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A Comparison of Alternative Programs for Climate Policies

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Key Points

This research paper compares the relative welfare impact of different options for allocating the financing burden of climate change mitigation policies. Focusing on efficient ways to finance policies aimed at climate change mitigation, not only at direct carbon reduction, could delink the issue of carbon taxation from carbon emissions.

A Pigouvian tax is the traditional way of correcting for negative externalities, or the undesirable consequences for society arising from the actions of a company or industry sector, by levying additional taxes on that activity. Pigouvian taxation corrects society's welfare loss, however, from the viewpoint of the private sector, such taxation imposes a deadweight economic loss with respect to the original private equilibrium.

As an alternative, we evaluate a methodology that could fund investments to reduce carbon dioxide (CO_2) emissions, and we show that the policy we consider to be optimal from a tax standpoint – Ramsey pricing – can both improve world welfare and be politically more acceptable than other pricing options. Rather than focus directly on emissions reduction by taxing energy, a Ramsey pricing solution can be designed to minimize distortions while raising funds for investment in climate change mitigation.

> Ramsey pricing is seen as permitting the application of the principle of recognizing common responsibility for climate change mitigation, but at the same time differentiating the ability of individual countries to contribute to the common goal. Applied to energy prices, this means that efficient taxation should be inversely proportional to the consumer (household) energy demand elasticity of the individual country. That is to say, the more inelastic a country's consumer energy demand, the higher the efficient taxation should be in that country.

> With the aid of an extensive data set of 106 countries that were responsible for around 90% of total world energy consumption and carbon emissions in 2014, we estimate a complete demand system for world household consumption behavior and use the resulting country price elasticity values to compute an optimal Ramsey price scheme for financing investment in climate change mitigation policies.

> Compared to other allocation approaches – such as a Pigouvian tax, which is proportional among countries – we found that the overall world benefit of the Ramsey approach is higher. This modeling exercise suggests that there are a number of cost reduction opportunities in using a Ramsey allocation. Furthermore, we believe that Ramsey pricing leaves room for negotiating compensations, which could be politically more acceptable than traditional taxation approaches.

Summary

In the global carbon policy debate, pricing is considered to be a key instrument to achieving the desired levels of emissions reductions.

The Pigouvian tax is theoretically the best solution to tax carbon emissions, in order to achieve emissions reduction through financial investment, but it has not proved to be politically viable. A Pigouvian tax sets out to correct negative externalities, or consequences for society – such as the consequences of climate change – by levying additional taxes. However, from the viewpoint of the private sector, such taxation imposes a deadweight loss with respect to the original private equilibrium. This generates political resistance that may impede achieving the theoretical optimal solution.

Most international policy meetings since the Kyoto Protocol agreement have resulted in lukewarm commitments from developed economies and strong resistance from emerging economies over the fair economic allocation of the burden associated with the various calls for emissions reduction. This kind of situation suggests the need for alternative formulations, in the realm of what economists call ‘second-best options,’ to tackle the issue of realistically financing alternative policies.

This paper considers alternative policy formulation aimed at funding investment for climate policies, based on the principle of minimizing deadweight losses associated with taxation and on consumer preferences. (A deadweight loss is the added burden placed on consumers and suppliers when the market equilibrium is altered because of tax, for example. It results when supply and demand are out of equilibrium.)

The policy proposal we examine here is a Ramsey allocation, which aims at designing an economically optimal taxation scheme for financing climate mitigation investments. A Ramsey pricing policy, applied to energy prices, would mean that efficient taxation should be inversely proportional to the consumer (household) energy demand elasticity of the individual country. In other words, the more inelastic a country’s consumer energy demand, the higher the efficient taxation should be in that country. The overall taxation scheme is optimal because it minimizes the deadweight loss.

This strategy is not aimed at directly reducing emissions, and hence energy consumption. It can, in a more general way, help to assist with providing efficient funding for a wider range of policies, such as carbon sequestration, alternative fuels, energy efficiency, and the earth’s albedo enhancing. In this framework, notice that carbon sequestration and artificially enhancing the earth’s albedo represent technological solutions aimed at reducing carbon dioxide (CO_2) concentration and adding sunlight reflecting aerosol in the soil or stratosphere, thereby cooling the climate in a different way than reducing carbon emissions (NAS 1992). The strategy makes explicit use of household preferences, as expressed through their energy demand behavior, econometrically estimated at the world level.

A Ramsey allocation can be integrated into the general principle of mutual cooperation that motivates climate agreements, as it reflects a common but differentiated burden of all parties.

Introduction

In the global climate change policy debate, carbon pricing is considered by many economists to be a key instrument for achieving carbon emissions reductions. The traditional solution of computing a Pigouvian taxation based on the criterion of adding marginal social damage to the marginal private cost has not proved to be viable, despite a long history of international political dialogue since the signing of the Kyoto Protocol. Moreover, the general outcome of these meetings has been a bitter confrontation between developed and emerging economies as to a fair economic allocation of the burden associated with carbon emissions reduction.

This unfortunate state of affairs has two important consequences for climate policy. First, in many cases different countries' preferences as regards cost allocation oppose each other. Second, the societal benefit of climate change policy constitutes a worldwide positive externality and thus could involve a sizable policy-induced market distortion. For these reasons, the carbon price has to be different from the private marginal costs, pointing to the need for a second-best solution. A Ramsey (1927) price scheme, which minimizes the deadweight losses – the added burdens placed on consumers and suppliers when supply and demand are out of equilibrium – associated with given market inefficiencies, is a possible theoretical solution to the problem of quantifying the real costs of not tackling climate change.

Surprisingly, the vast literature on carbon pricing has not explored this analytical tool as a mechanism for sharing the economic burden of climate policy. The approach used so far involves designing the individual country commitments in proportion to emissions or gross domestic product (GDP), valued at a common marginal price. In some economic circles, this could be considered as a proxy trade barrier. The main shortcoming of this is that it creates a burden for newly industrialized countries that produce goods which are ultimately consumed by advanced economies. In other words, energy-intensive manufacturing countries risk being penalized for the carbon content of the final goods consumed by higher-income economies. There are relevant differences across major economies, as shown by the energy embodied in the trade between major world economies (Table 1), computed after the major global recession, based on input-ouput data in 2009 (Gasim 2015). Many emerging countries show positive values, while most industrial countries have decentralized energy-intensive, and hence carbon-intensive, production sectors.

This paper examines the potential for an economically optimal taxation policy to finance investments in carbon emissions reduction, based on households' preferences, as expressed through their energy demand behavior. This is a more complex, yet more accurate, way to quantify the 'polluters pay' principle. Households are the final consumers of goods and services and consumption. Goods incorporate energy used in the production process, whether they are produced domestically or imported. In addition, households are the ultimate owners of the corporate sector and the final beneficiaries of government expenditures. Accordingly, allocating a tax burden based on household consumption is a more precise way to account for all the energy incorporated into a society's economic activity. There are two caveats, however. First, ideally it would be optimal to include the indirect use of energy that is involved in the production of other goods and services consumed. Second, if local policies distort energy prices, the estimated price elasticities may suffer from these distortions. These issues are outside the scope of the present work.

We assume that heterogeneous consumers value the marginal damage resulting from greenhouse gas emissions differently, due to differences in interest, perception, income and values across the world. For example, since carbon emissions are of greater concern to younger and more educated citizens, a younger society, such as some emerging economies, is likely to have a different perception of the importance of carbon emissions than an older society. In addition, the higher incomes in a developed economy, such as the United States (U.S.) and those in Europe, determine higher environmental awareness. However, the level of concern over environmental issues differs between generations.

We contrast the Ramsey optimized scheme with two traditional approaches: uniform price taxation, levied in proportion to the country's importance in terms of world GDP and/or carbon emissions, and a specific scheme, better aligned with the ability to pay, levied only on the richest subset of countries.

We calculate each country's share of the cost of climate change mitigation, independent of how that overall cost is calculated. One potential example of a cost estimate is the announced level of investment necessary to achieve the International Energy Agency's (IEA's) 450 parts per million (ppm) Scenario (IEA 2016). The latest IEA scenarios project that $100 billion of additional investment per year will be required to support mitigation policy to stabilize atmospheric CO2 concentration at that level by 2030.

Negotiators reached an agreement on goals to mitigate global climate change at the 2015 United Nations Conference of Parties (COP 21) (United Nations 2015) in Paris, after the resounding failures that plagued previous conferences. The agreement entered into effect once it was ratified by 55 countries, despite the notification of withdrawal by the U.S. It aims to limit global warming to less than 2 degrees Celsius by the year 2100, compared with preindustrial levels. The agreement referred to a commitment to deliver financial aid of at least $100 billion to poorer economies by 2020, a sum which could increase in the future. However, the agreement did not set out a way forward on the allocation of donor country contributions, nor specify which countries should receive financial aid.

This research is not concerned with the plausibility of the COP 21 goals, but with the most reasonable and responsible outcome — a cooperative solution reached between the wealthiest countries representing a large proportion of world emissions. To achieve this, we consider a hypothetical agreement that includes the top emitting countries and the richest countries in terms of GDP per capita, which together represent at least 55 percent of total emissions.

