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Simone Marsiglio, Nahid Masoudi

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AUTHORS

Simone Marsiglio
Department of Economics and Management
University of Pisa
HenU Center for Financial Development and Stability
Henan University
E-mail: simone.marsiglio@unipi.it

Nahid Masoudi (Corresponding Author)
Department of Economics
Memorial University of Newfoundland, Canada
HenU Center for Financial Development and Stability
Henan University
E-Mail: nmasoudi@mun.ca

IMPRESSUM

HenU Center for Financial Development and Stability
Dongliuzhai Building, 85 Minglun Street
Henan University, Minglun Campus
Shunhe, Kaifeng, Henan, China
Tel. +86 (30) 897 89-0
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Transboundary Pollution Control and Competitiveness Concerns in a Two-Country Differential Game

Simone Marsiglio*‡ Nahid Masoudi†‡

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Abstract

We analyze a transboundary pollution control problem in a heterogeneous two-country differential game in which each country's regulator cares for the implications of environmental policy on its competitiveness. We characterize and compare the noncooperative and the cooperative solutions, showing that under both scenarios, the heterogeneous countries impose different tax rates despite such competitiveness concerns. This may suggest that, while implementing some kind of mitigation policy is necessary to combat climate change, a universally homogeneous environmental tax may not be either desirable or optimal.

Keywords: Climate Change; Competitiveness; Mitigation Policies; Transboundary Pollution
JEL Classification: C70, Q54, Q58

1 Introduction

Over the last decades we have witnessed a substantial increase in the intensity of heat waves and droughts, in the strength of hurricanes and tornadoes, and in the frequency of earthquakes and tsunamis, which all provide strong evidence of how destructive climate change could be if it is not controlled in a timely manner. Moreover, future predictions are not comforting either, as they suggest that the global temperature level will keep rising over the next few decades, leading to even more drastic negative impacts if we continue to fail in considerably limiting the greenhouse gases (GHGs) produced by human activities (IPCC, 2007, 2018). Carbon price, whether implemented through a tax or emissions trading, is widely recognized as the most effective policy in controlling pollution accumulation (OECD, 2013). However, the effectiveness of carbon pricing schemes depends not only on how they are implemented in each single economy, but also on whether and how other countries implement them. Indeed, it is widely accepted that the benefits of unilateral domestic climate change mitigation policies in the absence of other complementary policies, like boarder tax adjustments, could be limited and it is highly dependent on the extent that other countries are implementing such policies. This is due to two different channels: the transboundary nature of the GHGs; and the competitiveness issues associated with mitigation policy. On the one hand, due to the

*University of Pisa, Department of Economics and Management, Pisa, Italy. Contact: simone.marsiglio@unipi.it.
†Department of Economics, Memorial University of Newfoundland, Canada. Contact: nmasoudi@mun.ca (Corresponding author: 🖂).
‡Henan University, School of Economics, Center for Financial Development and Stability, Kaifeng, China.

transboundary nature of the GHGs, their accumulation and evolution is jointly determined by the emissions and mitigation efforts of all individual countries, thus an effective combat against climate change requires cooperation across all countries (Ansuategi and Perrings, 2000; Ansuategi, 2003). On the other hand, implementation of unilateral environmental policies could potentialy, lead to a decline in domestic income and an increase in net imports by making domestic production more expensive and, as such, reducing the competitiveness of domestic firms (Copeland and Taylor, 2004; Levinson and Taylor, 2008). The former channel has been extensively discussed in the international pollution control literature from many different perspectives, whereas the latter, that is the impact and implications of competitiveness concerns, has not been formally analyzed in an international pollution control context yet. This paper aims at exploring a first step to close this gap and shed some light on how the presence of competitiveness considerations in the determination of environmental policies affects individual and collective mitigation strategies.

The transboundary pollution control literature studies the choice of optimal environmental policies from many different perspectives (van der Ploeg and Withagen, 1991; Athanassoglou and Xepapadeas, 2012; Saltari and Travaglini, 2014; La Torre et al., 2017). The transboundary implications of pollution are typically considered in a multi-country differential game setup, stressing the urgency of international cooperation to reduce GHGs, as well as, the difficulties of achieving an effective agreement amongst countries due to the extensive free riding incentives (van der Ploeg and de Zeeuw, 1992; Long, 1992; Rubio and Ulph, 2007; Masoudi and Zaccour, 2013). However, to the best of our knowledge, none has formally analyzed the competitiveness implications of environmental policy on the inefficiency arising from transboundary externalities. Indeed, as suggested by the pollution haven hypothesis, environmental regulation could lead to a loss of domestic competitiveness by making the domestic production more expensive and less attractive to domestic and international consumers causing an increase in net imports and possibly relocation of polluting firms to foreign countries with less stringent environmental standards. The argument behind this theory is intuitive and several theoretical explanations have been put forward to explore different channels through which this may occur (Pethig, 1976; Siebert, 1977; McGuire, 1982; Copeland and Taylor, 2004; Levinson and Taylor, 2008). However, empirical tests of this hypothesis have been difficult and early works could not support it (Jaffe et al., 1995; Ederington et al., 2005), nevertheless, recent studies have found statistically significant and reasonably sized effects by relying on richer data and methods (Levinson and Taylor, 2008; Aldy and Pizer, 2015; Carbone and Rivers, 2017; Dechezlepretre and Sato, 2017). Levinson and Taylor (2008) demonstrate that industries whose abatement costs increase most with environmental policy are those that experience the largest increases in net imports, and also that more than half of the total increase in trade volume is due to the increase in regulatory costs. Both Aldy and Pizer (2015) and Carbone and Rivers (2017) conclude that energy-(emissions-)intensive manufacturing industries are likely to experience decreases in production and increases in net imports as a result of domestic mitigation policies. Dechezlepretre and Sato (2017) show that environmental regulations can lead to adverse short run effects on trade, employment, plant location, and productivity, in particular in a subset of pollution- and energy-intensive sectors.

