policymakers and practitioners who may think that carbon taxes would provide certainty around the costs and revenues, and, hence, tend to see them as an initial policy response.

Table 1 shows the optimal tax rate on oil, natural gas and coal for different environmental targets. Logically, taxes on fossil fuels should increase as the planned environmental target becomes more demanding. Yet, according to these results, subsidizing oil and natural gas can also form part of an optimal strategy to reduce CO2 emissions. This finding is counterintuitive and, obviously, has to be viewed in the context of a theoretical economic model. For CO2 reductions below 30 percent, the optimal strategy would be to tax coal heavily and subsidize oil and, to a lesser extent, natural gas. As the CO2 target becomes more ambitious, the scope to subsidize oil and natural gas disappears. The economic intuition behind this result is that there would be an opportunity for governments to take advantage of the gap in emissions and the gap in marginal productivity among fossil fuels. Taxing coal heavily reduces carbon emissions and provides revenue that might be used to promote the consumption of more productive and less polluting fossil fuels, i.e., oil and natural gas. This idea is not new. For example, Van der Ploeg and Withagen (2012) suggest that policymakers should disincentivize consumption of coal in favor of oil. For the sake of completeness, Table 1 also shows the carbon tax required to achieve the environmental target.

This theoretical counterintuitive result could represent a valuable insight for policymakers. The volume of carbon emissions per caloric unit is a critical variable for environmental policies, but this variable must be considered in conjunction with its economic value.

Finally, and as a corollary, we compare the tax revenues that result from the optimal taxes and those that follow from a carbon tax. We find that, for any environmental target, the carbon tax leads to a higher level of tax revenues. This may create a dilemma for policymakers, given that revenues from taxation could also be a policy objective. Logically, as the environmental target becomes more ambitious, tax revenues for both tax strategies tend to converge. From a social point of view, it may be questioned whether the higher level of tax revenues is entirely an advantage from an environmental policy perspective. In terms of raising funding for new programs, for example, it might be viewed as an advantage, but higher taxes might be seen by taxpayers as unreasonable and could lead to a loss of support for the environmental policies the tax was intended to support. This potential loss of social mandate is one of the greatest risks to the successful implementation of sound environmental and climate change policies, which by nature requires very long-term commitment and support. For this reason, environmental taxation should be carefully measured and pitched at levels that households and businesses are able and willing to pay. In theoretical models, heavy taxes creating incentives for efficient behavioral change represent a positive factor, but this may appear far less appealing in practice, with potential unintended consequences. These could include jeopardizing the very environmental programs the taxation was planned to underwrite.

Table 1. Optimal tax mix (percentage).

Target of CO2 reduction compared to baseline scenario	10	20	30	40	50	60
Tax rate on oil	-22.3	-14.5	-4.8	7.9	25.0	49.7
Tax rate on natural gas	-1.3	8.6	21.0	37.0	58.8	90.1
Tax rate on coal	139.3	163.2	193.2	232.0	284.7	360.7
Carbon tax (constant euros 2010)	6.9	15.4	26.4	40.9	60.7	89.7

Source: KAPSARC.

Conclusions and Policy Implications

Carbon taxes are becoming a popular policy tool to curb greenhouse emissions. Intuitively, it would appear that the best way to reduce carbon emissions would be by making them more expensive through taxes. However, this intuitive supposition is not entirely correct. The objective of our study was to analyze what would be the optimal taxes on fossil fuels from the point of curbing carbon emissions, and to evaluate any welfare losses that might be associated with these optimal taxes. Following this assessment, we compare the results with those that could be achieved with a carbon tax. To do this we use a general equilibrium model that has been estimated for the Spanish economy. If regional or even global carbon taxes were to be introduced, global demand for fossil fuel would be affected, with a negative impact on international prices, something that is considered in this study.

