International coordination of environmental policies: Is it always worth the effort?

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ONLINE APPENDIX

1 Allowing for Transboundary Benefits

In this appendix, we examine how our results in Subsection 2.3 (Uncoordinated Regional Policies) are affected when the environmental benefits clean products are transboundary rather than local. A natural example could be technologies reducing air pollution. We incorporate transboundary environmental benefits into the model by modifying the regulators' welfare function defined in the text in equations (6) and (7). The regulators now choose the number of firms in thier respective regions to maximize

$$\text{[Regulator } A\text{]} \quad W^A(x,y) = CS^A(Q^A(x,y)) + \sum_i^x \{\pi_i^A(x,y) - F^A\} + d\left[Q^A(x,y) + Q^B(x,y)\right] \tag{6'}$$

and

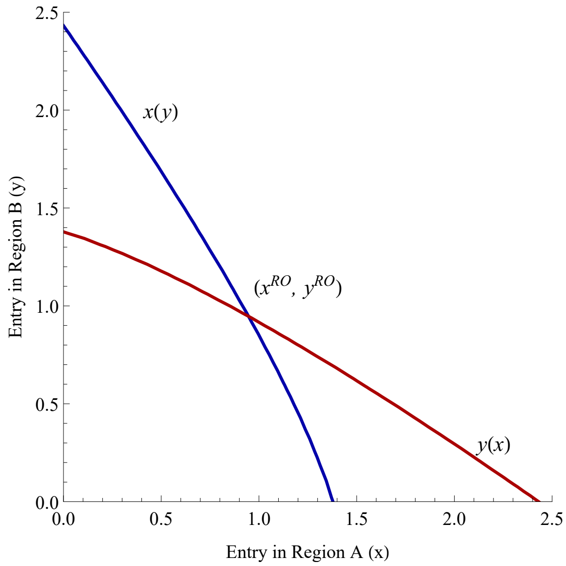
$$\text{[Regulator } B\text{]} \quad W^B(x,y) = CS^B(Q^B(x,y)) + \sum_j^y \{\pi_j^B(x,y) - F^B\} + d\left[Q^A(x,y) + Q^B(x,y)\right] \tag{7'}$$

Relative to expression (6) in the main text, the last term in (6′) includes $Q^B(x,y)$. Similarly, the last term in (7′) includes $Q^A(x,y)$. In this setting, the first-order conditions of regulators A and B are

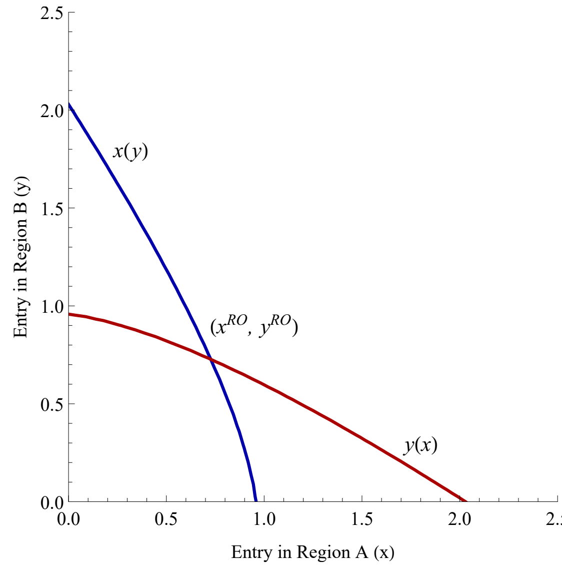
$$CS_Q^A Q_x^A(x,y) + \pi^A(x,y) - F^A + d\left[Q_x^A(x,y) + Q_x^B(x,y)\right] = x\pi_x^A(x,y) \tag{8'}$$

and

$$CS_Q^B Q_y^B(x,y) + \pi^B(x,y) - F^B + d\left[Q_y^A(x,y) + Q_y^B(x,y)\right] = y\pi_y^B(x,y) \tag{9'}$$



(a) With transboundary environmental benefits



(b) Without transboundary environmental benefits

Figure S1: Regulator's best response functions with and without transboundary environmental benefits.