Regardless of whether the empirical evidences on this issue are conclusive or not, the concerns for the eventual possibility of a negative impact of mitigation policies on competitiveness has been a significant factor in the discussion of environmental policy choices, where such concerns have given rise to a widespread skepticism generating reluctance and other forms of costly social unrest in response to environmental policies. We can find several examples of this in today's policy arena, where politicians use this argument as an excuse not to follow international environmental regulations or to postpone them to some unknown future date. For example, the Trump administration has frequently mentioned that they will not cut their emissions unless China and other countries do so first. The recent protests in France in reaction to an eco-tax on gas (led by the so-called "Gilets Jaunes" movement) has led to considerable loss, estimated about 0.1 percent of GDP only for the year 2018, for the French retail sector (Financial Times, December 10, 2018). During the 2018 UN climate policy negotiations in Katowice (Poland), the president Trump has exploited the French turmoil to reiterate his skepticism toward mitigation policies by tweeting: *"The Paris Agreement isn't working out so well for Paris... People do not want to pay large sums of money, much to third world countries (that are questionably run), in order to maybe protect the environment"* (@realDonalTrump, 8:34 PM - Dec 8, 2018). Similar concerns and reactions are present at the national level where provincial or state governments could follow their own distinct environmental policies. For example, in Canada, according to the Pan-Canadian Framework on Clean Growth and Climate Change, all provinces have been required in 2018 to implement a proper carbon pricing, either in the form of a direct pricing system or a cap-and-trade system (Government of Canada, 2017). To fulfill this obligation, the government of Newfoundland and Labrador (NL) has set the provincial carbon tax rates at $20 a ton on January 1, 2019 (Newfoundland Government, 2018), but concerns about its potential negative effects on the local competitiveness and provincial parity surged due to the fact that Nova Scotia (a neighboring province in Atlantic Canada) decided to adopt a cap-and-trade system which is not readily comparable with NL's tax. These concerns led the NL's government to review its initial plans with uncertain prospects for its carbon tax.

In order to take these considerations into account, in this paper we embed all these indirect sources of environmental regulations cost, which may be due to either economic or political factors, (hereafter referred to as competitiveness concerns) into a transboundary pollution control framework. We analyze a heterogeneous two-country differential game in which each country's regulator cares not only for the environmental costs and the direct regulation costs associated with mitigation policy but also for the indirect regulation costs related to competitiveness losses. Competitiveness concerns arise if domestic climate regulations are more stringent than the ones followed in other countries, since the eventual international relocation of production factors may take place only to the extent that environmental regulation is more lenient abroad. This introduces an additional layer of complexity in the determination of the domestic mitigation strategy, which in our setting takes the form of a carbon tax. We determine the carbon tax rates under two different scenarios: we focus first on the case in which countries do not cooperate with each other and play á-la Cournot, and then we analyze the cooperative case. In particular, we wish to understand whether it may be optimal for the two countries to set a universal global abatement policy, or whether their country-specific heterogeneities will require related but yet differentiated policies. Our results suggest that, both in the noncooperative and the cooperative scenarios, the carbon tax rates for the two countries are different after accounting for the competitiveness cost of regulation. In particular, apart from in some specific parametrization, any kind of heterogeneity will result in heterogeneous mitigation policies.

This paper proceeds as follows. Section 2 introduces our two-country differential game of transboundary pollution control. Section 3 derives the carbon tax rates for the two countries in the noncooperative scenario, while Section 4 derives the optimal carbon tax rates in the cooperative one. Section 5 compares the equilibrium outcomes under the two scenarios. Section 6 as usual presents concluding remarks. Technicalities are postponed to Appendix A.

2 The Model

We consider two neighboring countries, i and j, which share a common environment. Time is continuous and to simplify notation we drop the time index. The macroeconomic framework is extremely simple: in each country households entirely consume their disposable income as follows: $C_i = (1 - \tau_i)Y_i$, where C_i denotes consumption, $0 \leq \tau_i \leq 1$ the (carbon) tax rate and Y_i output. Pollution, P, which is the by-product of economic activities within these countries, is transboundary and its stock damages their common environment. For the sake of simplicity, we suppose that emissions are a linear function of production and each country's production is given, but its regulator can reduce emissions through a carbon tax. We assume that output is constant and without loss of generality it is normalized to unity, $Y_i \equiv 1$. Emissions are proportional to output and given by $\nu_i > 0$, which measures the degree of environmental inefficiency of economic activities in country i. The carbon tax has a one-to-one effect on emissions, thus reducing country i's emissions to $\nu_i (1 - \tau_i)$. Pollution accumulates according to the difference between net (of abatement) emissions of country i and j and its decay, where $\delta > 0$ is the natural decay rate of pollution. Therefore, given its initial level P_0, pollution evolves according to the following equation:

$$\dot{P} = \nu_i (1 - \tau_i) + \nu_j (1 - \tau_j) - \delta P. \tag{1}$$

The regulator in each country wants to minimize the social cost that is the infinite discounted sum of the instantaneous losses, L_i, which has two components: the environmental damage, D_i; and the losses associated with the regulation, R_i, i.e., $L_i = R_i + D_i$. Moreover, the regulation loss comprises two components: the direct taxation loss, R_i^t, and the indirect competitiveness loss, R_i^c: $R_i = R_i^t + R_i^c$. The former component measures the amount of resources diverted from consumption to abatement; the taxation loss function is assumed to be increasing and convex in the tax rate τ_i, and without loss of generality to be quadratic of the form $R_i^t (\tau_i) = \frac{1}{2}\alpha_i \tau_i^2$, where $\alpha_i > 0$ quantifies the weight of the direct taxation loss in the social cost function. The latter component measures the extent to which regulation in one country introduces a wedge between the degree of competitiveness of the country and that of its competitor, which clearly increases with the level of regulation in the home country, τ_i, and with the tax differential between the two countries, $\tau_i - \tau_j$; the competitiveness loss function is assumed to be increasing and convex in the country's own tax rate and linear in the other country's tax rate, and to take the form of $R_i^c (\tau_i, \tau_j) = \beta_i \tau_i (\tau_i - \tau_j)$, where $\beta_i > 0$ quantifies the weight of the indirect competitiveness loss in the social cost function. The environmental loss is measured by the environmental damage caused by pollution and it is assumed to be approximated by a linear function as follows: $D_i (P) = \gamma_i P_t$, where $\gamma_i > 0$ represents the weight of the environmental loss in the social cost function. Therefore, country i's instantaneous social cost is given by the following expression:

$$L_i (P, \tau_i; \tau_j) = \gamma_i P_t + \frac{1}{2}\alpha_i \tau_i^2 + \beta_i \tau_i (\tau_i - \tau_j). \tag{2}$$

