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Strategic incentives for a policy mix in the international car market

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Strategic incentives for a policy mix in the international car market[1]

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Abstract

The paper analyses the strategic environmental policy choices of governments for the car market. We consider two countries that each have a small number of car producers who sell cars at home and abroad, there are cross border pollution externalities and cross border R&D externalities. Each government can set a fuel tax and a fuel emission standard but tariffs are not allowed. We show that the symmetric cooperative equilibrium will have a fuel tax lower than global environmental damage and the fuel standard may not be needed as instrument. The symmetric non-cooperative fuel tax equals the local environmental damage. Non-cooperative governments always prefer to use a fuel tax rather than a fuel efficiency standard as the fuel tax allows to tax foreign profits. When car manufacturing is concentrated in only one country, the car importing country will opt for a higher fuel tax. The role of the fuel efficiency standard is enhanced when there is only a small number of producers, when there is a higher spill over rate and when crude oil prices are lower. The results are illustrated with a simple numerical model for the car market.

Keywords

Fuel taxes, fuel efficiency standards, strategic trade, international car markets

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1. Introduction

Since the failure of various global climate agreements, many governments have installed a unilateral, non-cooperative policy to reduce CO_2 emissions. As a result, current government policies not only differ in the stringency of their emission reduction targets, but also in the mix of policy instruments used. This certainly holds for the automobile sector where we see governments selecting different combinations of fuel efficiency standards and fuel taxes. In this paper, we use a stylized model of the international car market to analyze the strategic policy choices of governments.

Many papers have analyzed the efficiency and effectiveness of a single policy instrument in the car market, focusing on strategic car producer behavior and heterogeneous consumer preferences (for an overview see Parry et al., 2007). The efficiency of different instruments within a policy mix has also been analyzed (Roth, 2012). Although these studies take strategic supplier behavior to evaluate the choice of policy instruments into account, they do this in a national context and do not take into account the strategic interaction of governments in an international car market.

In a market with a global pollutant, like climate, but non-cooperative environmental policies, governments choose their policy instruments strategically, taking the policies in other countries into account. Each government pays attention to environmental damage but also considers the competitiveness of domestic producers and consumer surplus of its own citizens when choosing its policy instruments. The environment and trade literature (Sturm, 2003) considers these interactions, but this is rarely applied to the car market.

In this paper, we apply a model of strategic trade to a stylized international car market. We focus on two questions. First, we analyze what policy mix governments with a similar national car market will choose in a non-cooperative setting and how this differs from a cooperative setting. Second, we study the role of exogenous factors such as the crude oil price, the spillover rate of R&D, and the number of firms. Third, we study the role of differences in country characteristics like environmental damage and the presence of home producers for the choice of policy instruments.

First, we find that governments have no incentive to coordinate their environmental policy within the car market. Governments will impose a non-cooperative policy regardless of the instrument combination that is chosen. Whenever they can, governments will prefer a fuel tax. Second, the choice of policy instruments in this non-cooperative equilibrium is significantly affected by the level of R&D spillovers, by the number of producers and to a lesser extent by the pre-tax price of oil. A higher R&D spillover rate makes government choose far more stringent fuel economy standards. More producers means that spontaneous fuel economy efforts may be too large when countries rely only on gas taxes. A higher oil price decreases the need for a high fuel tax.

Third, we show that asymmetries in environmental concerns do not lead to a decrease in global welfare in contrast to asymmetric market characteristics between countries. When environmental concerns are different, the environmental leader opts for a higher fuel tax. When one country is mainly a car importer, it also choses a high fuel tax but it does this for strategic trade reasons rather than environmental damage motives.

The remainder of the paper is organized as follows. In section 2, we review the relevant literature. In section 3, we present the model and analyze the interactions between firms and countries for different sets of policy instruments. In section 4, we provide a numerical illustration to show the different mechanisms operating in the model. Section 5 concludes.

2. Literature review

Policy instruments in the car market can be divided into two categories. Market based policies (fuel tax, fuel efficiency subsidies, etc.) aim at reducing emissions by affecting total car use and/or fleet composition. On the other hand, technology-based policies (emission standards, R&D subsidies, etc.) reduce emissions through fuel economy improvements only. In the literature, these instruments are mostly approached in a one country-one government world. A first approach only considers one instrument and determines its optimal level (see Parry and Small (2005) for fuel taxes, Fischer et al. (2007) for emission standards). A second approach is to compare the cost effectiveness of different instruments to reach a given emission reduction target (Goulder and Parry, 2008). Focusing on the comparison between gasoline taxes and emissions standards[3], most studies show that the latter are far less cost-effective at reducing CO_2 emissions. Fuel taxes improve welfare by simultaneously increasing fuel economy and decreasing vehicle use. An emission standard only increases fuel economy which lowers fuel costs of driving and thus stimulates vehicle use. Of course, if one assumes that consumers do not correctly value fuel economy, this may tilt the choice back to fuel standards, however, the empirical evidence for this myopic behavior is rather weak (Allcott & Greenstone, 2012). Even when one takes on misperceptions by consumers, the ranking of instruments is not necessarily very different (Parry, Evans, Oates, 2014).

Most papers on instrument comparison in the car market rely on econometrically estimated market models with strategic behavior of car producers and idiosyncratic consumer preferences. Following Berry et al. (1995), the car market is then characterized as market with differentiated Bertrand-competition between producers on a given national market. Government policy is taken as given. In this paper, we make abstraction of heterogeneity of producers and consumers and focus on the strategic game between governments. We allow for imperfect competition within the car market by considering a symmetric oligopoly with one homogeneous car type that can only differ in fuel efficiency. This way, the model is simplified but still accounts for strategic producer behavior.

To understand governments' strategic behavior in an open economy, we rely on the standard models of the international trade and environmental policy literature[4]. One of the first authors to discuss such strategic policy setting in a context of imperfect competition was Barrett (1994). He analyzes how different forms of market imperfections influence the setting of environmental policy. Governments may weaken their environmental standards to improve competitiveness, which could lead to a 'race to the bottom, as feared by environmentalists. In his paper, Barrett only considers the problem of local pollution. Local pollution is pollution that only damages the country of emission. Global pollution in the form of environmental spillovers has been added in subsequent papers (see for example Ulph (1996) and Sturm and Ulph (2002)). One paper that is of particular interest for our research is Ulph and Ulph (2007) who analyze how a mix of instruments can be used to correct for environmental damage in a

[3] One can consult Kleit (2004), Austin and Dinan (2005), West and Williams (2005) and Jacobson (2013). A complete overview is given by Anderson et al. (2011) who survey the literature.

[4] For an overview, see Sturm(2003).

non-cooperative context. They analyze the introduction of a tax on emissions combined with a subsidy for R&D. They find that both instruments are affected by strategic behavior and R&D spillovers. Strategic considerations on the output market drive the government to set its environmental tax too low and its R&D subsidy too high. The authors do not discuss the net effects on welfare of the different policy interactions at work. In the next section, we propose a model close to Ulph and Ulph (2007) to demonstrate how policy choice in the car market can be affected by strategic considerations of governments. Compared to their paper, we add international R&D spillovers and focus on environmental pollution through consumption instead of production. We illustrate the theoretical results for the car market with a numerical example.

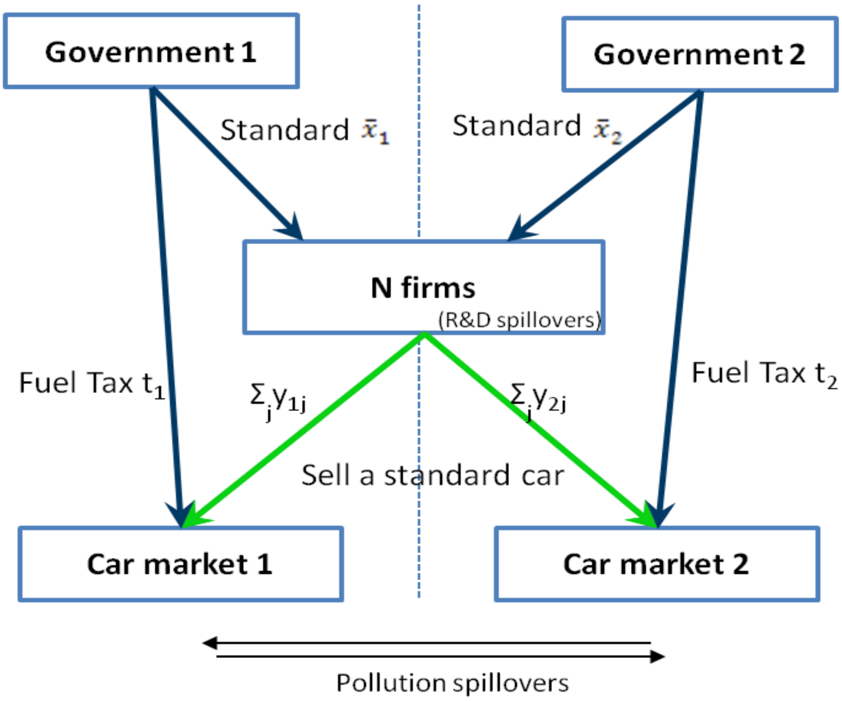
Three additional papers are closely related to our research. In Barla and Proost (2012), the efficiency of energy taxes and emission standards is compared in a non-cooperative world. The authors show that the lack of coordination across countries combined with international environmental spillovers and knowledge spillovers favor the introduction of emission standards over energy taxes. The main reason is that reducing emissions by standards produces comparatively more knowledge spillovers and therefore a larger total effect. Compared to Barla and Proost, we add imperfect competition in the car market and analyze combinations of different instruments. Another recent paper (Hattori, 2013) compares quantity and price regulations in a non-cooperative world with an international oligopoly. Similar to Ulph and Ulph (2007), this paper focuses on CO_2 emissions from the production of two firms, each located in a different country, but also adds welfare analysis of using the two instruments in a cooperative and non-cooperative model. In comparison with Hattori (2013), we focus on CO_2 emissions from consumption. We also allow for a policy mix and check for the equilibrium of instrument choice in non-cooperative settings. Finally there is the study of tariffs and environmental taxes in the presence of R&D by Tsai,Tu & Chiou (2014). They also use an Ulph and Ulph type of model but focus on the interrelations between an environmental tax and a tariff, while we focus on the combination of environmental tax and a standard.