Expression (8′) exhibits a new term on the left-hand side, $dQ_x^B(x, y)$, relative to first-order condition (8) in the main body of the paper. Intuitively, an increase in the number of firms in regulator A's jurisdiction, x, produces an increase in the sales of clean products in region B, $Q^B(x, y)$, which ultimately benefits region A in terms of a cleaner environment. A similar argument applies to regulator B's incentives to increase the number of firms in his jurisdiction, y. Therefore, both regulators have stronger incentives to increase the number of firms in the (x^{RO}, y^{RO}) equilibrium when environmental benefits are transboundary than otherwise. Using the same parameter values as in Figure 2 of the paper, Figure S1 illustrates that each region's best response function shifts upwards, i.e., the regionally optimal level of entry in each region increases when environmental benefits are transboundary. (As a reference, we reproduce Figure 2 on the right-hand panel.)

As in the local benefits case, the regionally optimal level of entry (x^{RO}, y^{RO}) does not necessarily coincide with unregulated level entry (x^U, y^U), as described in Lemma 3. We next examine Lemma 3 in a context with transboundary externalities.

Lemma 3′. *The regionally optimal level of entry exceeds the unregulated level of entry in region A, $x^{RO} > x^U$ (in region B, $y^{RO} > y^U$), if and only if the benefits of consuming clean products are sufficiently high, i.e., $d^k > \widetilde{d}^k$, where $\widetilde{d}^A \equiv (1-\gamma)d^{SO}$ for region A; and $\widetilde{d}^B \equiv \gamma d^{SO}$ for region B. Finally, $\widetilde{d}^A < \widetilde{d}^B$ if and only if $\gamma > 1/2$.*

The logic of the proof of Lemma 3′ is identical to Lemma 3 in the main text. Using the first order condition of the regulator's welfare maximization problem, we want to identify the cutoff in terms of environmental benefit, d, above which the uncoordinated level of entry exceeds the unregulated equilibrium entry. The regulators' welfare function differs in the environmental benefit term, which now includes transboundary benefits.

$$W_x^A(x^U, y^U) \equiv \gamma \frac{n^U(a-c)^2}{b(1+n^U)^3} - \frac{n^U(a-c)^2}{b(1+n^U)^3} + d\frac{a-c}{b(1+n^U)^2} = 0$$

where $x^U + y^U = n^U$ and we assume that $x^U = y^U = \frac{1}{2}n^U$. Solving for d^A,

$$\underline{d}^A \equiv \frac{n^U(a-c)}{1+n^U}(1-\gamma)$$

which, evaluated at $n^U = \frac{a-c}{\sqrt{Fb}} - 1$ is $\underline{d}^A \equiv (1-\gamma)\left(a-c-\sqrt{Fb}\right) = (1-\gamma)d^{SO}$. Since region B's welfare function differs from region A's by the inverse share of domestic consumption $(1-\gamma)$, the cutoff in region B is $\underline{d}^B \equiv \gamma\left(a-c-\sqrt{Fb}\right) = \gamma d^{SO}$.

Figure S2 illustrates cutoffs $\widetilde{d}^A$, $\widetilde{d}^B$, and d^{SO} in a setting with transboundary externalities. (For comparison purposes, the figure assumes the same parameter values as Figure 3 in the main body of the paper.) Partitions (1)-(4) represent the same cases as in Figure 3. Relative to Figure 3, however, both cutoffs $\widetilde{d}^A$ and $\widetilde{d}^B$shift downwards when environmental benefits are transboundary. Intuitively, regulators encourage entry under lower marginal environmental benefits (i.e., lower values of d). In addition, both cutoffs lie below d^{SO} implying that two uncoordinated regulators promote entry for lower benefits d. This result is due to the failure of each region to fully internalize the external cost of eroding profits even though they now internalize the transboundary environmental benefit.