Our model's formulation is consistent with the framework typically employed in the discussion of transboundary pollution control in a differential game setting (see Jorgensen et al., 2010; and Long, 2011, for good surveys). The main novelty is represented by the introduction of a second component in the regulation loss: while most papers account for the direct taxation loss, to the best of our knowledge none takes into account the competitiveness loss. However, in the determination of optimal environmental policy policymakers are often concerned with their eventual impact on the competitiveness of domestic firms and how this may in turn affect domestic employment and output. Indeed, as discussed in the pollution haven literature, a too stringent environmental regulation may reduce domestic competitiveness enough to make it convenient for domestic firms to migrate to countries with a less stringent environmental regulation, generating thus a loss of domestic employment and political reluctance to environmental regulation. In our setting this is quantified by the second term in (2), which depends both on the level of taxation within a country, τ_i, and on the taxation-differential between countries, $\tau_i - \tau_j$. The parameter β_i measures the degree of concern of the country i's regulator for the competitiveness loss arising from domestic environmental policy, which we shall refer to as "degree of competitiveness concern" in the following. The degree of competitiveness concern captures all those country-specific factors which, by affecting domestic competitiveness may determine aversion towards environmental regulation; for example, an economy heavily dependent on energy-intensive industries will be characterized by a high value of the parameter. We wish to analyze how the presence of such a degree of competitiveness concern, which may be eventually heterogeneous across countries, affects the determination of environmental policies.

3 Noncooperative Solution

We first focus on each country's policy choices under the business as usual scenario, that is countries do not cooperate and only care about their own cost. In this setting, given the initial pollution stock, $P_0 > 0$, and the discount rate, $\theta > 0$, county i's regulator faces the following problem:

$$\min_{\tau_i} \quad \mathcal{C} = \int_0^\infty \left(\gamma_i P + \frac{1}{2}\alpha_i \tau_i^2 + \beta_i \tau_i (\tau_i - \tau_j) \right) e^{-\theta t} dt, \tag{3}$$

$$s.t. \quad \dot{P} = \nu_i (1 - \tau_i) + \nu_j (1 - \tau_j) - \delta P. \tag{4}$$

Solving the above problem requires to find an explicit expression for the value function solving the Hamilton-Jacobi-Belllman (HJB) equation associated with the problem (3) and (4). After some algebra it is possible to claim the following (the proofs for all of the propositions are presented in the appendix A).

Proposition 1. *Assuming an interior solution, the noncooperative Cournot-Nash carbon tax rate in country i is given by:*

$$\tau_i^n = \frac{\gamma_i \nu_i (\alpha_j + 2\beta_j) + \gamma_j \nu_j \beta_i}{(\delta + \theta) [\alpha_i (\alpha_j + 2\beta_j) + \beta_i (2\alpha_j + 3\beta_j)]} \in (0, 1), \quad for\ i \neq j \tag{5}$$

Proposition 1 determines the noncooperative carbon tax rates in the case of an interior solution. Some simple sufficient conditions to ensure that an interior solution occurs read as follows: $\gamma_i < \delta + \theta$, $\nu_i < \alpha_i$ and $\gamma_j \nu_j < \gamma_i (2\alpha_j + 3\beta_j)$. As expected, economies with higher abatement levels are those more vulnerable to pollution due to either a dirtier production technology (higher ν_i) or a larger environmental damage (higher γ_i). Note that, since countries are not cooperating on their abatement efforts and the environmental damage function is approximated by a linear function, in a standard setup in which the degree of competitiveness concern is null ($\beta_i = 0$), we would observe country i's abatement decision not to be affected by the environmental damage of country j ($\frac{\partial \tau_i^n}{\partial \gamma_j} = 0$). However, whenever the degree of competitiveness concern is positive

($\beta_i > 0$) the marginal environmental damage of country j affects country i's abatement effort and, more specifically, the higher country j's marginal damage the higher country i's abatement ($\frac{\partial \tau_i^n}{\partial \gamma_j} > 0$). Therefore, as long as competitiveness concern partly drives the individual country's determination of its environmental regulation, the abatement policies of different countries become complements and not substitutes unlike what is typically concluded in the literature. A consequence of this complementarity is that a country will opt for a more stringent regulation the lower its own direct taxation loss (α_i) and the higher the other country's emissions (ν_j).

The presence of a nonnegative degree of competitiveness concern plays a crucial role in our setup, leading our results to depart from those typically discussed in related literature. However, this parameter affects individual countries' abatement policy in an ambiguous way and understanding a priori its implications for the carbon tax is not possible. In particular, country i's degree of competitiveness concern affects in the same direction the tax rate in both countries (i.e., $\frac{\partial \tau_i^n}{\partial \beta_i}$ and $\frac{\partial \tau_j^n}{\partial \beta_i}$ have always the same sign), and the magnitude of the cross-effect is smaller than the self-effect (i.e., $\left|\frac{\partial \tau_i^n}{\partial \beta_i}\right| \geq \left|\frac{\partial \tau_j^n}{\partial \beta_i}\right|$). Moreover, it is not possible for both pairs of self- and cross-effects ($\frac{\partial \tau_i^n}{\partial \beta_i}$ and $\frac{\partial \tau_j^n}{\partial \beta_i}$, and $\frac{\partial \tau_i^n}{\partial \beta_j}$ and $\frac{\partial \tau_j^n}{\partial \beta_j}$) to be positive, and in particular either both are negative or one pair is positive and the other negative; which of these two cases holds true critically depends on the parameters configuration. These results are summarized in Proposition 2.

Proposition 2. *Country i's abatement (τ_i^n) is increasing in its own and the other country's marginal environmental damage (γ_i and γ_j) and emissions (ν_i and ν_j), and decreasing in its own and the other country's direct taxation loss (α_i and α_j). However, the impact of its own and the other country's degree of competitiveness concern (β_i and β_j) on abatement is ambiguous.*

From Proposition 1 we can clearly see that introducing any source of heterogeneity (environmental damage, γ, direct taxation loss, α, competitiveness concern, β, or emission rate, ν) between the two countries will result in different environmental policies. Indeed, the difference between the two countries' carbon tax rates are given by the following expression:

$$\tau_i^n - \tau_j^n = \frac{\gamma_i \nu_i (\alpha_j + \beta_j) - \gamma_j \nu_j (\alpha_i + \beta_i)}{(\delta + \theta)\left[\alpha_i (\alpha_j + 2\beta_j) + \beta_i (2\alpha_j + 3\beta_j)\right]}, \tag{6}$$

from which it is clear that the two environmental policies will be equal only if the total marginal regulation loss, that is the sum of the marginal taxation loss and the marginal competitiveness loss, $\alpha_i + \beta_i$, weighted by the cross-emission-adjusted environmental damage, $\gamma_j \nu_j$, perfectly coincide between the two countries. We can therefore conclude the following.