3. Theoretical model

3.1. General setup

In the formal model we stick to the symmetric case with two countries and n car producers. Each country has half of the car producers. Each producer makes only one type of car which is sold in both countries. Cars only differ in their fuel efficiency. Governments can impose a fuel tax t on cars used within their country or they can determine a minimum level of fuel economy $\bar{x}$ for all cars sold and used in their country. As we impose that only one type of car is sold by each car company, the emission standard holds for both countries. The model structure is shown in Figure 1.

Figure 1. Model structure



The model is solved by a three-stage game. In the first stage, governments choose their policy instruments. They can choose to use only one instrument (tax or standard) or decide to use both instruments. Each government chooses the policy instruments that maximize the sum of home consumer surplus, fuel tax revenues and home firms' profits minus the damage of pollution. Governments can either cooperate or not cooperate. In the case of cooperative governments, instruments are chosen as to maximize joint welfare. In the non-cooperative case, each government optimizes domestic welfare for given policy levels of the other country. An overview of the different scenarios is given in Table 1.

Once governments have chosen their policy, car companies decide non-cooperatively on the level of fuel economy (x) in the second stage. They can choose to invest more in fuel economy than required by any government. In the third stage, the output (y) of the firms is determined by Cournot competition between the firms in each of the two markets. We solve the model using backward induction. We determine first the outcome of the third stage after which we analyze the choice of fuel efficiency by the car manufacturers. Finally, we consider the policy choice by each government, given the strategic decisions of car producers in stage 2 and 3. We assume two fully symmetric countries: demand and cost parameters are equal in both countries and for all car producers. The symmetry allows us to simplify the analytical model and the interpretation of the results. In section 4, we discuss the effect of different types of asymmetries numerically.

Table 1. Different policy options for governments.

	Cooperative Equilibrium	Non-Cooperative Equilibrium
Both Instruments	$\max_{t_i,\bar{x}_i} \sum_i W_i$	$\max_{t_1,\bar{x}_1} W_1 \ for\ given\ t_2, \bar{x}_2$
Fuel Tax	$\max_{t_i} \sum_i W_i$	$\max_{t_1} W_1 \ for\ given\ t_2$
Emission Standard	$\max_{\bar{x}_i,} \sum_i W_i$	$\max_{\bar{x}_1} W_1 \ for\ given\ \bar{x}_2$

Note: $t_i, \overline{x}_i$are respectively the tax and emission standard of country i, $W_i$is the welfare of country i.

3.2. Strategic decisions in the car market

In this section we set out the assumptions and definitions for the model. Next, we analyze the strategic decisions of car producers on output in the car market (stage three) and investments in fuel economy (stage two).

3.2.1. *Assumptions and definitions*

In each country, consumers buy cars for a fixed mileage. Although consumers generally have heterogeneous preferences over different car characteristics (Berry et al., 1995), we can simplify the model by using a homogenous car type without affecting the insights of the model. The only criterion for selecting a car is then the total user price of the car which consists of the purchase price and the discounted value of total expenditures on fuel. The total sales of cars in country *i* by company *j* is given by y_{ij} with $i, j = \{1,2\}$. For each country, we define the inverse demand function for cars.

$$p_i = a - b \left[\sum_j y_{ij} \right] \; for\ i = \{1,2\} \tag{3.1}$$

Each government can set a tax on fuel, expressed in Euro/litre. The price of fuel for the consumer consists of the world market price F plus the tax t_i paid to the government. Normalizing fuel efficiency (in litre/km) e_j to 1, the total fuel cost of a car $v_{ij}\,(t_i, e_j)$ used in country i and produced by company j equals the total mileage *g* times the tax rate t_i plus the pre-tax price F:

$$v_{ij}\left(t_i, e_j\right) = (t_i + F) g e_j \tag{3.2}$$

As the initial fuel efficiency of a car is normalized to 1, a company can improve this fuel efficiency level by extra efforts $x_j \in [0,1]$. Since a firm sells the same car on both markets, it selects only one level of fuel economy. Fuel efficiency of one producer has a positive effect on the fuel efficiency of the cars of the other producers. The fuel economy of each car produced by company j equals:

$$e_j = 1 - x_j - \delta \sum_k x_k \quad and \quad e_j \geq 0, k = 1, \ldots, n, k \neq j \tag{3.3}$$

where $\delta \in [0,1]$ is the spillover parameter for the R&D efforts.

By assumption, the cost of producing a more fuel efficient car does not depend on the production volume. We do not focus on fuel economy improvements as a result of a trade off with other car characteristics but look for radical improvements in fuel economy that are driven by R&D of the car producers. We assume that the cost for research and development does not depend on company size or total sales but that it is increasing and convex in the amount of realized fuel economy per vehicle and equals βx_j^2.

For a local pollutant, the damage cost for country *i* is a function of the emissions generated by the cars sold in that country: $D_i(\sum_j e_j y_{ij})$. For a global pollutant, the damage definition for each country becomes

$$D_i\left(\sum_j e_j\, g\left(y_{1j} + \theta y_{2j}\right)\right) \tag{3.4}$$

where θ is a parameter denoting the amount of pollution that spills over from the other country. For our theoretical analysis, we consider only global pollution ($\theta = 1$), which means that pollution not only affects the country of origin but every country within the model.

3.2.2. *Third stage: The Cournot equilibrium*

Assume that the government has decided on an environmental policy and that all firms have already chosen their level of fuel efficiency efforts (x). As a consequence, the cost functions for both companies are fixed. In each market, a firm then determines its output by maximizing profits, taking the output of the competitors as given. We analyze the optimal output for one market only. We can solve for the other market in a similar way. The maximization problem of firm j is (using 3.1):

$$\max_{y_{ij}} \pi_{ij} = \left[p_i\left(\sum_{j=1}^{n} y_{ij}\right) - v_{ij}\right] y_{ij} - d * y_{ij} \ , \ \ with\ y_{ij} \geq 0 \tag{3.5}$$

The variable production costs of a car are constant and similar for all companies and equal to d. By solving the first order conditions for all output levels, we can derive the Cournot equilibrium[5]. Optimal Cournot output is:

$$y_{ij} = \frac{a + \sum_k v_{ik} - n\, v_{ij} - d}{(n+1)b} \quad \text{for } j,k = \{1,..,n\} \text{ and } j \neq k \tag{3.6}$$

Expression (3.6) demonstrates the role of fuel economy for the car manufacturers: a decrease in the fuel cost v_{ij} of its own car or an increase in the fuel cost of a competitors' car increases the output level of the firm and thus increases gross profits.

3.2.3. *Second Stage: Optimal fuel economy*

Each car company decides on the optimal level of fuel economy. This decision is influenced by government policy in the first stage. If governments only use taxes, car producers choose their fuel economy level by optimizing profits for a given fuel economy level of other firms.

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[5] The derivation can be found in appendix A.

If governments impose a minimum fuel economy level, each car producer can still choose to invest more in fuel economy than is required by governments. The objective function of the firm is then maximized with respect to the fuel efficiency efforts, as long as this effort is higher than imposed by any of the governments.[6] For firm j, the objective function is

$$\max_{x_j} \sum_i b y_{ij}^2 - \beta x_j^2 , \quad \text{st } x_j > \overline{x_i} \; and \; e \geq 0 \tag{3.7}$$

This results from using the properties of a Cournot equilibrium (3.5) and (3.6): we see that every producer receives a profit mark-up $b y_{ij}$ on each car that is sold. We can thus write the producer profits in each market as in (3.7) solely in function of its total car sales. The cost of each producer depends on the choice of x_j. The choice of fuel economy by producer j affects its sales directly via its own fuel cost $e_j(x_1, .., x_n)$ but also indirectly via knowledge spillovers (at rate δ) on the fuel cost of its competitors. Trading off output effects and the cost of fuel efficiency efforts βx_1^2. , we find the condition for the equilibrium fuel efficiency efforts of each firm [7]

$$\sum_i^n 2\left(\frac{n-(n-1)\delta}{n+1}\right)(t_i + F \quad) g\, y_{ij} = 2\beta x \tag{3.8}$$

This expression shows that the fuel efficiency efforts of a producer are influenced by domestic and foreign tax rates in exactly the same way. Any increase in taxation directly stimulates fuel efficiency efforts by all producers.[8]

$$\frac{dx}{dt_i} > 0 \quad for \; i, j \in \{0,1\}$$

3.3. The policy choices of governments

When a government chooses its environmental policy, it takes the strategic response of the car producers, both on the level of fuel economy as well as on output, into account. In this section, we analyze the six different policy scenarios that we discussed in section 3.1. First of

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[6] We only analyze the case in which car producers decide to sell cars in both countries. As we impose complete model symmetry, this is the only relevant case: in equilibrium, any emission standard set by government will be equal for all governments. As long as total profits are positive for each firm, they will thus sell cars in both countries.