In the empirical estimation, we also take account of geographic differences in evaluating the household price elasticity of energy consumption, which is directly related to emissions. The elasticity is a revealed preference measure of households' willingness to pay for energy consumption and, indirectly, for their willingness to pay for emissions reductions. The inverse of the demand elasticity is used to calculate the Ramsey proportionality factor to compute the burden sharing of each country's climate policy. The deadweight losses associated with the Ramsey solution are compared with other traditional burden-sharing mechanisms.

Table 1. Embodied energy content in final consumption – values in $U.S., 2009.

Country	Net energy content
Australia	-7560
Austria	-4620
Belgium	-4200
Brazil	-1260
Bulgaria	2100
Canada	2940
China	125580
Cyprus	-420
Czech	1680
Denmark	2520
Estonia	420
Finland	420
France	-21000
Germany	-21000
Greece	-3360
Hungary	-840
India	420
Indonesia	840
Ireland	-2100
Italy	-21840
Japan	-23520
Latvia	-420
Lithuania	-420
Luxembourg	420
Malta	0
Mexico	-3780
Netherland	1260
Poland	840
Portugal	-1680
Romania	-840
Russia	74760
Slovakia	-840
Slovenia	-420
South Korea	15120
Spain	-10500
Sweden	0
Taiwan	15120
Turkey	-3780
United Kingdom	-22260
USA	-98700
Rest of world	**12180**

Note: A negative value refers to a net import of embodied energy in traded products, while a positive value indicates a net export.

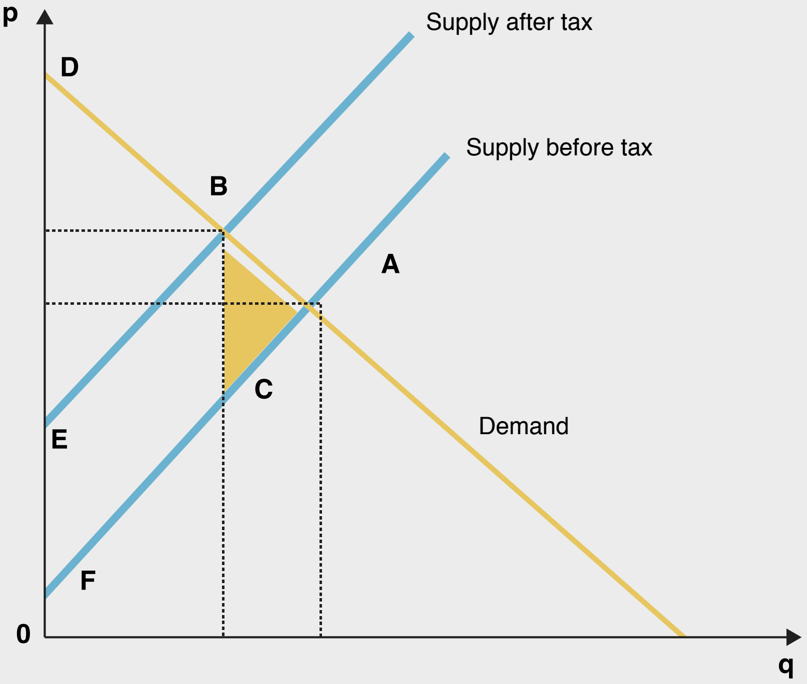
Source: Gasim 2015.

Deadweight loss and Pigouvian tax

When the market equilibrium of supply and demand is disturbed by tax – or, in general, by a price distortion – changes to the consumer and producer surplus result. Intuitively, a price increase for the product reduces the consumer surplus and a reduction in demand reduces the producer surplus. However, the additional government revenue is devoted to social goals and thus it can be seen to contribute to an increase in the welfare of society. The problem is that there is a net loss for society, described by economists as a 'deadweight loss.' It is a non-retrievable loss, calculated as the difference between the welfare of society before the tax (consumer + producer surplus) and after the tax (consumer + producer surplus + tax revenue).

Figure 1a illustrates this. The equilibrium before tax is shown at A. The area ADF represents the sum of the welfare of society (consumer + producer surplus). After tax, the new equilibrium is at B. The new welfare (consumer + producer surplus + tax revenue) is the area DBCF (consumer + producer get the area DBE; government revenue is BCEF). The difference is the area ABC, which is the deadweight loss.

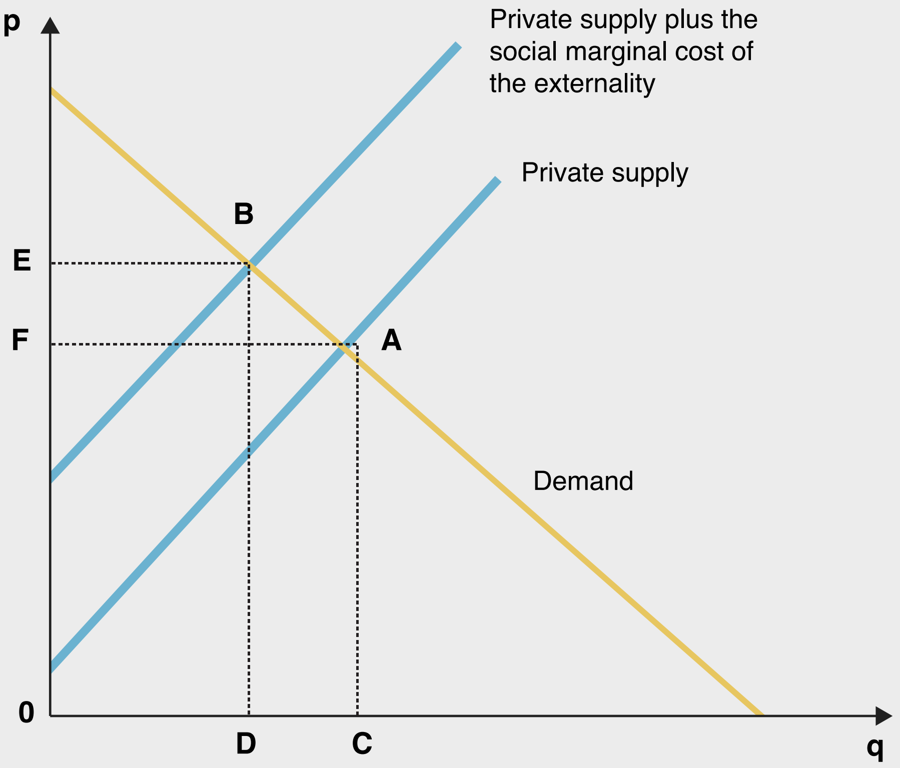
Figure 1a. Market equilibrium before and after tax and deadweight loss.



Source: KAPSARC.

We can also use a similar analysis to identify the optimal Pigouvian tax on a negative externality. In this case, the initial equilibrium is inefficient because it does not take into account the social damage that is inflicted by the existence of a negative externality. This initial equilibrium is point A in Figure 1b, where demand and private supply intersect. In point A, the additional social damage inflicted by the externality is not considered. But if we can add to private supply the correct measure of the cost of the externality (the damage associated with the externality), we can identify the efficient equilibrium, point B. Operationally, the Pigouvian tax is the tax that allows the market equilibrium to reach point B. The price increases from F to E and the quantity decreases from C to D. Point B is efficient because the sum of the marginal social and private cost is equal to the marginal benefit (the willingness to pay expressed by the demand curve).

Figure 1b. Market equilibrium before and after the Pigouvian tax.



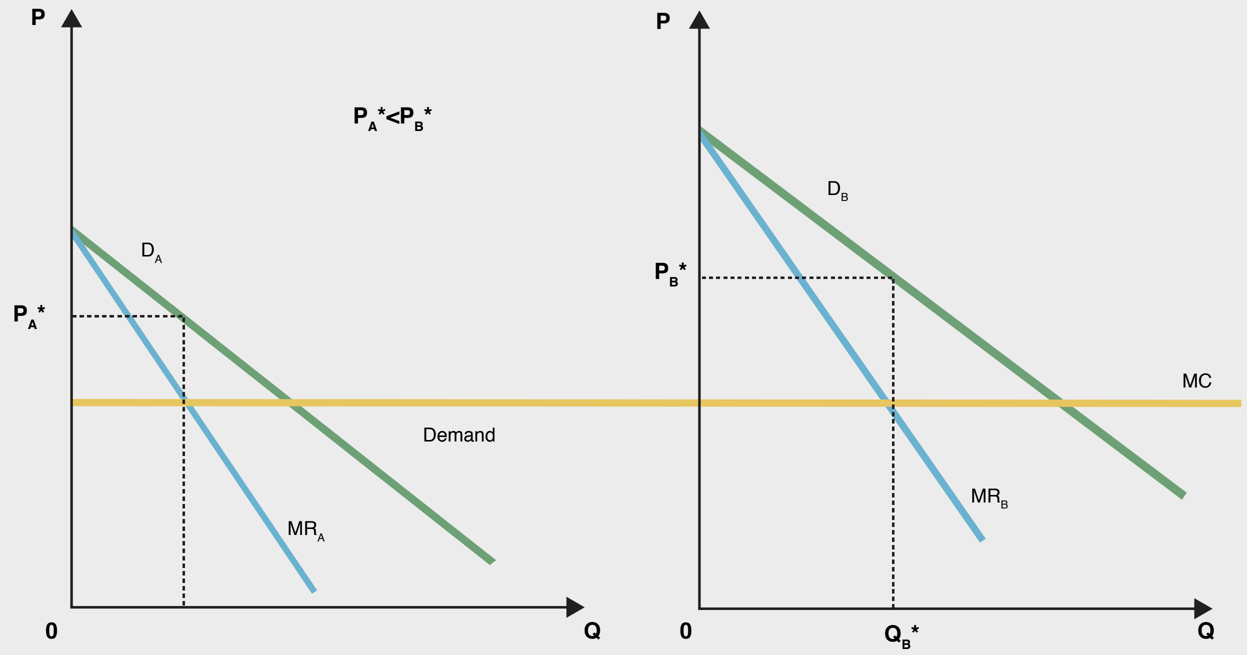
Source: KAPSARC.