Entry policies (Section 3). Propositions 1 and 2 are unaffected by the transboundary externality, but their cutoffs are. In particular, cutoff $\underline{d}^k$ in Proposition 1 shifts downwards to $\widetilde{d}^A = \gamma d^{SO}$ and $\widetilde{d}^B = (1-\gamma)d^{SO}$. Similarly, cutoff $\hat{d}^k$ in Proposition 2 shifts downwards to $\vec{d}^A \equiv (2-\gamma)d^{SO}$ and $\vec{d}^B \equiv (1+\gamma)d^{SO}$ For comparison purposes, Figure S3 below depicts cutoffs $\widetilde{d}^A$ and $\widetilde{d}^B$ using the same parameter values as Figure 5 in the main body of the paper. The figure shows that partition (4), where both regulators restrict entry in the *RO* policy, shrinks when environmental benefits become transboundary.

Figure S4 illustrates cutoffs $\vec{d}^A$ and $\vec{d}^B$ using the same parameter values as Figure 6 in the main body of the paper. Intuitively, regulators face stronger incentives to encourage entry, expanding the regions of (d, γ)-pairs for which either of the two regions subsidizes entry; as depicted in the shaded areas of the figure.

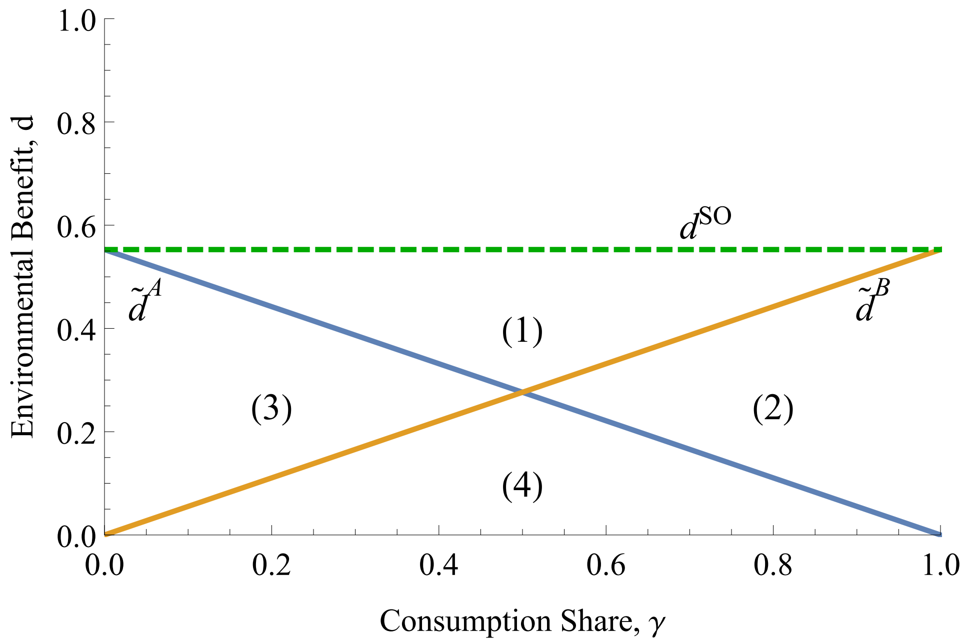


Figure S2: Cutoffs $\tilde{d}^A$ and $\tilde{d}^B$ divide the (d, γ)-space into four partitions. Regulator $k = \{A, B\}$ encourages entry above $\tilde{d}^k$ and discourages entry below $\tilde{d}^k$.