Corollary 1. *Two countries i and j impose equal abatement policies if and only if the total marginal regulation loss weighted by the cross-emission-adjusted environmental damage is the same in both countries, i.e. $\gamma_j \nu_j (\alpha_i + \beta_i) = \gamma_i \nu_i (\alpha_j + \beta_j)$.*

The parameter condition in Corollary 1 is very unlikely to hold true in reality and thus the carbon tax rates in the two countries will differ. In order to understand the extent of the difference between the two environmental policies, suppose without loss of generality that $\tau_i > \tau_j$. Since the self-effect of a parameter change is stronger than its cross-effect, from Proposition 2 it follows that the gap between abatement efforts of countries i and j is increasing (decreasing) in the marginal environmental damage, γ, and emissions,

ν, of country i (country j), and decreasing (increasing) in the taxation loss, α, of country i (country j). The effect of the degree of competitiveness concern, β, is instead less obvious. Indeed, whenever $\alpha_i\gamma_j\nu_j > \gamma_i\nu_i(2\alpha_j + 3\beta_j)$ the gap between the abatement efforts of countries i and j is unambiguously increasing in both countries' degree of competitiveness concern, while whenever $\alpha_i\gamma_j\nu_j < \gamma_i\nu_i(2\alpha_j + 3\beta_j)$ the gap is decreasing in the degree of competitiveness concern of country i and ambiguous in country j's. However, since the cross-effects are smaller than the self-effects, if τ_i^n is decreasing (increasing) in β_i, then the gap between the two abatement efforts (i.e. $\tau_i^n - \tau_j^n$) will be decreasing (increasing) in β_i.

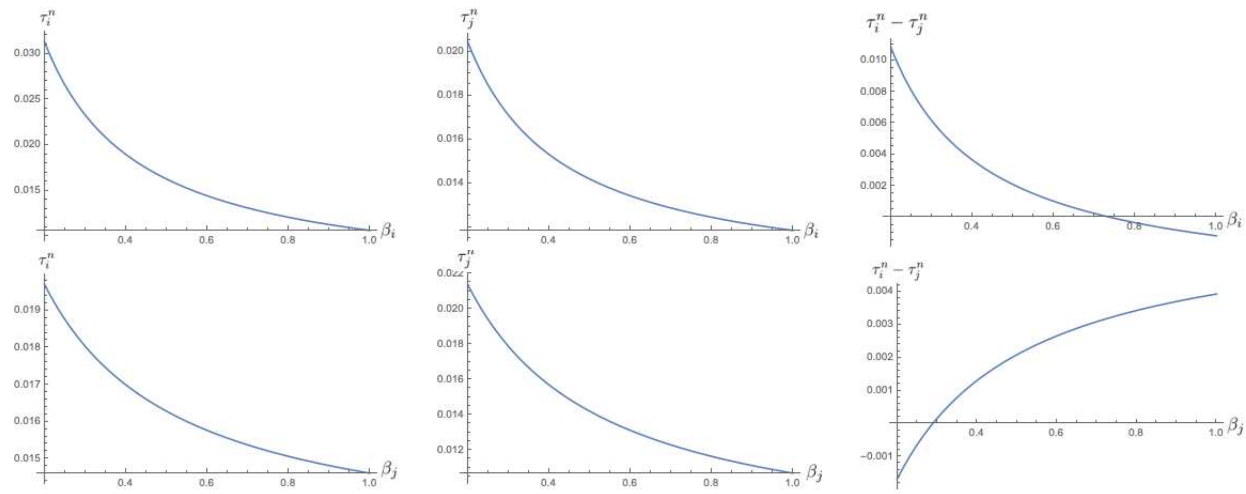

Figure 1: Effects of changes in the degree of competitiveness concern of country i and j on the noncooperative solution.

We have seen from Proposition 2 and from the above discussion that while the impact of most parameters on individual country's abatement policy, and thus their difference, is clear, the impact of the degree of competitiveness concern is not that clear. In order to shed some light on this we now present a numerical example in which we set all the parameter values except for the degree of competitiveness concern of both countries which we allow to vary; specifically we consider the following parameter values: $\alpha_i = 0.05$, $\beta_i \in (0.2, 1)$, $\gamma_i = 0.03$, $\nu_i = 0.03$, $\alpha_j = 0.2$, $\beta_j = 0.5$, $\gamma_j = 0.04$, $\nu_j = 0.02$, $\delta = 0.05$ and $\theta = 0.04$. Figure 1 shows the impact of changes in β_i (top panels) and β_j (bottom panels) on the carbon tax rate of country i (left panels) and country j (middle panels), along with their gap (right panels). We can see that, for the specific parametrization considered, the carbon tax rates of both country i and j fall monotonically with both their own and cross degree of competitiveness concern. By looking at the magnitude of the difference between the two countries' carbon tax rates, we can see that this falls with β_i and increases with β_j. These results suggest that understanding how different competitiveness concerns across countries will affect their individual environmental policies cannot be predicted a priori.

4 Cooperative Solution

The noncooperative solution earlier discussed is clearly not optimal since it does not minimize the joint social cost for the two countries, which is due to the fact that countries do not internalize the pollution externality that their production activities impose on each other. In order to determine such a jointly optimal equilibrium, which also represents the social optimum, we now focus on the cooperative setup assuming that the two countries agree to mutually determine their abatement efforts. The cooperative problem can be stated as follows:

$$\min_{\tau_i,\tau_j} \quad \mathcal{C}_i + \mathcal{C}_j = \int_0^{\infty} \left(\frac{1}{2}\alpha_i \tau_i^2 + \beta_i \tau_i (\tau_i - \tau_j) + \gamma_i P_t + \frac{1}{2}\alpha_j \tau_j^2 + \beta_j \tau_j (\tau_j - \tau_i) + \gamma_j P_t \right) e^{-\theta t} dt \tag{7}$$

$$s.t. \quad \dot{P} = \nu_i (1 - \tau_i) + \nu_j (1 - \tau_j) - \delta P. \tag{8}$$

By following the same approach employed before, it is possible to prove the following.