The Ramsey pricing

When a monopolist is facing different groups of consumers with different behavior, it is convenient to discriminate among them in order to maximize the profit. Intuitively, if a group of consumers is relatively price inelastic, an increase in price increases the revenue (because the quantity decrease is less proportional than the price increase). Conversely, if another group of consumers is price elastic, a decrease in price increases the revenue (because the quantity increase is more proportional than the price decrease).

Figure 1c illustrates this. Note that, for simplicity, the marginal cost MC is constant. The profit maximization equates marginal cost to marginal revenue for both groups. Because there are differences in behavior, the solution yields different prices. Namely, the price P_B* is higher than P_A* because the elasticity of demand D_B is lower than that of D_A.

Figure 1c. Ramsey pricing equilibrium.



Source: KAPSARC.

Review of the Applications of Ramsey Pricing

Policymakers have long studied opportunities for emissions reduction. In 2005, the European Union (EU) implemented, with much fanfare, a carbon emissions trading system (EU ETS) as the basis for its greenhouse gas emissions reduction strategy. Local industrial sectors were lukewarm to it and the ensuing 2009 world recession substantially constrained trading liquidity (Hu et al 2015). China also aims to reduce carbon dioxide emissions per unit of GDP by 60% from the 2005 level by 2020, stop emissions growth by 2030, and cut carbon intensity by 45% compared with 2005 levels (UNFCCC 2016).

In 2017, China implemented an effective emissions trading scheme (ETS), the most efficient and important policy measure for carbon emissions reduction in the country. The previous pilot market test from 2013-2016 showed trade of 94 million tonnes of emissions allowances at an average price of $3.72/tonne (Zhang 2017). This is in addition to previous energy productivity achievements from 1995 onward (Atalla and Bean 2015). However, most of the climate policies already implemented are local or regional; global agreements have faced stiff opposition. The agreement at COP 21 marks a turning point, but there is no accord on the allocation of the financial burden.

Because Ramsey pricing minimizes the welfare loss associated with taxation, applying this mechanism in the energy sector could offer a solution for efficient allocation. It has previously been applied in tariff regulations for public utility sectors, such as telecommunications, transport, and electricity and gas distribution (Laffont and Tirole 1996). Its theoretical justification is the need to generate sufficient revenue to support a public utility service when an economically efficient allocation is unobtainable. In that context, Ramsey schemes have been applied at the industrial level, such as in the oil refining sector analysis of Babusiaux and Pierru (2007) or the optimal California gasoline tax proposed by Lin and Prince (2009). In addition, the analysis of airport fare structures by Hakimov and Mueller (2014) illustrates the cost recovery problems of airport operation.

Many applications of Ramsey pricing have analyzed the heterogeneity of demand elasticity behavior to justify charging differentiated prices to different groups of customers. Such studies include analysis of residential electricity customers in the U.S. (Berry 2002), China (Qi et al. 2008, Sun and Li 2013), Russia (Nahata et al. 2007), Brazil (Santos et al. 2012), Japan (Matsukawa et al 1993) and European countries (Deeney et al. 2016). Most of these studies conclude that the actual tariffs are at variance with the optimal Ramsey pricing scheme. More recently, other studies focused on Ramsey pricing to make the optimal allocation of the social cost of externalities, such as the environmental cost of air traffic (Martín-Cejas 2010), or electric network congestion and security management (Bigerna and Bollino 2016). Van der Ploeg (2016) and Boeters (2014) discuss various options for optimal carbon taxation.

Two main observations follow from the literature review. First, policy strategies tend to impose inefficient pricing schemes. Typical examples are the different tariff structures for residential and industrial electricity users, the various tax rates on gasoline and diesel in the transport sector, and the multiple tax rates on electricity and natural gas for residential consumers. These examples raise the question of why policy actions tend to be inefficient and why policymakers do not use Ramsey schemes. The reliability of the empirical estimations needed to compute Ramsey pricing is one challenge: policymakers need plausible and robust knowledge of the demand behavior of different groups and their related price elasticities to implement Ramsey pricing.

Additionally, the status quo tariff structure reflects historical lobbying by different constituencies. The strongest constituencies may oppose tariff changes and it may be politically difficult to change the tariff structure based on innovative empirical findings.

A further challenge is that Ramsey pricing maximizes efficiency, but it does not take into account equity across groups. It is also politically challenging because it entails price discrimination among consumers. A typical example is the fact that poor consumers are less price elastic: they cannot afford flexible behavior as they do not often have easy access to more efficient capital stock. This can be seen in their inability to borrow to finance purchases of new capital equipment. However, the possibility of achieving a given target more efficiently would permit the use of the overall gain to bring about welfare transfers across groups. As such, this should not be a serious problem.

Optimal Pricing and Demand Behavior

To investigate further the option of applying Ramsey pricing to international policymaking, we measure the cost associated with alternative policy strategies, contrasting the deadweight loss of the Ramsey scheme to those of other options based on consumers' ability to pay. We recall that even if a Ramsey scheme does not take into account equity, this omission can be corrected by means of income transfer related to the marginal utility of expenditures (Diamond 1975). We take the viewpoint of a supranational entity that is interested in achieving global aggregate efficiency and must consider the distributional effects among countries. The application of Ramsey pricing to climate change policy is appropriate, because it solves the problem of setting an optimal price scheme in cases where the efficient rule of price equal to marginal cost has failed or, in other words, when market failures like free riding behavior lead to a suboptimal solution. Free riders declare a distorted willingness to pay, counting that others will bear the cost, and the aggregate consequence is that insufficient resources are committed to the target. This is precisely applicable to the worldwide dilemma of climate change policy. The literature on the free riding effect (e.g., Bigerna et al. 2016) and on the issues that lead to a failure in political negotiations to agree on the correct amount of resources to be committed to climate policy (e.g., Weitzman 2017) is vast.

The cost of climate policy must be superimposed on the pure market price of energy, and ideally this revenue should be collected in the least distortionary way. Ramsey pricing is an ideal solution for adapting carbon pricing to different countries, according to their consumers' willingness to pay for such a commitment. Nonetheless, to the best of our knowledge, the existing literature contains no application of Ramsey pricing to climate policy.

Ramsey pricing has been confined to the debate on public utility regulation, highlighting how price discrimination is used to maximize profits at the expense of consumers. In this paper, we view Ramsey pricing as the application of the principle of recognizing common responsibility for climate change mitigation, but at the same time differentiating the ability to contribute to the common goal. It can be consistent with the framework set at the international conventions on climate change, aligning with the idea that there is an efficient way to make the rich pay more and the poor pay less through adopting appropriate compensation schemes.

We also recognize that the adoption of Ramsey pricing for final users in an international scheme is challenging because policymakers do not know precisely the elasticity of demand of the entire population. We aim to resolve this difficulty by using the models and computations presented in this paper.

In brief, the aggregate demand of the household sector is modeled by assuming the individual heterogeneous agent displays cost minimization behavior. Our hypothesis considers each country as a representative agent that rationally optimizes the simultaneous choice of a bundle of goods, based on the aggregation of heterogeneous agents (Deaton and Muellbauer 1980) within each country. The theoretical model is used to create the parameters for a model that is estimated econometrically, so that its revealed behavior shows the demand elasticity of each country for each good. The quantitative model arrived at from the empirical estimation is the basis for the allocation scheme. A detailed description of the model specification and estimation can be found in the technical appendix.

Empirical Results and Discussion on Alternative Allocation Options

We construct data for the household sector by considering the final consumption expenditure – composed of two goods, energy consumption and other goods consumption – for 106 countries for the period 2000 to 2013. Quantities of energy consumption, in tonnes of oil equivalent (toe), include both energy for residential uses and energy for transportation, representing the actual direct expenditure of households for all energy uses, in constant 2005 U.S. dollars. This allows us to capture the households' preferences for direct energy use for all household needs. The average share of energy consumption in household expenditure is around 18 percent. For OECD countries, the average is lower, at around 9 to 10 percent. Brazil and Russia show a share of 8 percent, with China at around 21 percent. Energy is used as a factor of production in the industrial sector and is incorporated in the value of goods – both produced domestically and imported – that are sold to final consumers, according to traditional input-output accounts. For this scheme to be valid, we assume that households are aware of the indirect energy content of the goods they consume, and do not discriminate between direct and indirect energy consumption, knowing that they are the final bearer of all forms of energy taxation for environmental policy. The same reasoning applies to energy use in the transportation sector. Households are responsible for a large share of total diesel and gasoline consumption, according to the input-output data for the largest economies, as shown in Table 2.