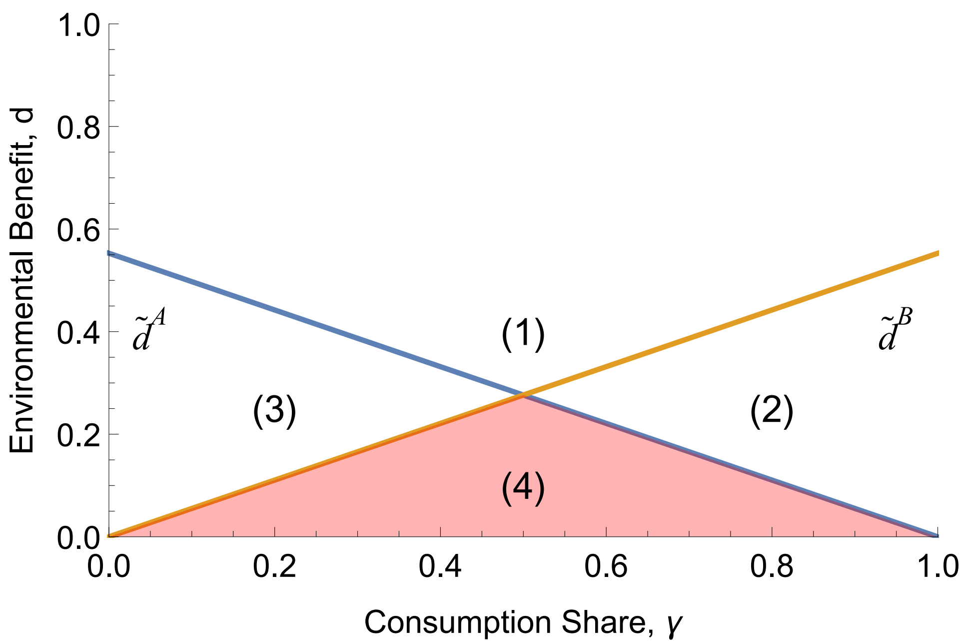


Figure S3: Cutoffs $\tilde{d}^A$ and $\tilde{d}^B$ divide the (d, γ)-space into four partitions characterized by the regulators preference for entry. The shaded area indicates the conditions under which the regionally optimal level of entry, (x^{RO}, y^{RO}), can be implemented with a quantity-based entry policy.

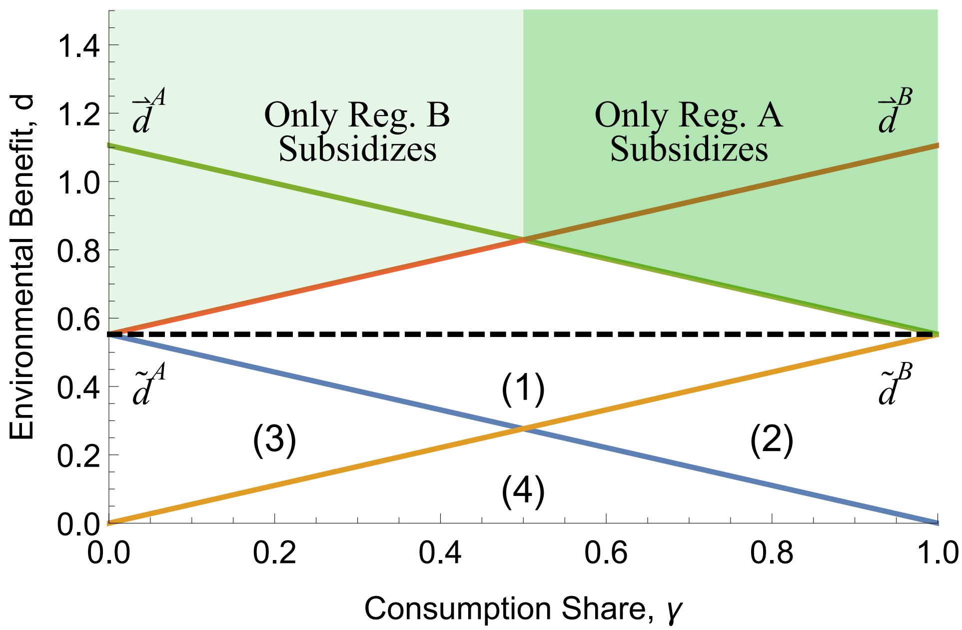


Figure S4: Cutoffs $\widetilde{d}^A$ and $\widetilde{d}^B$ are described in Figure S3. Cutoffs $\vec{d}^A$ and $\vec{d}^B$ further divide the parameter space into conditions that sustain an entry subsidy equilibrium (when $d > \hat{d}^k$).