Our modeling produced findings that may be of interest to policymakers. First, to be most effective in reducing CO2 emissions, any tax on coal should be substantial, since it is the fossil fuel with the highest carbon emissions and lowest level of energy productivity. In addition, we find that a lower level taxation of oil and natural gas could also form part of an optimal strategy. The results from our model show that, for modest environmental targets for reducing CO2 emissions, subsidizing oil and natural gas would form part of an optimal strategy. This is a counterintuitive result and, obviously, it has to be seen in the context of a theoretical economic model. Logically, as the planned carbon target becomes more ambitious, the scope for subsidizing oil and natural gas disappears. Second, our results suggest that for optimum effectiveness the tax on oil should be lower than the tax on natural gas and still less than that on coal. This unexpected finding comes about because oil's marginal productivity is the highest of the three fossil fuels. Third, we find that a carbon tax tends to converge with the optimal tax mix when the environmental target is very ambitious.

Regardless of the tax strategy implemented, the results suggest that the marginal abatement costs of CO2, in terms of social welfare and gross domestic product (GDP), increase as the environmental policy becomes more ambitious. In other words, abatement costs in terms of welfare tend to be exponential, not linear, suggesting that adaption to climate change may also form part of a strategy for curbing carbon emissions.

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Appendix 1: Literature Review

This study explores the interaction among taxes on fossil fuels, social welfare and carbon emissions in the long run. We developed a model that allows government to tax independently oil, natural gas, coal and carbon emissions in a general equilibrium framework. Our analysis is based on the model by Blazquez et al. (2017). They explore the relationship between international prices of these three primary fossil fuels and carbon emissions in the short term using a dynamic stochastic general equilibrium (DSGE) model. They find that international prices affect carbon emissions directly via their impact on the fossil fuel mix and indirectly via their impact on economic growth. Pereira and Pereira (2014) also explore the impacts of international prices of fossil fuels in Portugal, but through a dynamic general equilibrium model with endogenous growth. Pereira and Pereira (2014) find that fossil fuel prices have a clear impact on economic activity, tax revenues and, ultimately, carbon emissions. Using a DSGE model, Golosov et al. (2014) analyzed the optimal environmental taxation in the long run. They find that the optimal carbon tax is, in general terms, higher than the well-known estimates by Nordhaus and Boyer (2000). Golosov et al. (2014) also state that coal is the main threat to climate change due to its abundant reserves. Finally, Tumen et al. (2016) also developed a DSGE model with a representative fossil fuel input to assess the macroeconomic short-term impacts of taxes on fossil fuels. They find that environmental taxes have a negative impact on GDP and inflation in the short term.

Using a computable general equilibrium model (CGE), Barker et al. (2007) explored the short-term impacts of environmental tax on carbon leakage in six European countries. They find that carbon leakage is very small. Kumbaroğlu (2003), using the same methodology for a small emerging open economy, suggests that, in order to accelerate economic growth in the short term in Turkey, the government should use taxes to incentivize coal consumption and discourage oil and natural gas. Solaymani (2017) explores the impact of taxes on fossil fuels on carbon emissions in a small open economy using a CGE. He states that carbon taxes are more efficient than energy taxes to reduce CO2 emissions in Malaysia.

Other studies focus on the impact of environmental taxes on the economy and on emissions. Fraser and Waschik (2013), also using a CGE, find that environmental taxes on different types of energy resources, including oil, coal and natural gas, lead to a ‘double dividend’ in the case of Australia. They find that environmental taxes allow for a more efficient tax system, curbing carbon emissions while improving social welfare at the same time. Ferran (2010), using a similar methodology for Spain, states that elasticities of substitution among inputs play a critical role in achieving a double dividend.

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About the Project

The objective of this research is to understand how different policy tools could expedite the transition toward a low-carbon economy in a cost-effective manner. This project takes a pragmatic approach to climate change policies, recognizing the need to balance the economic and environmental impacts of these policies. Ignoring the cost of these policies could not only create a substantial economic burden but also lead to a loss of social mandate. This is one of the greatest risks to the successful implementation of sound climate change policy, which by its nature requires clear and predictable government commitment over the long-term.

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