In particular, households' consumption of gasoline is around 90 percent of the total for most countries. We estimate demand functions according to equation (7) in the Appendix at both stages, using the seemingly unrelated regression (SUR) method. We derive unconditional elasticities for each country over the period 2000-2013. Our estimations are based on observations for 106 countries and reflect a plausible accuracy. The econometric tests indicate that the simultaneous estimation method of the equations is significant and better than the single equation approach. Detailed results are shown in the Appendix.

Table 2. The share of household gasoline and diesel household consumption.

Country	Diesel share	Gasoline share
Italy	31	88
Germany	33	84
U.S.	3	49
China	15	81
India	22	89
France	47	90
U.K.	32	94
Brazil	17	86

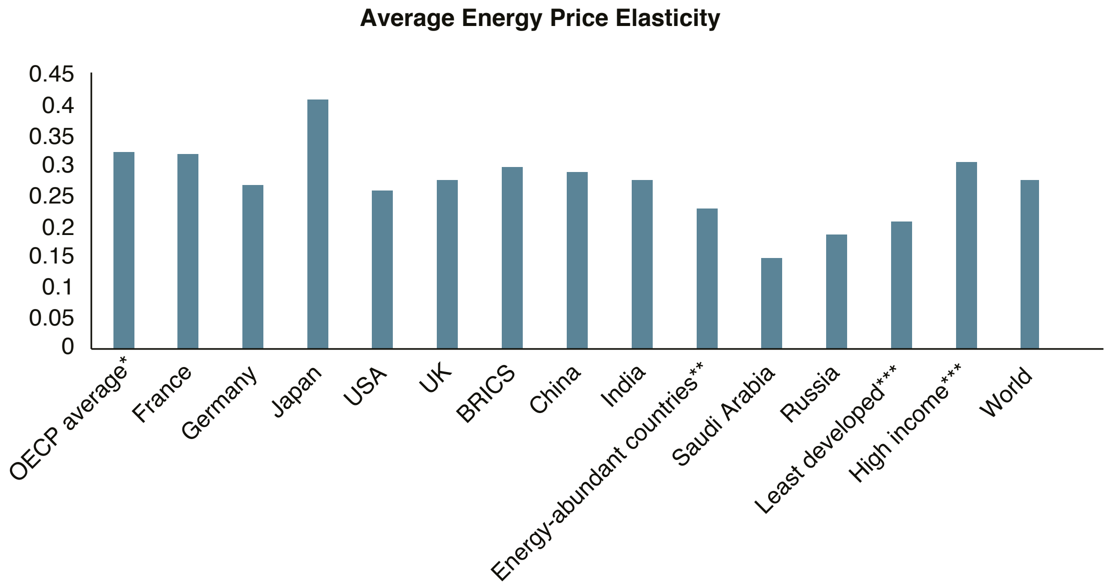
Note: The figures represent the shares of household consumption as part of total country consumption.

Source: KAPSARC.

We analyze household energy demand to meet both residential and transportation needs; the resulting demand elasticities reflect this aggregate behavior. We estimate the own-price elasticity, which shows the (percentage) change in consumption of a particular fuel when the price for that fuel changes. In other words, it measures the intensity of consumer responses to price changes. The estimated own-price elasticities for energy are significantly different across regions and countries and represent results for household behavior worldwide (shown in Figure 2 and Table A1 in the Appendix).

Note that in Figure 2 the elasticity values range from low to high absolute levels. The world average is around 0.28 in absolute value. The OECD average is higher, at around 0.32. The least developed countries' average elasticity is around 0.21, and the elasticity of energy- abundant countries is around 0.23. The behavior of Brazil, Russia, India, China and South Africa, the 'BRIC' countries is similar to that of OECD countries. Many Eastern countries and poor African countries have values around 0.1, and some large European countries have values around 0.4.

Figure 2. Energy price elasticities by regional averages – 2013.



(*) OECD excludes Israel, Estonia and Iceland.

(**) Net energy exporters, excludes Iran, Iraq and Venezuela.

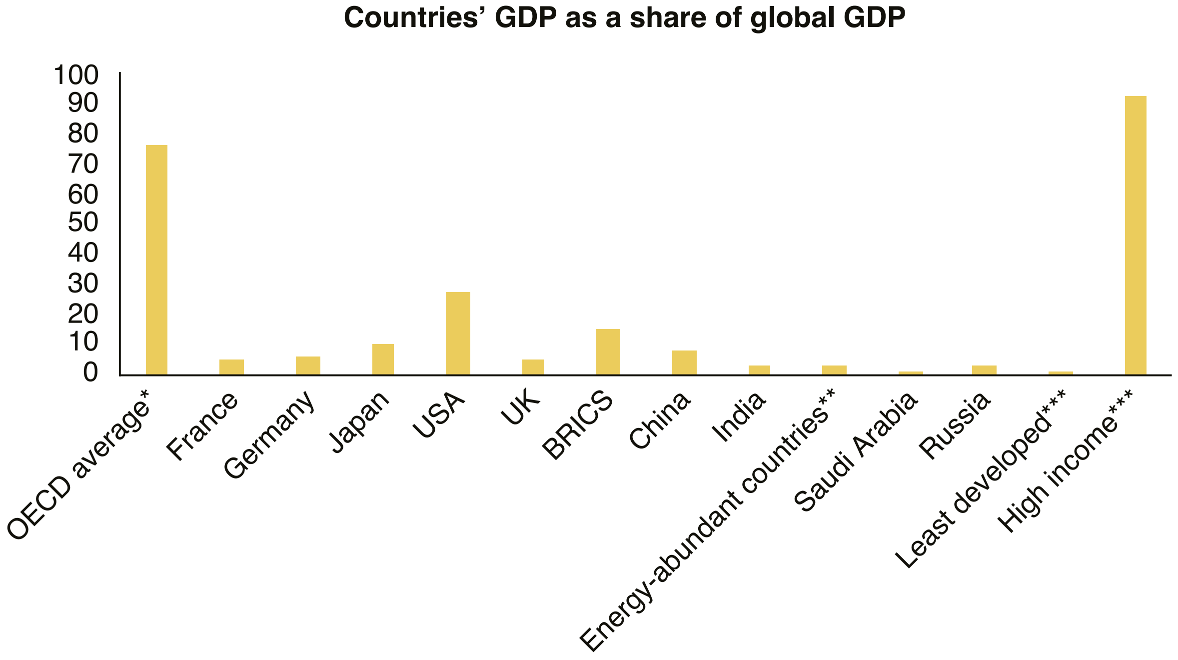
(***) Following the World Bank definition, includes economies with a gross national income per capita above $12,735 for high income and below $1,242 for least developed (for 2014).

Source: KAPSARC.

Numerous empirical estimations of energy demand elasticities appear in the existing literature. We checked our results against individual country estimations and worldwide comparative estimations. In particular, we considered two recent analyses of household behavior. Dahl (2012) provides elasticity estimates for transportation fuels only and Atalla and Hunt (2015) analyze demand elasticity solely for residential household energy consumption. Ourresults are generally consistent with both studies.The heterogeneity in these elasticities justifies our analysis of optimal prices by taking into account global wellbeing in constructing the social optimal pricing scheme.

The shares of world GDP for the main regions and countries are reported in Figure 3. For example, the OECD region accounts for 77 percent of world GDP and 20 percent of the world population, while energy abundant countries account for 2.5 percent of GDP and 7.9 percent of the population.

Figure 3. Countries' GDP as a share of global GDP – year 2013.



(*) OECD, excludes Israel, Estonia and Iceland.

(**) Net energy exporters, excludes Iran, Iraq and Venezuela.

(***) As per the World Bank definition, includes economies with a gross national income per capita above $12,735 for high income and below $1,242 for least developed (for 2014).

Source: KAPSARC.

We design alternative taxation pricing options, taking as a constraint the amount needed worldwide for climate policy, which is the exogenous amount G. This amount is determined in equation (6) in the Appendix. The latest IEA Scenarios (IEA 2016) forecast $100 billion of additional investment per year will be required to support mitigation policy to stabilize atmospheric CO_2 concentration at 450 ppm by 2030. In every scenario we calculate the allocation of this investment among countries according to alternative taxation options. The resource constraint is as follows: we consider that the amount of $100 billion (in real 2005 U.S. dollars) is on average 0.2% of world GDP, 0.3% of total household expenditure worldwide, or 2.5% of total household energy expenditure worldwide.

We construct seven alternative scenarios for energy price taxation of the household sector in each country (Table 3).

In each scenario, we introduce a surcharge on the existing energy price. The taxation revenue worldwide is the same for all scenarios and is constrained by the policy target. Scenario 1 designs a taxation burden for each country that is proportional to each country's share of world GDP. In Scenario 2, the allocation burden is proportional to each country's total household consumption expenditure, and in Scenario 3 the allocation burden is proportional to each country's household expenditure on energy. In Scenario 4, the allocation burden is proportional to each country's carbon emissions. Each of these four scenarios imposes a taxation burden proportional to a measure of the size of each country as a share of world GDP.