We conclude this section with a comparison of the welfare results under transboundary and localized environmental benefits (Table S1). We find that our welfare results are robust to the case with transboundary environmental benefits. The welfare gains from uncoordinated regulation are larger than those from coordinated regulation when environmental benefits are low. However, welfare gains from coordinated regulation exceed those from uncoordinated regulation when environmental benefits are large. In this latter case, the welfare gains are small since the positive environmental benefits of entry are internalized in the case of transboundary benefits.

Table S1: Aggregate welfare ($W = W^A + W^B$) of each regulatory context: no regulation, uncoordinated regulation, and coordinated regulation under low, moderate, and large environmental benefits. Welfare gains from moving between regulatory contexts are in parentheses (in percent change). Note that the values for d representing the low, moderate, and high range differ from the local benefits case described in the text because the cutoffs change when benefits are transboundary.

	No Reg W^U	Uncoord W^{RO}	(% change) $(W^U \to W^{RO})$	Coord W^{SO}	(% change) $(W^{RO} \to W^{SO})$	(% change) $(W^U \to W^{SO})$
Low Benefit ($d = 0.1$)	0.208	0.222	(6.71%)	0.230	(3.65%)	(10.61%)
Moderate Benefit ($d = 0.5$)	0.433	-	-	0.433	-	(0.46%)
Large Benefit ($d = 0.9$)	0.655	0.660	(0.63%)	0.666	(0.95%)	(1.58%)

2 Numerical Simulations

This appendix develops a numerical simulation of our results. We compare model outcomes under an entry tax/subsidy, a permit restriction, and coordinated policies (social optimum). The analysis is divided into three scenarios according to the level of environmental benefit d: "Low Benefit" ($d \leq d^{SO}$) where both regulators prefer to discourage entry relative to the unregulated equilibrium (partition (4) in Figure 6); "Moderate Benefit" ($\min\{\hat{d}^A, \hat{d}^B\} \geq d > \min\{\underline{d}^A, \underline{d}^B\}$) where the regionally optimal entry exceeds the unregulated equilibrium but neither regulator is willing to subsidize entry (partitions (1) - (3) in Figure 6); and "Large Benefit" ($d \geq \min\{\hat{d}^A, \hat{d}^B\}$) where a single regulator subsidizes entry despite the free-riding rival regulator (the shaded areas in Figure 6). Tables S2, S3, and S4 contain the aggregate welfare ($W^A + W^B$), number of firms ($x+y$), equilibrium price ($P(Q)$), aggregate output (Q), total net profits $(x+y)$ $(\sum_i^n \pi_i - F)$, and aggregate environmental benefits (dQ) for a series of simulations.[1]

Table S2: Welfare comparisons in the Low Benefit case ($d = 0.3$).

	Entry Tax Eq.	Entry Permit Eq.	Social Optimum
Aggregate Welfare	0.32	0.324	0.33
Number of Firms	1.23	1.11	1.00
Price of Clean Good	0.45	0.47	0.50
Aggregate Output	0.55	0.52	0.50
Aggregate Profit	0.00	0.02	0.05
External Benefit	0.16	0.16	0.15

2.0.1 Low Benefit

The low benefit case, described in Table S2, assumes a small environmental benefit, $d = 0.3$. The first column contains the results of the entry tax equilibrium where regions A and B set an entry fee of zero. Therefore, the equilibrium under an entry tax coincides with the unregulated equilibrium, n^U.[2] When entry permits are used (second column of Table S2), regulators in regions A and B find it optimal to restrict the number of firms to (x^{RO}, y^{RO}). This equilibrium is sustainable because, unlike the entry tax, relaxing the number of permits above x^{RO} to allow more entry would reduce domestic welfare in region A, suggesting that regulators do not have incentive to deviate from the RO permit level. A similar result applies for y^{RO} in region B. Aggregate welfare increases slightly from 0.32 to 0.324 in the unregulated equilibrium, since