Proposition 3. *Assuming an interior solution, the cooperative or socially optimal carbon tax rate in country i is given by:*

$$\tau_i^* = \frac{(\gamma_i + \gamma_j) \left[\nu_i (\alpha_j + 2\beta_j) + \nu_j (\beta_i + \beta_j) \right]}{(\delta + \theta) \left[\alpha_i (\alpha_j + 2\beta_j) + 2\alpha_j \beta_i - (\beta_i - \beta_j)^2 \right]} \in (0, 1). \tag{9}$$

Proposition 3 determines the optimal carbon tax rates in the case of an interior solution. Some sufficient conditions for this to be the case read as follows: $\gamma_i + \gamma_j < \delta + \theta$, $\nu_i < \alpha_i$, $\nu_j(\beta_i + \beta_j) < 2\alpha_j\beta_j$ and $\alpha_i (\alpha_j + 2\beta_j) + 2\alpha_j\beta_i > (\beta_i - \beta_j)^2$, which are clearly more restrictive than those discussed earlier in the noncooperative case. An inspection of (9) shows that the impact of the different parameters on the optimal abatement policies is exactly as discussed earlier in the noncooperative case. Proposition 4 summarizes the results.

Proposition 4. *The socially optimal abatement of country i, τ_i^*, is increasing in its own and the other country's marginal environmental damage (γ_i and γ_j) and emissions (ν_i and ν_j), and decreasing in its own and the other country's direct taxation loss (α_i and α_j). However, the impact of its own and the other country's degree of competitiveness concern (β_i and β_j) on county i's socially optimal abatement is ambiguous.*

From Proposition 3 we can see that, similar to the noncooperative case, introducing heterogeneity (in direct taxation loss, α, competitiveness concern, β, or emission rate, ν) for the two countries will result in distinct optimal environmental policies. The only difference is related to the environmental damage (γ) which in the cooperative scenario does not lead to different environmental policies. Intuitively, since by cooperating both countries will fully internalize the pollution externality, then what matters is the sum of the two environmental damages ($\gamma_i + \gamma_j$) and thus asymmetry in environmental damage will not be a source of heterogeneity in optimal regulation. Moreover, since the difference between the two countries' optimal carbon tax rates is given by the following expression:

$$\tau_i^* - \tau_j^* = \frac{(\gamma_i + \gamma_j) \left[\nu_i (\alpha_j + \beta_j - \beta_i) - \nu_j (\alpha_i + \beta_i - \beta_j) \right]}{(\delta + \theta) \left[\alpha_i (\alpha_j + 2\beta_j) + 2\alpha_j \beta_i - (\beta_i - \beta_j)^2 \right]} \tag{10}$$

it is clear that the two optimal environmental policies will be equal only if the difference between the total marginal regulation loss, $\alpha_i + \beta_i$, and the cross degree of competitiveness concern, β_j, weighted by the cross emission rate, ν_j, perfectly coincide between the two countries. We can therefore conclude the following.

Corollary 2. *Two countries i and j impose equal optimal abatement policies if and only if the difference between the total marginal regulation loss and the cross degree of competitiveness concern weighted by the cross emission rate is the same in both countries, i.e. $\nu_j(\alpha_i + \beta_i - \beta_j) = \nu_i(\alpha_j + \beta_j - \beta_i)$.*

By comparing the parameter conditions in Corollary 1 and Corollary 2 we can note that while the former depends on the cross environmental damage and does not directly depend on the gap in degree of competitiveness concern betweern the two countries, the latter is unaffected by environmental damages and is affected by the disparities between the degree of competitiveness concern in the two countries rather than their absolute values. The fact that these conditions are so different suggests that, even if under noncooperation (cooperation) the abatement rates for the two countries coincide this does not imply that the abatement rates under cooperation (noncooperation) will be equal. Returning to the parameter condition in Corollary 2 we can see that this condition is very restrictive and thus very unlikely to hold in reality. As a result we would expect that the optimal carbon tax rates in the two countries to differ. In order to understand the extent of the difference between the two optimal environmental policies, we suppose again without loss of generality that $\tau_i^* > \tau_j^*$. If $\alpha_j + \beta_j - \beta_i > 0$, then similar to the noncooperation case, the self-effect of marginal environmental damage (γ_i and γ_j), emissions (ν_i and ν_j), and marginal taxation loss (α_i and α_j) is stronger than the cross-effect, and thus the gap between the optimal abatement efforts is increasing (decreasing) in country i's (country j's) emission rate and in country j's (country i's) marginal taxation loss. Moreover, the gap between the two abatement efforts will be decreasing (increasing) in β_i (in β_j.).

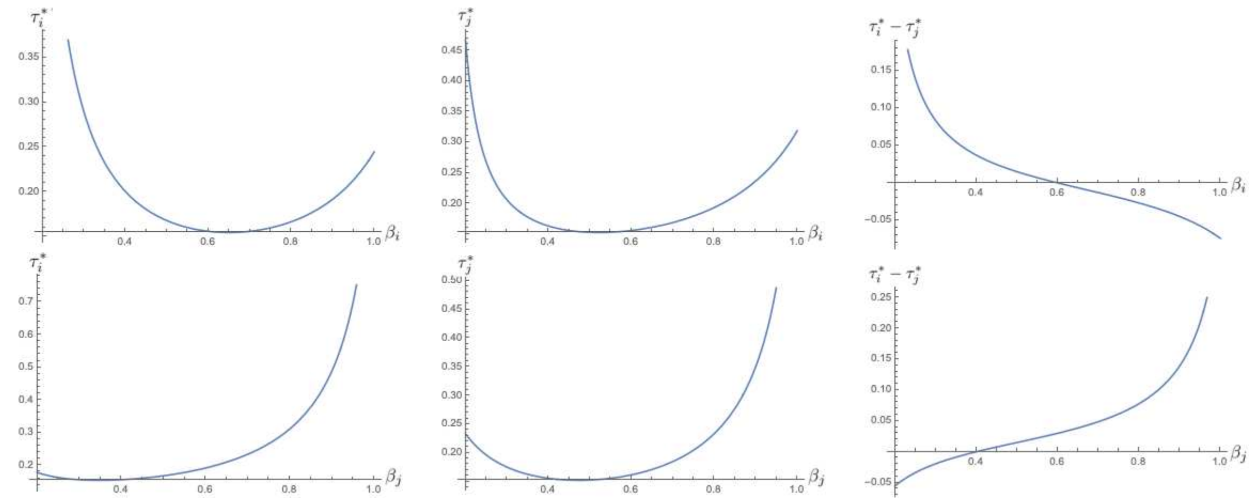

Figure 2: Effects of changes in the degree of competitiveness concern of country i and j on the cooperative solution.