We find that Scenario 5 is the optimal Ramsey pricing scheme, based on the estimated price elasticities. We compute optimal Ramsey prices for every country using the inverse of the absolute value of that country's estimated energy demand elasticity.

Scenarios 6 and 7 consider only the top countries in term of emissions and GDP per capita, in the spirit of the Paris COP 21 agreement. In this way, we identify the top 67 richest countries, for which we compute, in Scenario 6, the burden share of participating countries using their GDP shares, and Scenario 7 displays the burden based on the optimal Ramsey shares.

Table 3. Description of various scenarios implemented.

Scenario	Description
1	Allocation based on GDP shares
2	Allocation based on household consumption expenditure shares
3	Allocation based on household energy expenditure shares
4	Allocation based on carbon emissions shares
5	Allocation based on Ramsey optimal pricing
6	Allocation based on the GDP shares of top 67 countries as per COP 21
7	Allocation based on Ramsey optimal pricing of top 67 countries as per COP 21

Source: KAPSARC.

For all scenarios, we calculate the deadweight loss in each country associated with different taxation schemes. Deadweight loss is represented by the area under the energy demand function for each scenario between the pre- and post-taxation price of energy, after the imposition of the taxation surcharge. We set out the detailed results for all scenarios in Tables 4 and 5.

Scenarios 1 through 4 are variants of the proportional principle, where each country shares the world climate policy cost in proportion to the size of its GDP, household consumption expenditure, household energy expenditures or carbon emissions, respectively. This implies that the weighting of each country in terms of total world wellbeing forms the basis for its contribution to climate policy costs.

Scenario 5 is based on household behavior, as reflected in energy price elasticity, to minimize welfare losses resulting from the policy action taken. In this case, each country's contribution is based on its human and economic behavioral decision-making, as shown by observed utility maximization behavior. The optimal taxation regime based on this scenario may lead to inequalities because poorer developing countries use largely outdated and inefficient equipment and have less flexibility in fuel choice. This brings lower demand elasticity. As a result, these countries may end up being taxed a higher portion of their income. Equation 5 reflects this.

An interesting result from Scenario 5 is that optimal taxation would impose a lower burden on leading polluters such as the U.S., Japan, Brazil, United Kingdom, France and Italy and a higher burden on China, India and Russia, reflecting their lower elasticities.

Table 5 sets out the results of Scenarios 6 and 7, in which the 67 richest countries, as measured by GDP per capita, share the burden of climate policy. This group includes China, which has the lowest GDP per capita in the group but which is the largest emitter. In total, this subset of 67 countries is responsible for around 80 percent of 2014 global carbon emissions.

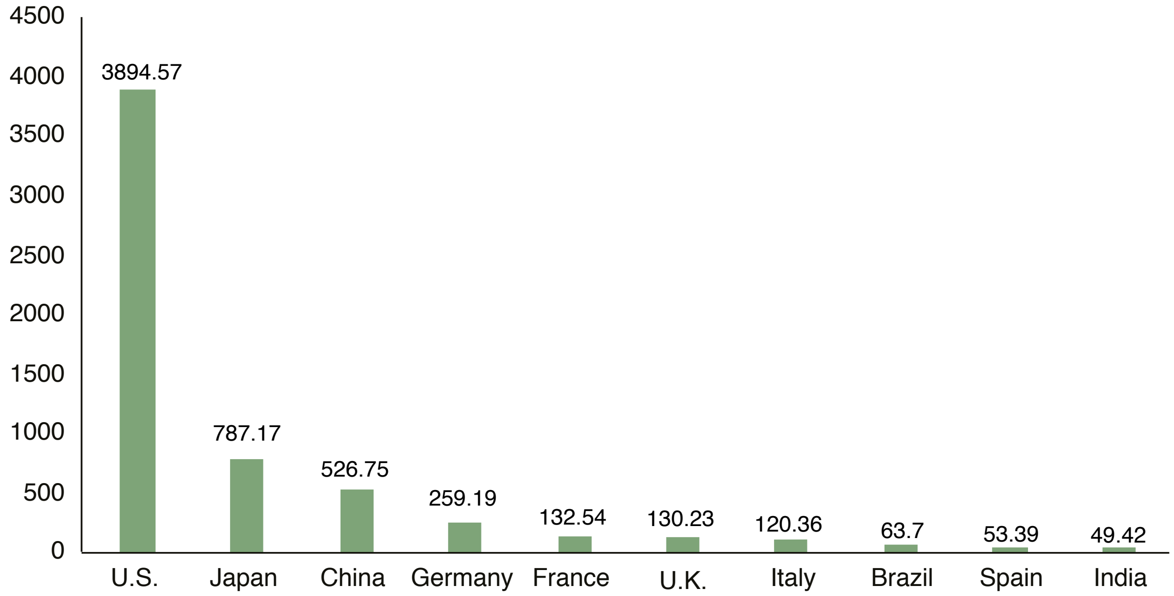
The climate policy cost for each country varies among the scenarios. In Scenario 1, the U.S. and China have shares of 29.5 percent and 7.8 percent, respectively. These values decrease to 22 percent and 6 percent in Scenario 5, 28 percent and 8 percent in Scenario 6 and 27 percent and 10 percent in Scenario 7. These results see China's tax burden vary considerably; more so when using the Ramsey scheme in Scenario 7, compared with Scenario 5. This shows that China must pay a high price to join the club of the richest countries, and thus the group of top donors, under the efficient Ramsey tax allocation.

Table 4 details the deadweight losses associated with Scenarios 1 and 5 while Table 5 reports deadweight losses for Scenarios 6 and 7. Comparing the loss associated with the various Scenarios, we find that Ramsey pricing shows the least loss. This is not surprising as the object of this methodology is to reduce economic inefficiencies. A proportional tax set at the same percentage in all countries yields a deadweight loss around five times larger than would be seen with Ramsey pricing. The scheme charging higher tax shares according to GDP (Scenario 1) yields an even greater loss. Efficiency would require a higher burden on upper mid-sized economies, such as Russia, India and Germany, and a lower burden on the big three economies of the U.S., China and Japan. This is quite different from the conventional negotiation strategies that were implemented at COP 21 and may implicitly explain the resistance of some advanced economies that see themselves as paying unjustly.

We can appreciate this point by comparing the deadweight losses between Scenarios 1 and 5 for major countries, as shown in Table 6 and Figure 4 (similar considerations can be made for Scenarios 6 and 7). In Scenario 1, the U.S. shows the highest loss compared with other regions of the world. Alternatively, in Scenario 5 the 28 EU member countries show a deadweight loss higher than the U.S. Note that the reduction in inefficiency due to Ramsey pricing of the first 10 countries – with a saving in deadweight loss as against Scenario 1 – is sufficient to compensate for the aggregate deadweight loss suffered by the last 66 countries. In addition, note that the monetary benefit for the winners far outweighs that for the losers (Table 6, bottom rows).

In other words, the burden imposed on the less efficient countries could be compensated for by the efficiency gains obtained by the richer and heavier-polluting countries. These results may help to rationalize the negative U.S. position, i.e., the U.S. withdrawal from the Paris agreement. The U.S. would have a significant proportionately higher burden under Scenario 1, the conventional burden sharing mechanism, taking up more than half of the world's deadweight loss, while its burden would be much lower in absolute and relative terms, under Scenario 5.

Figure 4. Deadweight loss savings in Scenario 5 vs. Scenario 1 – Major countries (million) – 2013.



Source: KAPSARC.

Table 4. Alternative taxation options – allocation of shares by countries worldwide – GDP and population shares (average 2008-2012). Numbers in parentheses correspond to scenarios.