[7] The complete derivation can be found in appendix B.

8 This result holds only for completely symmetric countries and for an interior solution of the model in which every producer has a positive output level ($y_{ij} \geq 0 \; for \; x_1, x_2 \in \,]0,1]$)

all, governments decide whether they choose policy instruments cooperatively or not. Second, they select a fuel economy standard, a tax on fuel or a combination of these two instruments.

3.3.1. *Coordinated policies*

We first assume that governments cooperate when selecting policies. Governments jointly maximize the total welfare that is generated by car usage over the two countries. The welfare function is given by (3.9) and includes the total consumer surplus in both countries, the profits of all firms over the two markets and the tax income for each government minus the environmental damage that affects both countries.

$$\max \left[\sum_{i} \frac{b}{2}\left(\sum_{j} y_{ij}(t_i, x_j)\right)^2\right] + \left[\sum_{i,j} b y_{ij}^2(t_i, x_j) - \sum_{j} \beta x_j^2\right] + \left[\sum_{i} t_i \left(\sum_{j} g\, e_j(x_j) y_{ij}(t_i, x_j)\right)\right] - \left[2D \left\{\sum_{i,j} g\, e_j(x_j) y_{ij}(t_i, x_j)\right\}\right] \quad (3.9)$$

$$subject\ to \begin{cases} t_i, y_{ij}, x_i, \geq 0 \ \ with\ i,j = \{1,2\} \\ 0 \leq\ e_j \leq\ 1 \end{cases}$$

Case 1: Combining an emission standard and fuel tax

In our model, we address multiple market failures. Governments have to correct for both environmental damage, R&D spillovers and monopolistic behavior of car producers. We expect thus that governments need a mix of policy instruments to obtain the optimal outcome. We consider the fuel tax to control for total market output and an emission standard that optimizes the investments of car producers in fuel economy. We maximize (3.9) with respect to fuel tax t_1 and emission standard $\bar{x}_1$. As a result of model symmetry, the equilibrium output levels, fuel economy and taxes are equal among countries and producers ($y_{ij} = y$, $\bar{x_j} = \bar{x},\ t_i = t\ \ for\ all\ i,j$). We can therefore write the optimal policy mix as:

$$-\frac{b\,y}{ge} = (t - 2D') \quad (3.10)$$

$$\frac{(2n+4)(1+(n-1)\delta)}{n+1}gy(t+F)+2(2D'-t)g\left(y-\frac{v}{(n+1)b}\right)(1+(n-1)\delta) = 2\beta\bar{x} \quad (3.11)$$

Equation (3.10) shows that the optimal fuel tax is lower than marginal damage (2D’): the monopoly margin of the firms already decreases total output. Therefore, the fuel tax is decreased with this margin. The optimal level of fuel economy (3.11) sets marginal gains of fuel economy equal to marginal costs and is driven by two forces. First, increasing fuel economy results in extra market surplus, which is represented by the first term on the left hand side. This extra surplus is created by efficiency gains from fuel economy that are not compensated by a higher cost per vehicle, as the cost of R&D does not depend on the output level. Second, the remaining damage that is not corrected by the fuel tax increases the incentives to invest in fuel economy. If the number of car producers (n) increases, we see that the fuel tax increases due to lower profit margins, while the optimal emission standard becomes less stringent as the fixed costs of R&D, aggregated over all companies, will increase. For increasing R&D spillovers δ, the emission standard increases as investments in fuel economy become more efficient. This increase in fuel economy lowers the need to reduce output on the car market, which means a lower optimal fuel tax.

The equilibrium defined by (3.10) and (3.11) imposes a minimum level of fuel economy for car producers and a fuel tax that is optimal given that producers comply to this standard. However, car producers can also choose a fuel economy level that is more stringent than the standard. This means that the solution is only optimal as long as the emissions standard set by governments is binding. If we compare the choice of producers (3.8) with the emission standard of governments (3.11), we see that, in the absence of spillovers in R&D, the government standard is binding as long as:

$$\frac{(2-n)}{n+1}g(t+F)+\frac{b}{e}\left(y-\frac{v}{(n+1)b}\right)>0 \quad (3.12)$$

For a high number of car producers, governments prefer a lower fuel economy effort than producers because R&D costs are fixed costs per firm. This means that for a high number of car producers, it might be sufficient to set a fuel tax without imposing a minimum effort in fuel economy. Car companies are always driven to invest in R&D for cleaner cars as long as there are no R&D spillovers. This results in a more competitive car at a fixed cost. Whenever

R&D spillovers are introduced in (3.12), firms tend to make less efforts and the government standard is more likely to determine the final fuel economy level via the emissions standard.

We summarize this result in proposition 1:

PROP 1 In the international cooperative symmetric solution, the fuel tax rate is set below the global environmental marginal damage to compensate for the monopolistic margins. Minimum fuel efficiency standards are not needed when there are many firms and the R&D spill over rate is low as firms use fuel efficiency as strategic competition instrument.

Case 2: Only fuel taxes

Governments cooperatively maximize the same welfare function but can only use a fuel tax as instrument. Car producers take the decision on fuel economy as no standard is imposed. We derive the first order condition:

$$2\frac{2-n+\delta(n^2+3n-4)}{n+1}\,y\,(t+F)\frac{dx}{dt}-\frac{e\,y}{(n+1)} = (t-2D')\left[\frac{g\,e^2}{(n+1)b}+2(1+(n-1)\delta)\frac{dx}{dt}(y-\frac{v}{(n+1)b})\right] \tag{3.13}$$

The incentives for a government are not different from the previous case where a fuel efficiency standard and gasoline tax were combined. The fuel tax differs from the marginal damage for two reasons. First, as before, the monopoly margin reduces the optimal fuel tax, which is represented by the second term on the left hand side of (3.13). Second, the fuel tax provides an incentive for firms to set the right level of fuel economy shown in the first term on the LHS of (3.13). With only a small number of firms and high R&D spillovers, the tax will be higher to ensure enough fuel economy efforts. With more car producers or a higher crude oil price, the tax should be lowered to decrease the overinvestment in fuel economy of car producers. As we modelled fuel economy efforts to be a fixed cost per firm, large fuel economy efforts become less efficient when there are many firms.

Case 3: Only emission standards

Governments can be reluctant to set any (higher) fuel tax as this increases the cost of driving for voters. If governments decide to use only emission standards to correct for global pollution, we can derive the objective function with respect to $\bar{x}$ and get the same first order condition as (3.11), where taxes are now set equal to zero.

$$\frac{(2n+4)(1+(n-1)\delta)}{n+1} g\, y\, F + 4\, D' g\left(y - \frac{v}{(n+1)b}\right)(1+(n-1)\delta) = 2\beta\bar{x} \qquad (3.14)$$

Compared to (3.11), the absence of the fuel tax has three effects. First, the output y of each firm increases as consumers no longer have to pay the fuel tax. This makes governments set a higher emission standard (second term of (3.14)). Second, the extra market surplus that is generated by fuel economy through R&D is smaller as this is now only generated by the world price of fuel F (first term of (3.14)), this relaxes the optimal emission standard.

The net effect on the emission standard is thus unclear: the emission standard can be lower or higher than when it is combined with an emission tax. In both cases, however, the emission standard is only binding as long as car producers are not willing to invest more in fuel economy. Without fuel taxes and in the absence of R&D spillovers, the standard is binding as long as :

$$\frac{(2-n)}{n+1} F\, y + 4D'\left(y - \frac{v}{(n+1)b}\right) > 0 \qquad (3.15)$$

In a cooperative equilibrium we see that a high concentration of car producers eliminates the need to set an emission standard. The competition among producers already drives the firms to invest (too) heavily in fuel economy.

The comparison between a policy mix and a policy in which only an emission standard or only a fuel tax is available is difficult as we cannot determine whether there is a need for a binding fuel emission standard. We will explore this issue further in the numerical illustration in section 4.

3.3.2. *Non-coordinated policies*

Governments are often not coordinating their policy instruments. In this section we analyze the policy choices when governments only care about the welfare of their own consumers and the surplus of the domestic car producers. They take the policy choices of the other governments as given. To keep the analytics tractable, we analyze only the cases in which the two governments use the same instruments. In the numerical illustration we will explore the case where governments use different instruments. Moreover, when we assume that the profits of the car producers are equally divided over the two countries, this results in symmetric outcomes so that the equilibrium conditions can be generalized as before ($y_{ij} = y$, $x_j = x,\ t_i = t\ for\ all\ i,j$). The non-cooperative choice of instruments by a government maximizes:

$$\max \frac{b}{2}\left(\sum_j y_{1j}(t_i,x_j)\right)^2 + \frac{1}{2}\sum_{i,j} by_{ij}^2(t_i,x_j) - \frac{n}{2}\sum_j \beta x_j^2 + t_1\left(\sum_j g\, e_j(x_j) y_{1j}(t_i,x_j)\right) - D\left\{\sum_{i,j} g\, e_j(x_j) y_{ij}(t_i,x_j)\right\} \qquad (3.16)$$

$$subject\ to\ \begin{cases} t_i, y_{ij}, x_i, \geq 0\ \ with\ i,j = \{1,2\} \\ 0 \leq\ e_j \leq\ 1 \end{cases}$$

Compared to (3.9), the welfare function of a non-cooperative country (3.16) consists only of local consumer surplus (first term), half of the firm profits (second and third term) and domestic tax income (fourth term) minus the damage to the own country. We next analyse the three possible combinations of instruments.