In order to shed some light on the impact of the degree of competitiveness concern on the abatement policies, we keep relying on our previous parametrization. Figure 2 shows that the optimal carbon tax for both countries i and j are non-monotonically affected, decreasing first and then increasing with the degree of competitiveness concern of both countries i and j. The magnitude of the difference between the two countries' optimal carbon tax rates instead falls (rises) monotonically with the degree of competitiveness concern of country i (country j), changing from positive (negative) to negative (positive) values as the parameter increases.

5 Cooperation vs Noncooperation

By comparing the noncooperative and the cooperative solutions, given by (5) and (9) respectively, we can observe that the abatement efforts for each country are clearly different under the two scenarios. Intuitively, the presence of the pollution externality which is not accounted for by single individual countries distorts the noncooperative outcome away from the socially optimal one, and in particular, cooperation always demands higher abatement efforts from both countries. This is summarized in the next proposition.

Proposition 5. *The socially optimal tax rates are higher than the noncooperative rates for both countries (i.e., $\tau_i^* - \tau_i^n \geq 0$ in each country i).*

Proposition 5 suggests that competitiveness concerns do not reverse the negative externality's distortion. However, the size of the distortion (i.e., the size of the gap between cooperative and noncooperative carbon taxes, $\tau_i^* - \tau_i^n$), for each country depends on a number of factors, including the degree of competitiveness concern. By comparing (5) and (9), it is clear that the distortion is increasing in the marginal environmental damage (γ_i and γ_j) and in the emissions (ν_i and ν_j) of both countries, and decreasing in the direct taxation loss (α_i and α_j) of both countries. The impact of the degree of competitiveness concern is a priori ambiguous and critically dependent on the parameters configuration. Proposition 6 summarizes the result.

Proposition 6. *The size of the distortion between the cooperative and noncooperative carbon taxes increases with an increase in either country's environmental damage (γ_i and γ_j) or emissions (ν_i and ν_j), while it decreases with either country's direct taxation loss (α_i and α_j). However, the impact of each country's degree of competitiveness concern (β_i and β_j) on the size of the distortion is ambiguous.*

By relying on our previous numerical example we can gain some further insight on the effect of the degree of competitiveness concern on the size of the distortion between the cooperative and non-cooperative carbon taxes. In Figure 3 for both country i (left panels) and country j (right panels) the size of the distortion is strictly positive (Proposition 5) and it changes non-monotonically with the degree of competitiveness concern of both countries. As expected, we can see that the size of the distortion is smaller when the gap in the degree of competitiveness concerns between the countries is small, but even this relationship is not monotonic. This suggests, in line with what discussed in the previous sections, that competitiveness concerns may play an important role in determining the effectiveness of real world environmental policies.

6 Conclusions

The carbon tax is widely considered as the most effective policy to mitigate the climate change. However, it is often claimed that the net benefits of unilateral environmental policies are limited since, as suggested by the pollution haven hypothesis, these domestic environmental policies do not prohibit companies from exporting the production and, as such, the emissions to countries with more flexible environmental standards. Besides, it is argued that unilateral environmental policies could have negative impacts on domestic firms and diminish their competitiveness by making their products more expensive. In order to examining the impact of such competitiveness concerns on environmental regulations, we extend a standard two-country differential game of transboundary pollution to allow each country's regulator to care not only for the environmental

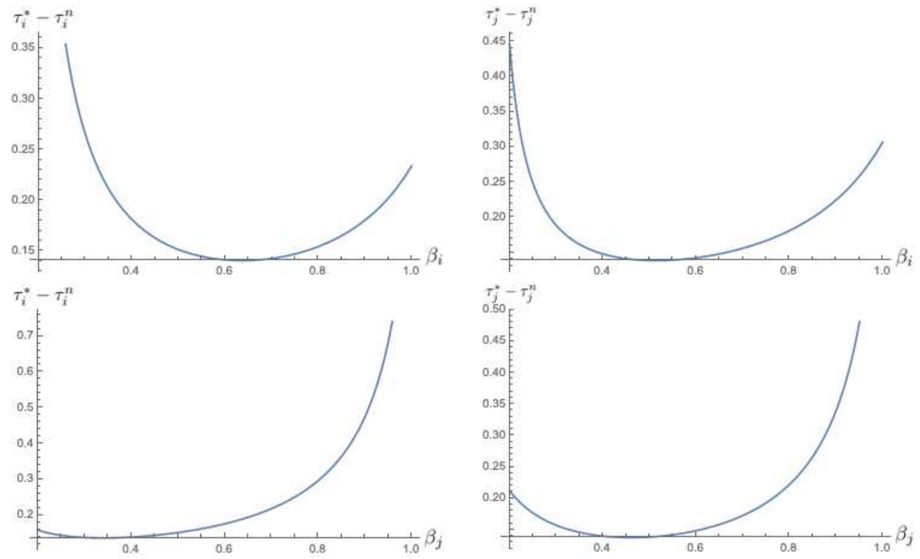

Figure 3: Effects of changes in the degree of competitiveness concern of country i and j on the difference between the cooperative and noncooperative solutions.

costs and the direct cost associated with carbon taxes, but also for the indirect regulation costs due to the competitiveness losses caused by the taxes. We derive the noncooperative and the cooperative solutions, showing that in both scenarios, the carbon tax rates for the two heterogeneous countries are different. These results suggest that unlike what commonly is argued in the policy arena, a universal global environmental tax may not be either desirable or optimal, and countries will benefit from following their own country-specific regulations taking all heterogeneities into account. We also show that the degree of competitiveness concern affects both the noncooperative and cooperative carbon tax rates in the two countries in an ambiguous way. These results suggest that competitiveness concerns may play an important role in determining the effectiveness of environmental policies.