Country	(1) GDP	(2) Total expend.	(3) Energy expend.	(4) Carbon emission	(5) Optimal Ramsey	Deadweight loss scenario (1)	Deadweight loss scenario (5)	Population share
Albania	0.02	0.03	0.04	0.02	0.02	-0.01	-0.03	0.05
Algeria	0.24	0.13	0.08	0.40	0.05	-0.20	-0.09	0.58
Armenia	0.01	0.02	0.01	0.02	0.00	0.00	-0.01	0.05
Australia	1.66	1.67	1.30	1.21	1.03	-17.39	-1.66	0.36
Austria	0.68	0.56	0.70	0.21	0.46	-4.55	-0.75	0.14
Azerbaijan	0.05	0.05	0.04	0.11	0.01	-0.04	-0.02	0.14
Bahrain	0.04	0.03	0.02	0.08	0.04	0.00	-0.06	0.02
Bangladesh	0.16	0.23	0.08	0.19	0.09	-0.07	-0.14	2.43
Belarus	0.09	0.20	0.16	0.21	0.35	-0.04	-0.57	0.15
Belgium	0.82	0.66	0.83	0.32	0.61	-5.99	-0.99	0.18
Bolivia	0.02	0.03	0.04	0.05	0.03	-0.01	-0.05	0.16
Bosnia-Herz.	0.03	0.04	0.04	0.08	0.08	0.00	-0.13	0.06
Brazil	2.21	2.80	2.07	1.44	0.94	-65.22	-1.52	3.18
Bulgaria	0.07	0.10	0.14	0.16	0.35	-0.02	-0.56	0.12
Burkina Faso	0.01	0.01	0.10	0.01	0.05	-0.02	-0.08	0.26
Cambodia	0.02	0.02	0.08	0.01	0.06	-0.01	-0.10	0.23
Cameroon	0.04	0.05	0.20	0.02	0.36	-0.03	-0.59	0.32
Canada	2.48	2.33	2.38	1.59	3.26	-27.36	-5.28	0.56
Chile	0.31	0.36	0.45	0.26	0.60	-0.66	-0.97	0.28
China	7.87	5.18	9.57	29.57	5.55	-540.46	-13.71	21.81
Colombia	0.38	0.45	0.30	0.24	0.37	-0.58	-0.60	0.75
Congo DR	0.02	0.08	0.26	0.01	0.40	-0.02	-0.65	1.06
Costa Rica	0.05	0.07	0.06	0.03	0.06	-0.02	-0.10	0.07
Cote d'Ivoire	0.04	0.05	0.18	0.02	0.83	-0.01	-1.34	0.32
Croatia	0.10	0.10	0.14	0.07	0.56	-0.02	-0.90	0.07
Cuba	0.11	0.09	0.02	0.12	0.01	-0.01	-0.02	0.18
Cyprus	0.04	0.04	0.06	0.02	0.03	-0.03	-0.05	0.01
Czech Rep.	0.31	0.22	0.42	0.36	2.03	-0.17	-3.28	0.17
Denmark	0.53	0.42	0.66	0.13	0.44	-3.30	-0.71	0.09
Dom. Rep.	0.09	0.14	0.14	0.07	0.10	-0.12	-0.16	0.16
Ecuador	0.09	0.14	0.08	0.12	0.04	-0.09	-0.07	0.24
Egypt	0.25	0.42	0.12	0.72	0.09	-0.25	-0.14	1.32
El Salvador	0.00	0.06	0.07	0.02	0.04	0.00	-0.07	0.10
Ethiopia	0.04	0.11	0.30	0.02	0.74	-0.03	-1.20	1.35
Finland	0.42	0.36	0.50	0.18	0.38	-1.76	-0.61	0.09
France	4.54	4.06	3.76	1.11	2.98	-137.36	-4.82	1.06
Gabon	0.02	0.01	0.06	0.01	0.03	-0.01	-0.06	0.02

Gambia	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.03
Georgia	0.02	0.03	0.03	0.03	0.01	-0.01	-0.02	0.07
Germany	6.11	5.13	6.52	2.39	6.14	-269.11	-9.92	1.33
Ghana	0.04	0.11	0.38	0.03	0.38	-0.09	-0.61	0.41
Greece	0.49	0.54	0.54	0.28	0.41	-2.25	-0.66	0.18
Guatemala	0.07	0.11	0.32	0.04	0.25	-0.17	-0.40	0.23
Guinea	0.01	0.01	0.06	0.01	0.11	0.00	-0.18	0.16
Honduras	0.02	0.03	0.07	0.03	0.03	-0.02	-0.05	0.12
Hungary	0.23	0.20	0.35	0.16	0.35	-0.51	-0.57	0.16
India	2.51	2.97	3.05	6.80	2.78	-53.91	-4.49	19.41
Indonesia	0.78	1.17	1.08	1.85	1.03	-5.73	-1.67	3.91
Ireland	0.42	0.28	0.36	0.12	0.19	-1.81	-0.31	0.07
Italy	3.62	3.46	3.41	1.30	2.16	-123.86	-3.50	0.99
Japan	9.45	7.30	8.20	3.89	5.08	-795.38	-8.21	2.08
Jordan	0.03	0.06	0.07	0.07	0.04	-0.03	-0.07	0.10
Kazakhstan	0.16	0.24	0.11	0.86	0.05	-0.24	-0.08	0.26
Kenya	0.05	0.08	0.59	0.04	2.50	-0.04	-4.04	0.67
Kyrgyz Rep.	0.01	0.01	0.02	0.02	0.01	0.00	-0.02	0.09
Latvia	0.03	0.05	0.07	0.03	0.07	-0.02	-0.12	0.04
Lebanon	0.06	0.09	0.06	0.07	0.04	-0.03	-0.06	0.07
Libya	0.11	0.05	0.03	0.13	0.03	-0.02	-0.06	0.10
Lithuania	0.06	0.07	0.10	0.05	0.15	-0.02	-0.24	0.05
Luxembourg	0.08	0.05	0.10	0.04	0.11	-0.05	-0.17	0.01
Malaysia	0.37	0.31	0.38	0.74	0.73	-0.46	-1.17	0.46
Malta	0.01	0.01	0.01	0.01	0.01	0.00	-0.01	0.01
Mauritania	0.01	0.01	0.02	0.01	0.02	0.00	-0.03	0.06
Mexico	1.92	2.40	1.46	1.53	0.83	-31.42	-1.34	1.85
Moldova	0.01	0.02	0.02	0.02	0.01	0.00	-0.02	0.06
Mongolia	0.01	0.02	0.02	0.06	0.01	0.00	-0.02	0.04
Morocco	0.15	0.14	0.19	0.19	0.08	-0.43	-0.13	0.52
Mozambique	0.02	0.03	0.12	0.01	0.27	-0.01	-0.43	0.38
Netherlands	1.40	1.01	1.16	0.55	1.58	-7.63	-2.55	0.27
N. Zealand	0.24	0.24	0.25	0.10	0.26	-0.36	-0.43	0.07
Niger	0.01	0.01	0.05	0.00	0.09	0.00	-0.14	0.25
Nigeria	0.32	0.59	1.67	0.29	5.40	-1.06	-8.72	2.58
Norway	0.66	0.55	0.47	0.15	0.27	-3.45	-0.43	0.08
Oman	0.09	0.06	0.04	0.21	0.02	-0.03	-0.04	0.05
Pakistan	0.27	0.55	0.43	0.54	1.44	-0.22	-2.33	2.83
Panama	0.05	0.05	0.06	0.03	0.04	-0.03	-0.07	0.06
Paraguay	0.02	0.03	0.04	0.02	0.06	0.00	-0.09	0.11
Peru	0.23	0.24	0.24	0.17	0.25	-0.33	-0.41	0.47
Philippines	0.27	0.34	0.53	0.27	0.77	-0.63	-1.25	1.52
Poland	0.79	0.79	1.34	1.04	2.50	-3.57	-4.05	0.63

Portugal	0.40	0.40	0.49	0.16	0.32	-1.93	-0.51	0.17
Qatar	0.19	0.06	0.02	0.28	0.03	-0.02	-0.05	0.03
Romania	0.24	0.44	0.33	0.28	0.69	-0.23	-1.12	0.35
Russia	1.90	2.97	1.87	5.93	2.45	-17.18	-3.96	2.32
Rwanda	0.01	0.01	0.04	0.00	0.03	0.00	-0.04	0.17
Saudi Arabia	0.74	0.47	0.13	1.71	0.22	-0.37	-0.36	0.44
Serbia	0.06	0.11	0.12	0.16	0.22	-0.02	-0.36	0.12
Slovakia	0.12	0.13	0.15	0.11	0.12	-0.15	-0.19	0.09
Slovenia	0.08	0.07	0.13	0.05	0.16	-0.05	-0.27	0.03
South Africa	0.60	0.78	0.76	1.56	0.47	-4.65	-0.76	0.81
South Korea	2.07	1.73	2.01	1.93	1.07	-49.79	-1.73	0.81
Spain	2.43	2.15	2.40	0.89	1.62	-56.01	-2.62	0.75
Sri Lanka	0.07	0.11	0.23	0.05	0.41	-0.05	-0.67	0.34
Sudan	0.08	0.14	0.19	0.05	0.13	-0.14	-0.20	0.65
Sweden	0.82	0.63	0.96	0.17	0.91	-5.33	-1.48	0.15
Switzerland	0.88	0.78	0.55	0.12	0.27	-6.29	-0.44	0.13
Tanzania	0.04	0.05	0.15	0.02	0.15	-0.03	-0.25	0.73
Thailand	0.43	0.39	0.69	0.99	0.37	-3.55	-0.59	1.13
Tunisia	0.08	0.09	0.11	0.08	0.19	-0.03	-0.31	0.17
Turkey	1.17	1.70	1.41	1.05	0.92	-16.02	-1.48	1.19
Ukraine	0.19	0.50	0.33	0.94	2.79	-0.05	-4.52	0.75
UAE	0.44	0.54	0.19	0.59	0.12	-0.87	-0.20	0.12
U.K.	4.86	5.15	3.99	1.47	3.62	-136.08	-5.85	1.02
U.S.	26.86	29.50	22.76	17.40	22.46	-3930.87	-36.30	5.04
Uruguay	0.05	0.07	0.07	0.03	0.37	0.00	-0.60	0.05
Vietnam	0.15	0.28	0.40	0.57	0.24	-0.66	-0.38	1.42
Total world	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**-6339.24**	**-166.39**	**100.00**

Source: KAPSARC.

Note: Columns 1-5: country share in the scenario. Columns 6-7 deadweight loss $million. Column 8: country population share.

Table 5. Scenario as per COP 21 Paris Agreement using optimal Ramsey tax and GDP share tax and deadweight loss in million (average 2008-2012). Numbers in parentheses correspond to scenarios.