Case 1: Combining an emission standard and fuel tax

If we maximize (3.16) with respect to the fuel tax and emission standard, taking the instruments of the other governments as given, we have first order conditions (3.17) and (3.18) that determine the equilibrium.

$$t = D' \qquad (3.17)$$

$$\frac{(2n+4)(1+(n-1)\delta)}{n+1} gy(t+F) + 2(2D'-t)g\left(y - \frac{v}{(n+1)b}\right)(1+(n-1)\delta) = 2\beta x \qquad (3.18)$$

There are two main differences in the policy behavior of cooperative and non-cooperative governments. First of all, the fuel tax in the cooperative equilibrium is now set below global marginal damage (2D’) and only takes the damage to local consumers D’ into account. This result is specific to our model formulation. Besides, the effect on environmental damage, the setting of taxes takes on board two other effects. First, as governments only care about domestic profits, the incentive of a government to increase company profits by setting a lower tax is reduced because the government is interested in taxing away the profits of the foreign producer. Second, lower fuel taxes also allow to correct the too-low duopoly output. Due to symmetry, these two effects cancel out and make the optimal tax simply equal to the local damage.

While the fuel tax is affected by non-cooperative behavior, the incentives for the emissions standard are exactly the same as in the cooperative case. As a result, conditions (3.11) and (3.18) are the same. In the non-cooperative equilibrium, the marginal gains of fuel economy are exactly half of the global marginal gains. Also, the costs are divided equally over the two countries. Therefore, the same condition can be used to determine the emission standard set by the governments. We summarize our results so far in proposition 2:

PROP 2 In a non-cooperative symmetric equilibrium, countries set the fuel tax equal to the local rather than the global environmental damage because the motive to tax foreign profits is compensated by the motive to correct the monopolistic margins. The fuel efficiency standard is only used when the number of firms is small and the R&D spill over rate is low.

Symmetric first order conditions do not result in the same final choice of fuel economy, as this also depends on the level of the fuel tax set by the government. In addition, the condition for a binding emission standard is also affected by the choice of the fuel tax.

In comparison with (3.15), expression (3.19) leads to a lower fuel tax as only local marginal damage is taken into account. This means that the emission standard imposed in the non-cooperative equilibrium will be more easily non-binding compared to the cooperative equilibrium.

$$\frac{(2-n)}{n+1} g(t+F)\, y + 2D' \left(y - \frac{v}{(n+1)b} \right) > 0 \tag{3.19}$$

Case 2: Only fuel taxes

Maximizing (3.16) taking into account the strategic fuel economy decisions of car producers results in equilibrium condition (3.20). As in case 1, the tax serves to capture part of the foreign producer surplus, so that the non-cooperative tax increases rather than decreases with the profit margin of the producer. The tax is different from marginal damage for two more reasons. First, the government again tries to optimize the fuel economy of the cars produced by domestic companies via the tax rather than the fuel efficiency standard. The first term of the LHS of (3.20) incorporates the strategic fuel economy decision of car producers as in (3.8). Second, the government can influence the foreign emissions that cause domestic damage, by setting a stricter standard, which is represented by the second term on the LHS of (3.20). Compared to (3.17), the effect of the tax on the fuel economy choice of car producers will determine whether the tax is higher or lower than the marginal damage to the local consumers. If car producers overinvest in fuel economy (in case of low spillovers, high market concentration and high fuel prices), governments will tend to decrease the tax to lower the fuel economy efforts. In the opposite case, governments will set a higher tax to encourage more fuel economy.

$$\frac{2-n+\delta(n^2+3n-4)}{n+1}\,y\,(t+F)\frac{dx}{dt}+D'\left[(1+(n-1)\delta)\frac{dx}{dt}(y-\frac{v}{n+1b})\right] = (t-D')\left[\frac{g\,e^2}{(n+1)b}+(1+(n-1)\delta)\frac{dx}{dt}(y-\frac{v}{n+1b})\right] \tag{3.20}$$

Case 3:Emission standards only

The last case, in which only an emission standard is imposed, is the only case in which governments have no strategic incentive to deviate from the cooperative outcome in (3.14). This means that strategic behavior never leads to welfare losses if governments can only set emission standards. However, this does not automatically imply that, in a non-cooperative setting, an emission standard outperforms other instrument choices in global welfare terms. First, we need the emission standard to be binding, which means that (3.15) still needs to hold in equilibrium. This will only be the case for a small number of producers and a lower R&D spillover rate. Second, the absence of a fuel tax will result in very high output when there are many car producers.

3.3.3. *Optimal policy choices*

Both for the cooperative and for the non-cooperative symmetric case, we have analysed the preferred mix of policy instruments. However, we are mainly interested in the relative efficiency of each policy.

In the cooperative and in the non-cooperative equilibrium, the relative efficiency of fuel taxes, emission standards or a combination of the two instruments depends on the degree of market competition, the pre-tax price of gas and the degree of technology spillovers. As long as in equilibrium the fuel tax is positive and the emission standard is binding, it is always best to use both instruments:

- The emission standard enforces the car producers to set the level of fuel economy that trades off the societal benefits and costs of investments in R&D; the optimal level of fuel economy for society will differ from the car producers' choice as a result of market competition (too high fuel efficiency efforts in the case of many firms) and R&D spillovers (insufficient fuel efficiency efforts in case of large spillovers between firms).
- The remaining environmental damage can be taxed as long as the profit margins of car producers do not already correct for this remaining damage. However, non-cooperative behavior significantly affects the tax instrument, as it provides the government with an incentive to have too low taxes as it considers only local external effects but also with an incentive for too high taxes as it also wants to tax the profits of foreign car producers.

In case of a non-binding emission standard, the government will use the tax to correct for the remaining environmental damage, but will be careful in raising the tax as it also wants to limit the incentives for fuel efficiency efforts as they are already excessive. As a result, the tax will be lower compared to the two-instrument case, as the fuel economy choice of car producers (which increases with the fuel tax) is inefficiently high compared to the optimal emission standard.

To assess the cooperation incentives of the governments, the implicit definition of the equilibrium is insufficient. We need to analyze the implications of deviating from each equilibrium to understand the dominant strategy of both governments. We can solve the explicit solution in each case for the fuel tax, emission standard and welfare in both countries. The analytical results are given in Appendix C and formulated in proposition 3.3. We summarize our findings in the following proposition:

PROP 3 Every individual government has an incentive to deviate from the cooperative equilibrium: each government prefers to impose a non-cooperative fuel tax, regardless of any emission standard that is imposed. When environmental damage has a global character and is large, this leads to too low fuel taxes. When environmental damages are small, this leads to too high fuel taxes.

In the symmetric equilibrium, it is thus very unlikely that governments set a cooperative policy, as the dominant strategy is to set a different fuel tax. However, it is difficult to predict the relative importance of the different incentives as they are highly dependent on characteristics such as the degree of market competition, the pre-tax price of gas and technology spillovers. In the next section, we use a numerical illustration to better understand the interplay between the different considerations.

4. A numerical illustration for the car market

The analytical approach shows that the relative efficiency of instruments depends on the model parameters. In this section, we use a small numerical simulation model to better understand the different interactions. We first calibrate a benchmark case to demonstrate the results of the analytical section. We analyze the different policy options for each government and compare the total welfare for cooperative and non-cooperative policies. Second, we analyze the role of different model parameters as there are market competition, R&D spillovers and the pre-tax gas price in the model. We show their impact on both instrument efficiency and incentives for non-cooperative policies. In a final section, we redirect our attention towards asymmetric cases. We analyze how differences in environmental damage and the market share of the domestic car industry can lead to an equilibrium with asymmetric policy decisions.

4.1. The benchmark equilibrium

4.1.1. Calibrating the parameters

We divide the world into two countries. Relying on general sales statistics[9], we see that in most countries, the top eight car manufacturers represent approximately 80% of total car sales. For our benchmark, we thus assume that there are eight producers, equally divided over the two countries. For the calibration, we assume that there are no spill overs in R&D and that the four plus four car producers sell their car type in both markets. We first construct an equilibrium in which no fuel taxes are levied. The incentives for fuel efficiency are driven by

[9] Sales statistics retrieved from the International Organization of Motor Vehicle Manufacturers (OICA).

the pre-tax gas price only. Next, we analyze the optimal fuel tax level in both the cooperative and non-cooperative equilibrium.

An overview of all demand and cost parameters for this numerical example is given in Table 2. We assume the demand for car travel to be linear and symmetric in both countries: The inverse demand function is given by $p = 90{,}000 - 0.01\,Y$. Each car drives 20,000 km each year during 10 years. The producer price of fuel is fixed at 0.5 €/litre.

The production cost of a car is constant and equal to 12,000 €. All producers sell the same type of car. Cars only differ by their fuel economy. Every car company produces initially a car with a fuel efficiency of 10 l/100km. Producers can improve the fuel efficiency at a cost of 400 x^2 where x is the percentage of fuel consumption reduction per km. For the benchmark case, we do not consider any R&D spillovers to other producers.