To the best of our knowledge, this is the first paper integrating competitiveness concerns in a transboundary pollution control setting, and thus we have maintained our framework as simple as possible. However, in order to improve its ability to reflect real world situations the model could be extended along different directions. First, we can extend the number of countries to more than two. This extension gives us the possibility to investigate the impact of the competitiveness concerns on the size and effectiveness of international environmental agreements. Second, we fully acknowledge that some of our results are the consequences of our assumption of a linear environmental damage cost, thus introducing a non-linear damage cost is clearly an extension worth analyzing.

A Technical Appendix

A.1 Noncooperative Solution

In the noncooperative case the solution to the problem (3) and (4) should satisfy the following Hamilton-Jacobi-Belllman (HJB) equation, where $J_i^n(P)$ represents the country i's regulator value function and $J_{i,P}^n =$

$\frac{\partial J_i^n}{\partial P}$:

$$\theta J_i^n(P) = \max_{0\le\tau_i<1}\left\{\gamma_i P_t + \frac{1}{2}\alpha_i\tau_i^2 + \beta_i\tau_i(\tau_i-\tau_j) + J_{i,P}^n\left[\nu_1(1-\tau_1)+\nu_2(1-\tau_2)-\delta P\right]\right\}. \tag{11}$$

The first order condition yields:

$$\alpha_i\tau_i + 2\beta_i\tau_i - \beta_i\tau_j - J_{i,P}^n\nu_i = 0. \tag{12}$$

We conjecture that the value function $J_i^n(P)$ has the following form:

$$J_i^n(P) = A_i^n + B_i^n P, \tag{13}$$

where A_i and B_i are some constants to be determined. Plugging the first order conditions for the regulators of the two countries and the conjectured value function into (11) and solving for A_i and B_i yields $B_i = \frac{\gamma_i}{\theta+\delta}$.[1] Using these results to substitute back into the first order condition leads to noncooperative carbon tax rate given in (5).

The derivatives of the carbon tax rate in (5) undoubtedly yields: $\frac{\partial\tau_i^n}{\partial\gamma_i} > 0$, $\frac{\partial\tau_i^n}{\partial\gamma_j} > 0$, $\frac{\partial\tau_i^n}{\partial\alpha_i} < 0$, $\frac{\partial\tau_i^n}{\partial\alpha_j} < 0$, $\frac{\partial\tau_i^n}{\partial\nu_i} > 0$, $\frac{\partial\tau_i^n}{\partial\nu_j} > 0$. The effect of the degree of the competitiveness concern is instead ambiguous, since the following results apply:

$$\frac{\partial\tau_i^n}{\partial\beta_i} = \frac{(\alpha_j+2\beta_j)(\alpha_i\nu_j\gamma_j-(2\alpha_j+3\beta_j)\nu_i\gamma_i)}{(\delta+\theta)\left[\alpha_i(\alpha_j+2\beta_j)+\beta_i(2\alpha_j+3\beta_j)\right]^2}, \tag{14}$$

$$\frac{\partial\tau_j^n}{\partial\beta_i} = \frac{\beta_j(\alpha_i\nu_j\gamma_j-(2\alpha_j+3\beta_j)\nu_i\gamma_i)}{(\delta+\theta)\left[\alpha_i(\alpha_j+2\beta_j)+\beta_i(2\alpha_j+3\beta_j)\right]^2}, \tag{15}$$

i.e. $\frac{\partial\tau_i^n}{\partial\beta_i} \le (\ge) 0$ if $(2\alpha_j+3\beta_j)\nu_i\gamma_i \ge (\le)\alpha_i\nu_j\gamma_j$, while $\frac{\partial\tau_i^n}{\partial\beta_j} \le (\ge) 0$ if $(2\alpha_i+3\beta_i)\nu_j\gamma_j \ge (\le)\alpha_j\nu_i\gamma_i$.

The derivatives of the difference between the carbon tax rates in (6) is given by the following expressions which are again ambiguous:

$$\frac{\partial(\tau_i^N-\tau_j^N)}{\partial\beta_i} = \frac{(\alpha_j+\beta_j)(\alpha_i\gamma_j\nu_j-\gamma_i\nu_i(2\alpha_j+3\beta_j))}{(\delta+\theta)\left[\alpha_i(\alpha_j+2\beta_j)+\beta_i(2\alpha_j+3\beta_j)\right]^2},$$
$$\frac{\partial(\tau_i^N-\tau_j^N)}{\partial\beta_j} = -\frac{(\alpha_i+\beta_i)(\alpha_j\gamma_i\nu_i-\gamma_j\nu_j(2\alpha_i+3\beta_i))}{(\delta+\theta)\left[\alpha_i(\alpha_j+2\beta_j)+\beta_i(2\alpha_j+3\beta_j)\right]^2}.$$

However, $\frac{\partial\tau_i^n}{\partial\beta_i}$ and $\frac{\partial(\tau_i^N-\tau_j^N)}{\partial\beta_i}$ has same sign, while signs of $\frac{\partial\tau_i^n}{\partial\beta_j}$ and $\frac{\partial(\tau_i^N-\tau_j^N)}{\partial\beta_j}$ are opposite.

A.2 Cooperative Solution

In the cooperative case the solution to the problem (7) and (8) should satisfy the HJB equation, where now $J_i^*(P)$ represents the social (joint) value function and $J_P^* = \frac{\partial J^*}{\partial P}$:

$$\theta J^*(P) = \max_{0\le\tau_i,\tau_j<1}\Big\{(\gamma_i+\gamma_j)P_t + \frac{1}{2}\left(\alpha_i\tau_i^2+\alpha_j\tau_j^2\right) + (\beta_i\tau_i-\beta_j\tau_j)(\tau_i-\tau_j) + $$
$$+J_P^*\left[\nu_1(1-\tau_1)+\nu_2(1-\tau_2)-\delta P\right]\Big\}. \tag{16}$$

The first order condition yields:

$$(\alpha_i+2\beta_i)\tau_i = (\beta_i+\beta_j)\tau_j + \nu_i J_p^*. \tag{17}$$

Our informed guess for the form of the value function is $J^*(P) = A^* + B^*P$, where A^* and B^* are constant to be determined. Replacing this conjectured value function and the first order condition into (16) leads to

[1] The expression for A_i is not reported since it is too long but is available upon request.

$B^* = \frac{\gamma_i+\gamma_j}{\theta+\delta}$. Using the result to substitute back into the first order condition leads to cooperative carbon tax rate given in (9).