Country	(6) GDP share as per COP 21	(7) Optimal Ramsey pricing as per COP 21	Deadweight loss using GDP weights	Deadweight loss using Ramsey weights
Albania	0.02	0.03	-0.02	-0.01
Algeria	0.25	0.07	-0.27	-0.02
Australia	1.77	1.27	-23.63	-0.30
Austria	0.72	0.57	-6.18	-0.13
Bahrain	0.04	0.04	-0.01	-0.01
Belarus	0.09	0.43	-0.06	-0.10

Belgium	0.87	0.75	-8.13	-0.18
Bosnia-Herzegovina	0.03	0.10	-0.01	-0.02
Brazil	2.35	1.16	-88.62	-0.27
Bulgaria	0.07	0.43	-0.03	-0.10
Canada	2.63	4.02	-37.18	-0.94
Chile	0.33	0.74	-0.90	-0.17
China	8.35	10.45	-734.36	-2.45
Colombia	0.40	0.46	-0.79	-0.11
Costa Rica	0.05	0.07	-0.02	-0.02
Croatia	0.10	0.69	-0.03	-0.16
Cuba	0.12	0.02	-0.02	0.00
Cyprus	0.04	0.04	-0.04	-0.01
Czech Rep.	0.32	2.50	-0.23	-0.59
Denmark	0.56	0.54	-4.49	-0.13
Dominican Rep.	0.10	0.12	-0.16	-0.03
Ecuador	0.10	0.05	-0.13	-0.01
Finland	0.45	0.47	-2.39	-0.11
France	4.82	3.67	-186.64	-0.86
Gabon	0.02	0.04	-0.02	-0.01
Germany	6.49	7.56	-365.66	-1.77
Greece	0.52	0.50	-3.06	-0.12
Hungary	0.24	0.43	-0.69	-0.10
Ireland	0.45	0.24	-2.47	-0.06
Italy	3.84	2.67	-168.30	-0.63
Japan	10.04	6.25	-1080.75	-1.47
Kazakhstan	0.16	0.06	-0.33	-0.01
Latvia	0.04	0.09	-0.02	-0.02
Lebanon	0.06	0.05	-0.05	-0.01
Libya	0.11	0.04	-0.02	-0.01
Lithuania	0.06	0.19	-0.03	-0.04
Luxembourg	0.09	0.13	-0.07	-0.03
Malaysia	0.39	0.89	-0.63	-0.21
Malta	0.01	0.01	0.00	0.00
Mexico	2.04	1.02	-42.69	-0.24
Netherlands	1.49	1.94	-10.37	-0.46
New Zealand	0.25	0.33	-0.48	-0.08
Norway	0.70	0.33	-4.69	-0.08
Oman	0.09	0.03	-0.04	-0.01
Panama	0.05	0.05	-0.04	-0.01
Peru	0.25	0.31	-0.45	-0.07
Poland	0.83	3.08	-4.86	-0.72
Portugal	0.42	0.39	-2.63	-0.09
Qatar	0.20	0.04	-0.03	-0.01
Romania	0.25	0.85	-0.32	-0.20

Russia	2.02	3.01	-23.35	-0.71
Saudi Arabia	0.78	0.28	-0.51	-0.06
Serbia	0.06	0.27	-0.03	-0.06
Slovakia	0.13	0.14	-0.21	-0.03
Slovenia	0.09	0.20	-0.07	-0.05
South Africa	0.63	0.58	-6.31	-0.14
South Korea	2.20	1.32	-67.65	-0.31
Spain	2.58	1.99	-76.10	-0.47
Sweden	0.88	1.12	-7.25	-0.26
Switzerland	0.93	0.34	-8.55	-0.08
Thailand	0.45	0.45	-4.83	-0.11
Tunisia	0.09	0.23	-0.05	-0.05
Turkey	1.25	1.13	-21.77	-0.27
UAE	0.47	0.15	-1.18	-0.04
U.K.	5.16	4.46	-184.90	-1.05
U.S.	28.52	27.66	-5341.16	-6.49
Uruguay	0.05	0.46	-0.01	-0.11
World total	**100.00**	**100.00**	**-8526.91**	**-23.48**

Source: KAPSARC.

Note: Columns 1-2: country share in the scenario. Columns 3-4: deadweight loss $million.

Table 6. Deadweight loss savings under the Ramsey scheme ($billion) – year 2013.

Countries	Scenario 5 vs.1	Scenario 7 vs. 6
U.S.	3894.57	5334.67
China	526.75	731.91
Japan	787.17	1079.28
Russia	13.22	22.64
EU_28	718.12	1031.64
Winners	6208.47 (39)	8504.24 (54)
Losers	-35.75 (67)	-0.75 (13)

Note: Column 1: Deadweight loss of scenario 5 minus scenario 1.
Column 2: Deadweight loss of scenario 7 minus scenario 6.
Number of countries in parenthesis.

Source: KAPSARC.

Conclusions and Policy Implications

We consider that the model we have developed provides a coherent and integrated empirical tool for policymakers to quantify how energy demand responds to policy. We created it by estimating a complete demand system for world household energy consumption behavior and used the resulting country price elasticity values to compute an optimal Ramsey price scheme to support investment in climate change mitigation policies.

Our approach is unique in accurately estimating demand response to prices by explicitly modeling a utility-maximizing rational behavior for consumers in each of the countries studied. The study finds that households in emerging economies have less price elasticity than advanced ones.

This leads us to two conclusions:

> First, we have identified an efficient worldwide taxation scheme to fund investments in climate change mitigation policies. This taxation strategy depends on the heterogeneity of household behavior in countries around the world. Accordingly, policy actions could be designed around the efficiency principle, with eventual compensation for political reasons, rather than on a debatable equity principle that leads to greater economic inefficiency.

> Second, our empirical estimation shows significant differences in the burden allocation when the allocation involves only the world's richest countries. However, this means that some countries might pay a high 'access price' to be part of the group of richest countries. To be successful, negotiations must deal with the risk of opportunistic behavior by countries attempting to avoid this high price.

The issue of raising taxes is a difficult task for any policymaker because it inevitably involves distortions. In general, a policymaker is confronted with funding limitations and the associated efficiency-equity trade-off. Pricing policies based on the ability to pay have a role in improving the living conditions of poor households, but usually impose a societal cost in terms of market inefficiency. By contrast, when implementing policies to promote maximum economic efficiency, the poorest in society often suffer. Our research has shown that there is room for compensation without compromising efficiency.

In this respect, our approach demonstrates to policymakers the quantitative range of the associated efficiency-equity trade-off. Our estimations of demand elasticities should prove useful in constructing the minimum distortion pricing policy – the so-called Ramsey pricing – that is one cornerstone of the efficiency-equity trade-off. We also construct the maximum equitable solution based on countries' share of total world GDP and/or household expenditure and/or carbon emissions. Policymakers also need to assess the economic impact associated with equitable intervention, such as price subsidies for the poor and elderly.

We provide a method of measuring this in terms of deadweight loss. (A deadweight loss is the added burden placed on consumers and suppliers when the market equilibrium is altered because of, for example, tax. It results when supply and demand are out of equilibrium.)

Our results suggest that governments could adopt a more inclusive approach, taking into consideration the behavior of their populations rather than purely abstract technical standards. The estimated elasticities are behaviors that can be monitored over time: as the population progresses and becomes richer, tastes and behaviors evolve, and consequently, the elasticities change and the Ramsey scheme is updated.

In other words, given the political difficulty of implementing a pure textbook Pigouvian taxation, our proposal could provide a different route. It could also prove to be more viable, with higher chances of political acceptance because it minimizes the deadweight loss. Consequently, this proposal is not a mere redistributive policy, creating winners and losers within the political constituencies involved, but one that creates a net welfare improvement, i.e., reduced deadweight loss. This is a positive item which may be used for compensation and thus could enhance political consensus.

In conclusion, this paper advocates a new global policy stance that takes estimated consumer demand elasticity as a new basis for discussion and for differentiating taxation allocation worldwide. Policymakers will likely be aware that they will face politically responsible economic agents who require an efficient proposal that is beneficial to the welfare of society to pay for investments to help mitigate climate change.

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Technical Appendix

The country agent faces the simultaneous choice between 'energy' e and a 'composite good' y, which is a representation of the rest of the goods and services demanded by the agent. The optimal allocation is dependent on a set of exogenous variables not explicitly considered by the agent in the preference set (Browning and Meghir 1991). These variables include the available capital stock and country-specific climate conditions. Both variables influence the allocation between energy and other goods, insofar as they capture the level of available technology and the country's natural environment. We are particularly interested here in accurately modeling energy demand, recognizing that including capital stock and climate ensures unbiased empirical estimates (Deaton and Muellbauer 1980).