According to An and Fauer (2004), for each litre of gasoline driven, a car produces on average 2,32kg of CO_2. We assume a world social cost of carbon of 50€/ton[10]. Combining these data, each litre of gasoline has a global pollution damage of 0.12 €. In addition, we also take into account local pollution. Using data from a Belgian study (Delhaye et al., 2010), other external environmental costs, excluding CO_2 emissions, are estimated at 0.25 €/litre. We neglect congestion and traffic safety costs[11].

Table 2. Demand and cost parameters

Demand for cars	P=90 000 - 0.01 Q
Traveled distance	200 000 km/car
Fuel production cost	0.5 €/l
Initial fuel efficiency	10l/ 100km
Production costs	12 000 €
R&D costs (bln €)	400 x^2
Local external costs	0.25 €/l
Costs of climate change	0.12€/l

4.1.2. *Benchmark results*

Table 3 provides the results of the benchmark case. In the equilibrium without government policy we see that 6.1 million cars will be sold annually[12] in each country. Consumers pay

[10] A survey on the social cost of carbon can be found in Tol (2008).

[11] They can be addressed by other instruments.

[12] Which corresponds to US sales in 2011, as retrieved from OICA

29,255 € for driving, which consists of a fuel cost of 9,328€ over the lifetime of the vehicle and a car price of 19,630 €. We find a point price elasticity for car travel equal to -0.47 and a price mark-up of each producer of approximately 39%[13]. Any investment in fuel efficiency is driven by the fuel price. Every producer invests 3% of its annual sales into R&D[14], which results in a fuel economy of only 3.20%.

If we introduce government policy, welfare is highest in the cooperative case if governments only use a fuel tax, without imposing an emission standard. The reason is that the large numbers of producers, combined with the absence of spill overs, already generates too high fuel efficiency investments. The equilibrium conditions that determine the optimal combination of an emission standard and a fuel tax (3.10 and 3.11), result in an emission standard that is not binding for car producers. This generates optimal taxes that are lower than the global marginal damage.

If no taxes can be used, the emission standard becomes binding and generates more investments in fuel economy in comparison with the case of no government policy. However, the standard is much less efficient compared to the fuel tax as it increases total car sales, which has a negative effect on total pollution. In general, differences in welfare are rather limited[15]. Compared to a fuel tax, an emission standard generates a yearly loss of respectively 420 mln €. This is illustrated in the first two columns of Table 3.

If governments determine their policy non-cooperatively, we obtain the results in the last three columns of Table 3. We see that the emission standard is not affected by strategic government behavior (Prop.2). However, if they can only use the fuel tax, the fuel tax is much higher than in the cooperative case because the global environmental damage is relatively small. In the cooperative case, there was a significant incentive to set a tax below the global environmental damage as the profit margin of car producers already reduces total output. This incentive is now offset by the tax raising revenue incentive of each government. The side effects are an overinvestment in fuel economy by car producers and a total output that is too low. The welfare losses of strategic behavior by governments are significant and

[13] These results are comparable to the assumptions on price markup in Austin and Dinan (2005) and the price elasticity of VMT in Parry and Small (2005).

[14] Comparable to the industry average of 4% in 2012 (European Commission, 2012).

[15] Note that the absolute total welfare is not relevant for the comparison of scenarios as it is mainly consumer surplus that depends on the curvature of the willingness to pay for cars.

amount to 2.43 bln € (1.20+1.23) each year if only the fuel tax is implemented. When both instruments can be used, the high tax disappears but there remains an important welfare loss of 2.88 bln €.

Table 3. Benchmark results (with 8 car producers, equally divided over the two regions).

	No Policy	Cooperation			No Cooperation		
			Fuel Tax	Emission standard	Both	Fuel Tax	Emission standard
Taxes (€cents/l)	0		9.2	0	0.37	33.5	0
Emission standard	0			3.70%	3.58%		3.70%
Firm choice of x	3.20%		3.89%	3.37%	5.29%	5.13%	3.37%
Final fuel economy	3.20%		3.89%	3.70%	5.29%	5.13%	3.70%
total sales per country	6.1		5.92	6.08	5.47	5.53	6.08
price of driving (€)	29,255		30,782	29,225	35,315	34,745	29,225
Δ Welfare (Bln €)	**0**		**1.20**	**0.68**	**-1.90**	**-1.23**	**0.68**

Finally, we turn to the incentives for the non-cooperative governments to select one particular instrument. In Table 3 we reported results for the case where both governments always selected the same instrument, but can this be a non-cooperative equilibrium? We check this in Table 4 where we analyze the domestic welfares in the non-cooperative equilibrium for all possible combinations of instruments. We start with the diagonal cases where both countries use the same type of instruments non-cooperatively. As countries are identical, their domestic welfare is the same when they use the same instrument and, as in Table 3, the emission standard performs better than the fuel tax and then the mix of instruments.

Consider now the case where both countries use only emission standards, this is the instrument mix that produces the highest global welfare in the non-cooperative case. Will countries have in incentive to deviate from this equilibrium by using other instruments? Consider country 1, we see that it can improve domestic welfare by also using a fuel tax. Comparing cell (1,1) with cell (3,1), country 1 improves domestic welfare from 171.3 to 172.3, but country 2 loses in this operation as it moves from 171.3 to 167.1. The result will be that country 2 will also implement a fuel tax and end up in cell (3,2) where it only uses a fuel tax. The equilibrium in terms of choice of instruments will, in this case be, that both countries only use a fuel tax: a country cannot improve its pay-off by adding a fuel standard.

Of course, if countries can agree to use only one instrument, a fuel standard would be a better non-cooperative equilibrium. But as illustrated in Table 4, every country is strongly tempted to also use fuel taxes making an agreement on the mix of instruments difficult.

Table 4. Yearly domestic welfare (bln €) of both countries, for different mixes of non-cooperative policies .

		Country 2		
		Emission Standard	**Fuel tax**	**Both instruments**
Country 1	**Emission standard**	171.3 171.3	168.3 173.5	167.1 172.3
	Fuel tax	173.5 168.3	170.3 170.3	170.4 170.1
	Both instruments	172.3 167.1	170.1 170.4	170 170

In terms of overall welfare, the fuel tax non-cooperative equilibrium does better than the non-cooperative equilibrium where both instruments are used. But the fuel tax equilibrium does even worse than the no-policy equilibrium.

We summarize this result in our proposition 4:

PROP 4 In a symmetrical non-cooperative equilibrium, individual countries will always prefer a fuel tax instrument as this allows to tax the profits of foreign producers.

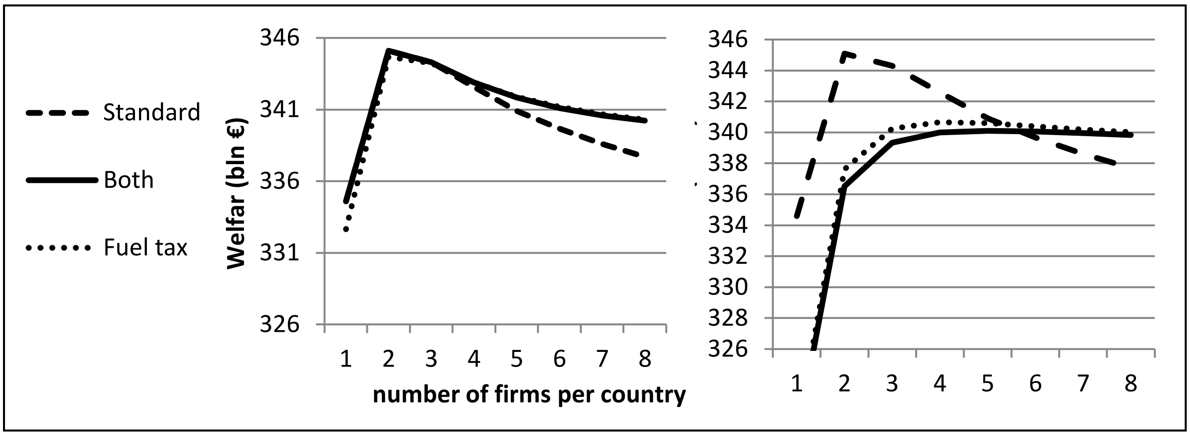
4.2. Market concentration, R&D spillovers and the pre-tax price of gas

So far, we have assumed a fixed pretax price of gas, eight car producers and no R&D spillovers between those car producers. In this section, we analyze the effect of each of these parameters on instrument efficiency (taxes vs. standards) and their effect on the incentive to opt for a particular instrument mix in a non-cooperative setting. We focus mainly on the general welfare effects and maintain the assumption of symmetric countries.

4.2.1. Market concentration

In the analytical section, we have already discussed the role of competition in the car market for instrument efficiency. In this section, we show numerically that an increase in the number of car producers improves the efficiency of tax instruments. In figure 2, we plot total welfare for different numbers of car producers for each country[16]. We see that in both the cooperative case (left part of Figure 2) and the non-cooperative case (right part of Figure 2), the emission standard generates less welfare than the fuel tax or policy mix. The reason is straightforward: with more competition, the profit margin of each car producer is lower, which means that more cars will be sold and that the motive of profit-taxation of foreign profits largely disappears. Lower car prices result in more environmental pollution damage which can be handled most easily via a fuel tax. In addition, we find that more market competition also results in higher fuel economy investments by the car producers. As a result, the emission standard in the policy mix becomes a redundant instrument.[17]

Figure 2 Total Welfare in the cooperative (Left) and non-cooperative (Right) equilibrium for different numbers of firms



We can also compare the (non)-cooperative strategies of both governments. With more car producers entering the market, all policy measures converge to the same level: the fuel tax levels in the cooperative and non-cooperative case are similar for a high level of market competition. Governments can no longer gain in tax income by unilaterally setting the fuel tax equal to local marginal damage (equation 3.17) as the fuel tax in the cooperative level can even be higher when global damage is taken into account and the larger number of firms

[16] In the Cournot equilibrium, an increase of car producers corresponds to an increase in competition among producers. We could do the same exercise for the differentiated Bertrand equilibrium by varying the level of product differentiation between cars.