The derivatives of the carbon tax rate in (9) undoubtedly yields: $\frac{\partial \tau_i^*}{\partial \gamma_i} > 0$, $\frac{\partial \tau_i^*}{\partial \gamma_j} > 0$, $\frac{\partial \tau_i^*}{\partial \alpha_i} < 0$, $\frac{\partial \tau_i^*}{\partial \alpha_j} < 0$, $\frac{\partial \tau_i^*}{\partial \nu_i} > 0$, $\frac{\partial \tau_i^*}{\partial \nu_j} > 0$. The derivatives with respect go to the degree of competitiveness concerns are instead ambiguous:

$$\frac{\partial \tau_i^*}{\partial \beta_i} = -\frac{(\gamma_i+\gamma_j)\left[2\alpha_j^2\nu_i - \beta_i^2\nu_j - 2\beta_i\beta_j(2\nu_i+\nu_j) + \alpha_j(6\beta_j\nu_i - 2\beta_i\nu_i - \alpha_i\nu_j + 2\beta_j\nu_j) + \right.}{(\delta+\theta)\left[2\alpha_j\beta_i - (\beta_i-\beta_j)^2 + \alpha_i(\alpha_j+2\beta_j)\right]^2}$$
$$\frac{\left. +\beta_j(4\beta_j\nu_i - 2\alpha_i\nu_j + 3\beta_j\nu_j)\right]}{(\delta+\theta)\left[2\alpha_j\beta_i - (\beta_i-\beta_j)^2 + \alpha_i(\alpha_j+2\beta_j)\right]^2}$$

$$\frac{\partial \tau_i^*}{\partial \beta_j} = \frac{(\gamma_i+\gamma_j)\left\{2\beta_i\nu_j(\beta_j-\alpha_i) + \beta_j^2(2\nu_i+\nu_j) - \beta_i^2(2\nu_i+3\nu_j) + \alpha_j\left[2\beta_j\nu_i + \alpha_i\nu_j + 2\beta_i(\nu_i+\nu_j)\right]\right\}}{(\delta+\theta)\left[2\alpha_j\beta_i - (\beta_i-\beta_j)^2 + \alpha_i(\alpha_j+2\beta_j)\right]^2}$$

The derivatives of the difference between the carbon tax rates in (10) is given by the following expressions which are again ambiguous:

$$\frac{\partial(\tau_i^*-\tau_j^*)}{\partial \beta_i} = -\frac{(\gamma_i+\gamma_j)}{(\delta+\theta)}\left\{\frac{\nu_i\left[2\alpha_j^2 + (\beta_i-\beta_j)^2 + \alpha_i(\alpha_j+2\beta_j) + 2\alpha_j(2\beta_j-\beta_i)\right] +}{\left[2\alpha_j\beta_i - (\beta_i-\beta_j)^2 + \alpha_i(\alpha_j+2\beta_j)\right]^2}\right.$$
$$\left.\frac{+\nu_j\left[(\beta_i-\beta_j)^2 + \alpha_j(2\beta_j-\alpha_i) + 2\alpha_i\beta_i\right]}{\left[2\alpha_j\beta_i - (\beta_i-\beta_j)^2 + \alpha_i(\alpha_j+2\beta_j)\right]^2}\right\}$$

$$\frac{\partial(\tau_i^*-\tau_j^*)}{\partial \beta_j} = \frac{(\gamma_i+\gamma_j)}{(\delta+\theta)}\left\{\frac{\nu_i\left[\beta_i(\beta_i - 2\beta_j + 2\alpha_i) + \alpha_j(2\beta_j-\alpha_i) + \beta_j^2\right] +}{\left[2\alpha_j\beta_i - (\beta_i-\beta_j)^2 + \alpha_i(\alpha_j+2\beta_j)\right]^2}\right.$$
$$\left.\frac{+\nu_j\left[2\alpha_i^2 + \beta_i(2\alpha_j+\beta_i-2\beta_j) + \alpha_i(4\beta_i - 2\beta_j + \alpha_j) + \beta_j^2\right]}{\left[2\alpha_j\beta_i - (\beta_i-\beta_j)^2 + \alpha_i(\alpha_j+2\beta_j)\right]^2}\right\}$$

A.3 Cooperation vs Noncooperation

The derivatives of the size of the distortion obtained by subtracting (5) from (9) yield:

$$\frac{\partial(\tau_i^*-\tau_i^n)}{\partial \beta_i} = \frac{\gamma_i+\gamma_j}{(\delta+\theta)}\left\{\frac{\nu_j\left[2\alpha_j\beta_i - (\beta_i-\beta_j)^2 + \alpha_i(\alpha_j+2\beta_j)\right] - 2(\alpha_j-\beta_i+\beta_j)\left[\alpha_j\nu_i + \beta_i\nu_j + \beta_j(2\nu_i+\nu_j)\right]}{\left[2\alpha_j\beta_i - (\beta_i-\beta_j)^2 + \alpha_i(\alpha_j+2\beta_j)\right]^2}\right\} +$$
$$\frac{1}{(\delta+\theta)}\left\{\frac{(\alpha_j+2\beta_j)\left[\nu_i\gamma_i(2\alpha_j+3\beta_j) - \alpha_i\nu_j\gamma_j\right]}{\left[\alpha_i(\alpha_j+2\beta_j) + \beta_i(2\alpha_j+3\beta_j)\right]^2}\right\},$$

$$\frac{\partial(\tau_i^*-\tau_i^n)}{\partial \beta_j} = \frac{\gamma_i+\gamma_j}{(\delta+\theta)}\left\{\frac{\alpha_j\left[2\nu_i(\beta_i+\beta_j) + \nu_j(\alpha_i+2\beta_i)\right] + 2\beta_i\nu_j(\beta_j-\alpha_i) + \beta_j^2(2\nu_i+\nu_j) - \beta_i^2(2\nu_i+3\nu_j)}{\left[2\alpha_j\beta_i - (\beta_i-\beta_j)^2 + \alpha_i(\alpha_j+2\beta_j)\right]^2}\right\} +$$
$$\frac{1}{(\delta+\theta)}\left\{\frac{\beta_i\left[\nu_j\gamma_j(2\alpha_i+3\beta_i) - \alpha_j\nu_i\gamma_i\right]}{\left[\alpha_i(\alpha_j+2\beta_j) + \beta_i(2\alpha_j+3\beta_j)\right]^2}\right\}.$$

From the above expressions it is clear that the sign of these derivatives cannot be determined unambiguously.

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