Formally, the country agent's consumption cost function can be defined as:

$$C=C(p_e,p_y,K,W,U)= \min\,[(p_e\, e + p_y\, y) \mid U(e,y,K,W)] \tag{1}$$

which depends on the prices of energy and of the composite good $[p_e, p_y]$, total utility U, the capital stock K and country-specific climate conditions W. An indirect utility function can be defined, inverting equation (1):

$$U=V(p_e, p_y,K, W, C) \tag{2}$$

from which the Marshallian demand function can be defined using Roy's identity. The duality theory allows demand functions to be expressed using Roy's identity, which states the demand function is the negative of the ratio of the partial derivative of the indirect utility function with respect to price and the partial derivative with respect to expenditure:

$$h_i= - \partial V/\partial p_i /\partial V/\partial C = g_i(p_y, p_e, K, W, C) \text{ where } i= y, e \tag{3}$$

Equation (3) defines the demand functions h_i for $i=[y, e]$, where h_y is the demand for composite good y and h_e is demand for energy. From equation (3) price demand elasticity for each good can be calculated.

We assume that policymakers have correct knowledge of country-specific demand functions and are willing to charge optimal prices to buyers in each country, taking into account efficiency objectives.

We also assume that policymakers consider the observed price without carbon-associated externalities and want to determine the optimal charge tj to be levied to each country j that must be added to the market price to satisfy the constraint that the total tax revenue equals the agreed-upon world target:

$$p_{ej}^{*}=p_e + t_j \tag{4}$$

In equation (4) the optimal Ramsey price is defined as the sum of the observed energy market price and the country's optimal tax.

The optimal Ramsey (1927) price can be computed as for all countries j as:

$$[(p^*_{ej} - p_e)/p_e] / [(p^*_{ei} - p_e)/p_e] = (1/|\varepsilon j|) / (1/|\varepsilon i|) \tag{5}$$

subject to the constraint:

$$G = \Sigma p_{ej} e_j = \Sigma p_{ej}^{*} e_j \tag{6}$$

Equation (5) states that the relative increase in the observed market price in country j over that in country i is inversely proportional to the ratio of the demand elasticities of the two counties. This defines the efficient price p^*_{ej} increase over the market price, where p^*_{ej} and p^*_{ei} are optimal prices, p_{ej} are historical country prices, e_j are quantities, and ε_{ej} are estimated own price elasticities of energy for all countries i and j.

The quantity G in equation (6) is the exogenous target revenue. It can be interpreted as the world revenue derived by charging t_j to each country j according to its behavior. In the Ramsey scheme, there is no room for distributive equity considerations because the aim is to minimize inefficiency.

The empirical specification of equation (3) is the Generalized Almost Ideal demand model proposed by Bollino (1987), which satisfies consumer theory restrictions, i.e., adding up, symmetry, homogeneity and heterogeneous consumer exact aggregation constraints. We use this parametrization because it is suitable for the estimation of flexible demand behavior, especially with large variability across heterogeneous agents (Bigerna and Bollino 2015). Formally, the parametric function to be estimated is:

$$h_{ij} = \gamma_{ij} + E_j^s/p_i\, [\alpha_{ij} + \textstyle\sum_t \alpha_{tij}\, ln(p_t) + \beta_{ij}\, ln(E_j^s/p^s)] \quad E_{js} = E_j - (\textstyle\sum_{\gamma ij}\, p_j)$$

$$p^s = \sum w_j\, ln(p_j) \tag{7}$$

For the two demand functions, $i = e,y$ and for each country j. E_j and E_j^s denotes the expenditure and supernumerary expenditure, respectively; while p^s denotes the Stone price aggregator.

The estimated parameters are γ_{ij}, γ_{ij} expressing the committed quantity parameters; α_{ij}, α_{ij}, αi_{tj}, αi_{fj}, β_{ij}, β_{ij} are structural coefficients; w_i, are average budget shares. After the econometric estimation of the structural parameters, we take the derivatives of equations (7) and (8) with respect to prices to compute the elasticities ε_{ij} for goods i and for each country j, i at the equilibrium prices and quantities. We set out below the shares of goods in the household budget and the estimated elasticities (Table A1).

Table A1. Shares of goods and energy in final household consumption and energy demand elasticity – average 2008-2012(*)
(*)W1 = share of other goods; W2 = share of energy; Elasticity = energy demand elasticity

Country	W1	W2	Elasticity
Albania	0.822	0.178	-0.53
Algeria	0.926	0.074	-0.40
Armenia	0.910	0.090	-0.75
Australia	0.911	0.089	-0.32
Austria	0.858	0.142	-0.38
Azerbaijan	0.912	0.088	-0.84
Bahrain	0.897	0.103	-0.17
Bangladesh	0.962	0.038	-0.22
Belarus	0.885	0.115	-0.12
Belgium	0.856	0.144	-0.35
Bolivia	0.879	0.121	-0.31
Bosnia-Herz.	0.872	0.128	-0.15
Brazil	0.913	0.087	-0.56
Bulgaria	0.837	0.163	-0.10
Burkina Faso	0.171	0.829	-0.54
Cambodia	0.625	0.375	-0.32
Cameroon	0.506	0.494	-0.14
Canada	0.883	0.117	-0.18
Chile	0.856	0.144	-0.19
China	0.785	0.215	-0.44
Colombia	0.924	0.076	-0.20
Congo DR	0.639	0.361	-0.16
Costa Rica	0.904	0.096	-0.24
Cote d'Ivoire	0.546	0.454	-0.05
Croatia	0.838	0.162	-0.06
Cuba	0.979	0.021	-0.30
Cyprus	0.851	0.149	-0.50
Czech Rep.	0.785	0.215	-0.05
Denmark	0.823	0.177	-0.38
Dominican Rep.	0.881	0.119	-0.36
Ecuador	0.931	0.069	-0.48
Egypt	0.967	0.033	-0.34
El Salvador	0.860	0.140	-0.41
Ethiopia	0.615	0.385	-0.10
Finland	0.841	0.159	-0.33
France	0.894	0.106	-0.32
Gabon	0.564	0.436	-0.41
Gambia	0.659	0.341	-3.60

Georgia	0.850	0.150	-0.64
Germany	0.855	0.145	-0.27
Ghana	0.616	0.384	-0.26
Greece	0.884	0.116	-0.34
Guatemala	0.676	0.324	-0.32
Guinea	0.538	0.462	-0.14
Honduras	0.763	0.237	-0.51
Hungary	0.800	0.200	-0.25
India	0.877	0.123	-0.28
Indonesia	0.891	0.109	-0.27
Ireland	0.855	0.145	-0.48
Italy	0.888	0.112	-0.40
Japan	0.872	0.128	-0.41
Jordan	0.863	0.137	-0.43
Kazakhstan	0.948	0.052	-0.57
Kenya	0.186	0.814	-0.06
Kyrgyz Rep.	0.809	0.191	-0.47
Latvia	0.819	0.181	-0.25
Lebanon	0.923	0.077	-0.39
Libya	0.938	0.062	-0.20
Lithuania	0.833	0.167	-0.16
Luxembourg	0.766	0.234	-0.25
Malaysia	0.858	0.142	-0.13
Malta	0.893	0.107	-0.42
Mauritania	0.721	0.279	-0.24
Mexico	0.930	0.070	-0.45
Moldova	0.837	0.163	-0.57
Mongolia	0.796	0.204	-0.57
Morocco	0.851	0.149	-0.60
Mozambique	0.536	0.464	-0.11
Netherlands	0.869	0.131	-0.19
New Zealand	0.882	0.118	-0.24
Niger	0.500	0.500	-0.14
Nigeria	0.608	0.392	-0.08
Norway	0.902	0.098	-0.45
Oman	0.935	0.065	-0.39
Pakistan	0.908	0.092	-0.07
Panama	0.855	0.145	-0.36
Paraguay	0.828	0.172	-0.18
Peru	0.888	0.112	-0.24
Philippines	0.819	0.181	-0.17
Poland	0.806	0.194	-0.14
Portugal	0.861	0.139	-0.39
Qatar	0.954	0.046	-0.20

Romania	0.915	0.085	-0.12
Russia	0.926	0.074	-0.19
Rwanda	0.552	0.448	-0.44
Saudi Arabia	0.967	0.033	-0.15
Serbia	0.870	0.130	-0.14
Slovakia	0.870	0.130	-0.32
Slovenia	0.784	0.216	-0.20
South Africa	0.887	0.113	-0.41
South Korea	0.867	0.133	-0.48
Spain	0.872	0.128	-0.38
Sri Lanka	0.771	0.229	-0.14
Sudan	0.822	0.178	-0.38
Sweden	0.825	0.175	-0.27
Switzerland	0.919	0.081	-0.52
Tanzania	0.763	0.237	-0.22
Thailand	0.795	0.205	-0.48
Tunisia	0.854	0.146	-0.15
Turkey	0.904	0.096	-0.39
Ukraine	0.922	0.078	-0.03
U.A.E.	0.958	0.042	-0.40
U.K.	0.912	0.088	-0.28
U.S.	0.912	0.088	-0.26
Uruguay	0.877	0.123	-0.05
Vietnam	0.827	0.173	-0.43

Source: KAPSARC.

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About the Project

Although there has been extensive analysis of different schemes of allocations of financial burdens across countries to implement climate mitigation policies, no attempt has previously been made to estimate the use of efficient Ramsey allocation schemes.

For the first time, and with the aid of an extensive data set, demand elasticities have been estimated for 106 countries, from which a Ramsey allocation scheme has been computed. This modeling exercise showed a number of cost reduction opportunities in using a Ramsey allocation scheme.

Notes

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