[17] In this case, no spillovers in R&D investments have been imposed.

decreases the monopolistic distortion. In a market with strong competition, the fuel tax serves purely environmental purposes while with less competition, a high fuel tax is driven by strategic incentives of the government. This result only holds for the symmetric case. We summarize our findings in proposition 5.

PROP 5 When the number of firms increases and in the absence of R&D spill-overs, the fuel tax approaches the marginal damage cost, in the non-cooperative equilibrium only the local damage is taken into account.

4.2.2. R&D Spillovers

The introduction of R&D spill overs is an important factor for the analysis of instrument efficiency as the need for a binding emission standard depends heavily on the spill-over rate. For a high R&D spill-over rate, car producers have a lower incentive to invest in fuel economy because their efforts also spill over to their competitors. We analyze the six different policy options for different spill-over rates of fuel economy. Table 5 shows the results for spillovers rates that vary between 0 and 20%.

In any policy scenario, the introduction of R&D spillovers generates large welfare improvements compared to the benchmark case. However, part of this welfare increase should be attributed to economies of scale in the R&D market as we assume a fixed cost for each car producer for all investments in fuel economy. By not allowing car producers to collaborate in R&D, the spillovers that we introduce also represent welfare gains that would be incorporated by car producers if cooperation in R&D is modelled endogenously. Nevertheless, the net effect of spillovers in R&D on welfare is positive regardless of the cooperation level between car producers.

When we compare the different policy instruments in the cooperative equilibrium, we see that the fuel tax is a very inefficient instrument to correct for increasing R&D spillovers. The only way a fuel tax can generate more efforts in fuel economy is by setting the fuel tax inefficiently high and thus reducing market output more than necessary. In contrast, an emission standard is more efficient to stimulate R&D efforts. Even for small spillovers (10%), the emission standard is now binding for the car producers and thus governments set the fuel economy level. The introduction of R&D spill overs demonstrates that, whenever there is a need to correct for more than one externality, two instruments perform better than one.

Table 5. Fuel taxes, emissions standards, final fuel economy and welfare for different spill over rates and different instrument choices (with 4 car producers per country).

	0	10%	20%
Cooperative Fuel tax			
Taxes (€cents/l)	9.2	21	31.4
company efforts in fuel economy	3.89%	4.12%	4.18%
final fuel economy	3.89%	7.01%	10.00%
Welfare (bln€)-BEST	0	-1.37	-9.19
Cooperative Policy mix (=BEST)			
Taxes (€cents/l)	10.8	6.7	0
Emission standard	3.65%	6.34%	9.28%
company efforts in fuel economy	3.98%	6.34%	9.28%
final fuel economy	3.98%	10.78%	22.27%
Welfare (bln €) = BEST	342.88	351.1	364.40
Cooperative Emission Standard			
Emission standard	3.70%	6.41%	9.28%
company efforts in fuel economy	3.98%	6.41%	9.28%
final fuel economy	3.98%	10.9%	22.8%
Welfare (bln€)-BEST	-0.3	-0.06	0
Non-cooperative fuel tax			
Taxes (€cents/l)	33.5	39.7	45.7
company efforts in fuel economy	5.12%	4.98%	4.76%
final fuel economy	5.12%	8.46%	11.40%
Welfare (bln €)-BEST	-2.22	-3.28	-9.93
Non-cooperative policy mix			
Taxes (€cents/l)	37	37	37
Emission standard	3.58%	6.23%	9.11%
company efforts in fuel economy	3.98%	6.23%	9.11%
final fuel economy	3.98%	10.59%	21.86%
Welfare (bln €)-BEST	-2.58	-2.25	-2.75
Non-cooperative emission standard			
Emission standard	3.70%	6.41%	9.28%
company efforts in fuel economy	3.98%	6.41%	9.28%
final fuel economy	3.98%	10.9%	22.8%
Welfare (bln €)-BEST	0	-0.06	0

In the policy mix, governments set a binding emission standard and a lower fuel tax. With increased efforts in fuel economy, a lower level of remaining CO_2 emissions requires less intervention in the output market. The profit margin of the car producer can already increase the cost of driving sufficiently to correct for the remaining environmental damage. The net result is that for increasing spillovers, the optimal policy requires a stricter standard and a lower fuel tax.

As in the benchmark, governments always have the incentive to deviate to a non-cooperative fuel tax policy, regardless of the policy choice of other countriesThis is demonstrated in Table 6, for a spillover rate of 10%. In contrast with the non-cooperative benchmark case in Table 4, the policy in which only a fuel tax is imposed no longer dominates the policy in which both instruments are combined. If one country sets a binding emission constraint, the other government will no longer affect the fuel economy of any car by its fuel tax. The fuel tax will only be used to extract foreign profits. Therefore, equation (3.20) can be simplified to (3.17). The best reaction is to set the fuel tax equal to local damage.

Table 6. Yearly domestic fuel welfare (bln €) of both countries, for different policy choices of each government and a spillover rate of 10 %.

		Country 2		
		Emission Standard	**Fuel tax**	**Policy mix**
Country 1	**Emission standard**	175.5 175.5	172.5 177.5	172.5 177.5
	Fuel tax	177.5 172.5	173 173	174.4 174.2
	Policy mix	177.5 172.5	174.2 174.4	174.5 174.5

In a non-cooperative equilibrium, governments will always set a fuel tax to extract profits of foreign car producers. However, if spill overs in R&D are high enough, they will combine the fuel tax with a strict emission standard. This reduces the strategic incentives that drive up the fuel tax and improves welfare compared to a single policy.

This result can be summarized in the following proposition.

PROP 6 In a symmetric equilibrium, the higher the rate of R&D spillovers, the more important the fuel efficiency standard becomes. In the non-cooperative equilibrium, the fuel efficiency standard is still accompanied by a fuel tax.

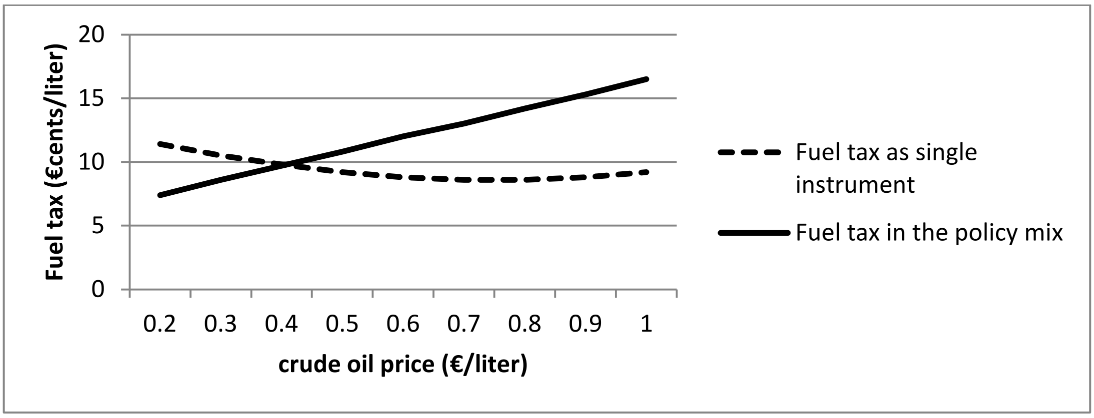
4.2.3. Crude oil price

Another exogenous parameter we consider in the model is the price of crude oil which determines the pre-tax price of gasoline. We vary the pretax price of gasoline per litre from 0.2€ to 1€. It is straightforward that higher fuel prices will always lead to lower welfare. Therefore, we analyze the effect of oil prices on the optimal policy directly.

First, we find that the fuel economy of a car is always positively influenced by the oil price, either by a stricter emission standard of governments or by more efforts of the car producers in case of a non-binding standard. However, as long as R&D spillovers are absent, producers increase their R&D investments more than is desired by both governments. Therefore, increasing fuel prices result in less binding emission standards by the government.

Second, we can analyze the effect on the fuel tax. In the non-cooperative equilibrium, the fuel tax is hardly affected by the crude oil price. Under the assumption of symmetric countries, the fuel tax does not depend on the profit margin of the firms, but is only affected by the local environmental damage; as the marginal damage per liter is constant, the environmental damage is not affected by the fuel tax. For the cooperative equilibrium, the optimal fuel tax is represented in Figure 3 in function of fuel prices. In contrast to the intuition, a higher crude oil price increases the optimal fuel tax, both as a single policy instrument and in the policy mix. However, if the tax instrument is used as a single policy, the increase only occurs for very high oil prices. The explanation for this result is given by (3.10) and (3.13). In the case of a policy mix, the fuel tax is driven by the profit margin of the firms (LHS) and the environmental damage (RHS). For a higher crude oil price, the environmental damage of driving is not affected, but the profit margin is lower as producers incorporate the higher crude oil price in their car price policy. Therefore, the profit margin no longer incorporates the same amount of remaining environmental damage. The argumentation is similar to the previous analysis of more market competition: a lower profit margin requires a higher fuel tax to correct for environmental damage. If the fuel tax is applied as a single instrument, the same argument applies but is compensated by its effect on investments in fuel economy. High oil prices and fuel taxation lead to over-investment in fuel economy. The resulting fuel tax will depend on the net effect of the two incentives. In this example, governments will reduce over-investments by setting a lower fuel tax as long as pre-tax price of fuel is below 0.8€/liter. For higher oil prices, the marginal effect on fuel economy is very limited and governments focus on the lower profit margin which results in a higher fuel tax.

Figure 3. optimal fuel taxes in the cooperative equilibrium



4.3. Asymmetric policy choices

In a symmetric environment, where each government is confronted with the same market characteristics and environmental damage, the final choice of policy instruments will always be equal across countries. In this section we relax the assumption of perfect symmetry. We study two specific cases. First, we assume that all damage created by CO_2 emissions is incurred by one country only, while the other country only cares about the other external costs of driving. We refer to a situation in which the costs of global warming are divided unequally over the different countries. Second, we assume that all car producers are located in one country, while the other country has no car industry[18].

We focus on these cases for two specific reasons. First, we do not change the total damage for both countries. As a result, cooperation between governments will always result in the same outcome as before. The only differences in policy choices can be found in the non-cooperative equilibrium. Therefore, we can compare the results with the benchmark in Table 4. A second reason is that these cases allow us to illustrate the difference between environmental policy as a measure to reduce environmental damage or to strategically influence welfare levels between countries.

[18] In our model, we use the profits of the car producers to measure the importance of the car industry for each government where we assume that this profit is returned to national shareholders. If governments only care about the presence of car production rather then profits, this results in exactly the same outcome as long as profits are related to total car production.

4.3.1. *Environmental damage*

In the benchmark case, we assumed that each government faces a constant marginal damage of CO_2 emissions equal to 0.12 €/l. In this scenario, we assume that the total marginal costs (0.24€/l) are incurred by one country, while the other country has no damage associated to CO_2 emissions. All other model parameters are equal to the benchmark in section 4.2. We calculate the impact on welfare of each country for a given instrument choice of both governments. Results are presented in Table 7.

Table 7. Yearly domestic welfare (bln €) of both countries, for different strategic policy choices where country 1 faces all environmental pollution damage.

		Country 2 (without pollution damage)		
		Emission Standard	**Fuel tax**	**Policy mix**
Country 1 (with pollution damage)	**Emission standard**	143.3 / 199.0	141.8 / 200.3	141.8 / 200.3
	Fuel tax	147.2 / 192.8	146.2 / 194	146.2 / 194
	Policy mix	147.2 / 192.8	146.2 / 194	146.2 / 194

Compared to the benchmark case in section 4.1, we see that both governments are indifferent between two options: they can either set a fuel tax or an emission standard combined with the fuel tax. Any emission standard imposed will not influence the final fuel economy of the car as the R&D investments are only driven by the oil price and fuel taxes. The level of the fuel tax, however, differs among countries: only the country that faces damage from CO_2 emissions will incorporate this damage in the fuel tax. Interestingly, the asymmetric damage does not affect total welfare in the non-cooperative equilibrium. The aggregated tax burden of both governments is approximately the same as in the benchmark, which is reflected in the same fuel economy level as before (3.30%).

4.3.2. *Strength of domestic car producers*

We assume now that all car producers are located in country 1.

The results are only in one way similar to the case of asymmetric environmental pollution: Country 1 acts as an 'environmental leader' and sets both a high fuel tax and emission standard, while country 2 hardly imposes taxes or an emission standard. However, the incentives to conduct these environmental policies are driven by strategic trade policies rather than bt environmental concerns.

Countries without a strong car industry (country 1) have two incentives to set an environmental policy: to reduce global emissions and to redirect foreign profits to their own country. In this case, governments will set an emission standard that improves fuel economy with 12%, which is much higher than is socially optimal as they do not face the cost of investing in R&D for fuel economy[19]. The remainder of the profits of car producers are taxed away with a high fuel tax. The country that has a strong car industry (country 2) has no interest in setting any environmental policy at all as it tries to protect their car industry and the policy of the other government already reduces pollution damage. In contrast with the previous case, we find a very significant impact on welfare. Global welfare decreases by approximately 10% in comparison to the benchmark with an equal number of car producers in each country due to high emission standards.

Table 8. Yearly domestic fuel welfare (bln €) of both countries, for different strategic policy choices of each government and when car producers are located in country 2.

		Country 1 (no car producers)		
		Emission Standard	Fuel tax	Policy mix
Country 2 (car producers)	Any policy	167 142	192 146	162 148

4.3.3. *Model application*

The two asymmetric cases that we discuss demonstrate in a simplistic setting the interaction between environmental concerns and trade incentives that influence the government's decision to choose environmental policy instruments. The results are straightforward. Using the environmental policy as a trade instruments significantly decreases welfare. Cooperation between governments can reduce these trade incentives but is not likely to occur as all governments always deviate from the cooperative equilibrium to increase their own welfare. Furthermore, asymmetric concerns on global pollution damage do not affect the global welfare as the environmental policy instruments are used to reduce this pollution. With

[19] If we allow for an endogenous number of car producers, the government without car producers will set an emission standard that is even higher in order to reduce total car producers on the market. As a result, this will even reduce welfare further and only reinforces our analysis.

asymmetric trade incentives however, the governments will rely much more on environmental policy to extract market rents which reduces global welfare.

In order to keep the analysis of the model clear, we focused on specific cases where we allowed only limited parameter changes. We did not discuss the interactions between the several cases that can occur. For example, if we allow for spillovers in R&D, the policy choices for both asymmetric cases change significantly. For asymmetric environmental pollution levels, we will have one country that sets a strict emission standard while both fuel tax levels will be low. For an asymmetric car industry, we even find that no fuel taxes will be imposed at all. Furthermore, we could allow for a combination of asymmetric pollution and a difference in car industry, which would result in a fuel tax in 1 country and an emission tax in the other. However, for each of these scenarios the underlying incentives for each government are analogous to the cases that we discussed and the net result in environmental policy will be an aggregation of the different elements analyzed in both the analytical model and the numerical exercise.

5. Conclusion

In the car market, non-cooperative policies to reduce CO_2 emissions have led to the implementation of policy instruments that differ among countries. Emission reduction is targeted using a wide range of policy instruments. This has led to a very heterogeneous mix of policy instruments between governments. In this paper, we analyze the welfare effects of combining policy instruments in the international car market to reduce carbon emissions. Our model is a variant of the Ulph and Ulph (2007) model and is kept simple. We focus on two questions. First, we look into the effect of cooperative and non-cooperative policies on the instrument choice for reducing CO_2 emissions in the car market. We analyze the role of fuel prices, market concentration and R&D spillovers on instrument choice. Second, we analyze how governments with a similar car market but different country characteristics opt for a different environmental policy instrument in a non-cooperative setting. We allow for differences in environmental damage and strength of domestic car producers in the car market.

First, the analytical model shows that governments have no incentive to coordinate their environmental policy within the car market. Each government will always try to use its policy instruments to combine the reduction of CO_2 emissions with the protection of domestic producers and consumers, either by safeguarding their direct market surplus or by taxing foreign profits in order to raise government revenue. Particularly when global environmental damage is low, non-cooperative governments may opt for too high fuel taxes in order to tax foreign profits. This may then generate too high fuel efficiency efforts from producers. The fuel efficiency standard becomes a more important instrument when there is only a small number of producers, when there is a higher spill over rate and when crude oil prices are lower. Countries that mainly import cars use strict fuel efficiency policies and high fuel taxes while car exporting countries do not use fuel effiency policies and set low fuel tax rates.

Both the analytical model and the numerical example demonstrate how market environments, producer decisions and country characteristics determine the final decision of governments to conduct environmental policy in the car market and how these policies interact with each other. The insights of this model can be used to analyse questions like how governments react if one country decides to change its policy mix, what is the effect of encouraging cooperation (spillovers) in research and development? how will a higher fuel price impact the choice and level of different policy instruments? and to what extent is the observed environmental policy of a government the result of trade incentives or environmental concerns?

The model can be adapted in many more ways. For any number of countries and car producers, we can allow for differences in size, R&D policies, market concentration and domestic car production, pre-tax fuel prices and production costs or other market characteristics. Each of these elements will affect the instrument choice of governments and therefore also the strategic game between different governments and its effects on welfare in all countries.

In order to complete this paper with an empirical analysis of currently observed policies, several limitations still need to be addressed. First, we have assumed that fixed costs of R&D cannot be shared among car producers. But, car producers might cooperate on the level of research and development, which results in the internalization of spillovers by each car producer. Further research is necessary to fully understand the interaction between cooperative R&D and the choice of environmental policy instruments. Second, our interpretation of the strategic decisions of car producers can incorporate elements of the traditional literature on econometric car market models. Although these studies find an effect of environmental policy on producer decisions which is similar to ours, the incorporation of product differentiation and other car characteristics can provide a more accurate estimation of the numerical effects of the strategic policy game between governments.

6. References

Allcott, H. and M. Greenstone (2012). Is there an energy efficiency gap?, *Journal of Economic Pespectives*, Vol 26, 1,3-28

Anderson, S., I. Parry, J. M. Sallee, and C. Fischer (2011). Automobile Fuel Economy Standards: Impacts, Efficiency and Alternatives. *Review of Environmental Economics*, 5 (1), 89-108.

Austin, D. and T. Dinan (2005). Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increased Gasoline Taxes. *Journal of Environmental Economics and Management*, 50 (3), 562-582.

Barla, P. and S. Proost (2012). Energy efficiency policy in a non-cooperative world. *Energy economics*, 34 (6), 2209-2215.

Barrett, S. (1994). Strategic Environmental Policy and International Trade. *Journal of Public Economics* 54 (3), 325-338.

Berry, S., J. Levinsohn and A. Pakes (1995). Automobile Prices in Market Equilibrium. *Econometrica*, 63 (4), 841-940.

Fischer C., Harrington W. and Parry I. (2007). Should Automobile Fuel Economy Standards be Tightened? *The Energy Journal*, 28 (4), 1-29.

Gerard, D. and Lave L. (2003). The Economics of CAFE Reconsidered: A Response to CAFE Critics and a Case for Fuel Economy Standards. AEI-Brookings Joint Centre for Regulatory Studies, Regulatory Analysis 03-01, Washington.

Goulder, L. and I. Parry (2008). Instrument choice in environmental Policy. *Review of environmental economics and policy*, 2 (2), 152-174.

Hattori, K. (2013). Environmental innovation and policy harmonization in international oligopoly. *Environment and Development Economics,* 18 (2), 162-183.

Jacobson, M.R. (2013). Evaluating US Fuel Economy Standards in a Model with Producer and Household Heterogeneity. *American Economic Journal: Economic Policy,* 5 (2), 148–187.

Kleit, A.N. (2004). Impacts of Long-Range Increases in the Fuel Economy (CAFE) Standard. *Economic Inquiry*, 42 (2), 279-294.

Parry, I. and K.A. Small (2005). Does Britain or The United States Have the Right Gasoline Tax? *American Economic Review,* 95 (4), 1276-1289.

Parry, I., M. Walls and W. Harrington (2007). Automobile Externalities and Policies. *Journal of Economic Literature*, 45 (2), 373-399.

Parry, I. ,D.Evans, W.E.Oates (2014), Are energy efficiency standards justified?, *Journal of Environmental Economics and Management*, 67,104-125

Roth, K. (2013). The Unintended Consequences of Uncoordinated Regulation: Evidence from the Transportation Sector. *Cornell University Working Paper,* 466-478.

Sturm, D. and A. Ulph (2002). Environment and Trade: The Implications of Imperfect Information and Political Economy. *World Trade Review*, 1 (3), 235-256.

Sturm, D. (2003). Trade and the Environment: A Survey of the Literature. In: Marsiliani, L., Rauscher, M., Withagen, C. ,eds, Environmental Policy in an International Perspective. *Kluwer Academic Publishers*: 119–149.

Tsai, T.H., K.-I. Tu, J.-R. Chiou. (2014), Tariffs and Environmental Taxes in the presence of Environmental R&D, *Environment and Resource Economics*, publ. online 23 April

Ulph, A. (1996). Environmental Policy and international trade when governments and producers act strategically. *Journal of environmental economics and management,* 30 (3), 265-281.

Ulph, A., and D. Ulph (2007). Climate change – Environmental and technology policies in a strategic context. *Environmental and Resource Economics,* 37 (1), 159-180.

West, S. and R. C. Williams (2005). The Cost of Reducing Gasoline Consumption. *American Economic Review*, 95 (2), 294-299.

Appendix A

We derive the output levels in the Cournot equilibrium. The profit function of each firm is given by equation (3.5):

$$\max_{y_{ij}} \pi_{ij} = \left[p_i \left(\sum_{j=1}^{n} y_{ij} \right) - v_{ij} \right] y_{ij} - d * y_{ij} \ , \ \ with\ y_{ij} \geq 0$$

We derive the profit function of company 1 in country 1with respect to output level y_{11} for a given level of output for each competitor in that country. We know that the market prices is given by (3.1) and the fuel cost v_{ij} is fixed. In the equilibrium, this first order condition will equal zero.

$$\frac{d\pi_{11}}{dy_{11}} = \left[a - b \left(\sum_{j=1}^{n} y_{1j} \right) - by_{11} \right] - (v_{11} + d) = 0$$

We can derive the first order condition for each firm. The Cournot equilibrium is given by solving the system of n first order conditions for the n output levels:

$$\begin{cases} a - (by_{12} - by_{13} - \dots \ -by_{1n}) - 2by_{11} = (v_{11} + d) \\ a - (by_{11} - by_{13} - \dots \ -by_{1n}) - 2by_{12} = (v_{12} + d) \\ \dots \\ a - \left(by_{11} - by_{12} - \dots \ -by_{1(n-1)}\right) - 2by_{11} = (v_{1n} + d) \end{cases}$$

Solving the system of equations, we find a solution for y_{11} in function of costs and demand parameters:

$$y_{11} = \frac{a + \sum_k v_{1k} - n\, v_{11} - d}{(n+1)b} \ where\ k \neq 1$$

Generalizing the result, we get the definition of output as given by equation (3.6):

$$y_{ij} = \frac{a + \sum_k v_{ik} - n\, v_{ij} - d}{(n+1)b} \quad \text{for } j,k = \{1,..,n\} \text{ and } j \neq k$$

Appendix B

We derive the first order condition that determines the optimal fuel economy level for each firm. The profit firm to be maximized is given by the profit margin on each car minus the costs of R&D for fuel economy.

$$\max_{x_j} \pi_j = \sum_i \left[\left(p_i - v_{ij}\right) y_{ij} - \ d * y_{ij} \right] - \beta x_j^2$$

From the derivation of the first order condition in the third stage (see appendix A), we know that the profit margin of the producer on every car equals to

$$p - (v_{11} + d) = by_{11}$$

This results in the simplified profit function as presented in equation (3.7):

$$\max_{x_j} \ \sum_i by_{ij}^2 - \ \beta x_j^2\,, \ \ \text{st}\, x_j > \overline{x_\iota} \ and\ e \geq 0$$

We know that the output is affected by the fuel cost, both of the own car (v_{ij}) the of the competitors' car (v_{ik}), that both depend on fuel economy x_j. The first order condition equals

$$\frac{d\pi_j}{dx} = \sum_i 2by_{ij} \left(\frac{dy_{ij}}{dv_{ij}} \frac{dv_{ij}}{dx_j} + \frac{dy_{ij}}{dv_{ik}} \frac{dv_{ik}}{dx_j} \right) - 2\beta x_j = 0$$

Using definition (3.6) for the output level and equation (3.2) and (3.3) for the fuel cost of each car, we can derive the output with respect to the fuel cost and the fuel cost with respect to fuel economy. The latter is given by

$$\begin{cases} \dfrac{dv_{ij}}{dx_j} = (t_i + F) g \dfrac{de_j}{dx_j} = -(t_i + F) g \\ \dfrac{dv_{ik}}{dx_j} = (t_i + F) g \dfrac{de_k}{dx_j} = -\delta (t_i + F) g \end{cases}$$

We can know easily compute the first order condition with respect to fuel economy x as given by equation (3.8).

$$\sum_{i}^{n} 2\left(\frac{n-(n-1)\delta}{n+1}\right)\left(t_i + F_p\right) g\, y_{ij} \;= 2\beta x$$

Appendix C

To understand the welfare implications of cooperative and non-cooperative policy, we need to derive explicit solutions for the fuel tax and emission standard. In this appendix, we assume that the emission standard is always binding. The same analysis applies for a non-binding standard. First we will show that total welfare is always higher in a cooperative equilibrium compared to the non-cooperative equilibrium. Next, we show that each government has an incentive to deviate from this cooperative equilibrium.

We solve the first order conditions for both emission standard x and fuel tax t. for the cooperative equilibrium (C), we have that

$$t = \frac{2(a-d)\mathrm{D}'(2\mathrm{D}'+F)g^2 + b\left(a-d-g\left(F+2\mathrm{D}'(1+n)\right)\right)\beta}{g\left((a-d)(2\mathrm{Dam}+F)g - bn\beta\right)}$$

$$x = \frac{(2\mathrm{D}'+F)g(-a+d+(2\mathrm{D}'+F)g)}{(2\mathrm{D}'+F)^2 g^2 - bn\beta}$$

The welfare in equilibrium is given by

$$Welfare_C = -\frac{(-a+d+(2\mathrm{Dam}+F)g)^2 n\beta}{(2\mathrm{Dam}+F)^2 g^2 - bn\beta}$$

The welfare is positive as longs as we have an interior solution $x > 0$ and $t \geq 0$. We can do the same analysis for the non-cooperative equilibrium (NC) and have

$$Welfare_{NC} = \frac{(a-d)^2\mathrm{D}'^2 g^2 n + b(a-d-(\mathrm{D}'+F)g)n(a(2+n)-d(2+n)-g(F(2+n)+\mathrm{D}'(4+3n)))\beta}{b(-(\mathrm{D}'+F)g^2(F(2+n)+\mathrm{D}'(4+3n))+b(1+n)^2\beta)}$$

By use of the definitions of taxes, emission standards and output, we can show that the difference in welfare is always positive

$$Welfare_C - Welfare_{NC} > 0$$