[1] We continue using the same base set of parameters used throughout the paper: $a = b = 1, c = 0, F = .2$, and $\gamma = 0.5$ unless otherwise specified. The share of consumption, $\gamma = 0.5$, is chosen for simplicity because the cutoffs in regions A and B coincide, $\underline{d}^A = \underline{d}^B = \underline{d} = 0.55$ and $\hat{d}^A = \hat{d}^B = \hat{d} = 1.65$. However, these comparisons hold for all (γ, d)-pairs within the defined partitions and can be provided by the authors upon request.

[2] This result also applies to cases in which the externality is negative, $d < 0$. Hence, this finding suggests that increasing entry fees to mitigate the growth of dirty industries is perilous because rival regulators continually face the incentive to capture market share by reducing the entry fee. See Markusen *et al.* (1995) for a detailed discussion on the role of tax competition in regulating polluting firms who choose where to operate.

the additional profits offset the smaller environmental benefits.

Policy coordination (third column) goes a step further and requires that the total number of permits issued (or fees) in regions A and B be set even lower (1 rather than 1.11 under permits or 1.23 under entry taxes). By further restricting entry, aggregate welfare increases to 0.33 due to even higher aggregate profits (0.05, rather than 0.02 or zero).

Table S3: Welfare comparisons in the Moderate Benefit case ($d = 1$).

	Subsidy/Permit Equilibrium	Social Optimum
Aggregate Welfare	0.71	0.72
Number of Firms	1.23	1.63
Price of Clean Good	0.45	0.38
Aggregate Output	0.55	0.62
Aggregate Profit	0.00	-0.09
External Benefit	0.55	0.62

2.0.2 Moderate Benefit

Table S3 contains the results of the simulation for the moderate benefit case ($d = 1$), as in partitions (1) - (3) in Figure 6. In this case, the regionally optimal number of firms (x^{RO}, y^{RO}) exceeds that under the unregulated equilibrium, (x^U, y^U), in both regions. However, as discussed in section 3.2, the number of firms each region would independently choose to maximize welfare, (x^{RO}, y^{RO}), is not implementable with a subsidy or permit policy because one of the regulators always has the incentive to free-ride off of the benefits provided by firms in the other region. Therefore, the equilibrium under a subsidy (first column in Table S3) implies a zero subsidy by both regulators, which results in the unregulated equilibrium, and an aggregate welfare of 0.71.

The number of firms in the social optimum represented in the second column (1.63) exceeds that under the unregulated entry (1.23), but does not result in significant welfare gains (0.72 versus 0.71). While policy coordination fully internalizes the external benefit of production (which increases from 0.55 to 0.62), the additional firms increase competition, which reduces the price (from 0.45 to 0.38) and aggregate profits, ultimately yielding a small increase in welfare.

2.0.3 Large Benefit

Table S4 contains the results of the simulation for the large benefit case ($d = 2$), as depicted in the shaded areas of Figure 6. As in the moderate benefit case, permit restriction plays no role because regulators seek to promote entry, implying that outcomes when using permits (first column) coincide with those in the unregulated equilibrium (U). However, in contrast to the moderate benefit case, the regulator in either

Table S4: Welfare comparisons in the Large Benefit (d=2).

	Permit Equilibrium	Subsidy Equilibrium	Social Optimum
Aggregate Welfare	1.26	1.29	1.39
Number of Firms	1.23	1.38	2.39
Price of Clean Good	0.45	0.42	0.30
Aggregate Output	0.55	0.58	0.70
Aggregate Profit	0.00	-0.03	-0.27
External Benefit	1.10	1.16	1.41

region A or B finds it optimal to subsidize the entire industry; as illustrated in the second column. The region with a larger share of consumption chooses to subsidize because it captures the largest benefit from entry. The region that does not subsidize enjoys the benefit of increased production in the subsidizing region and does not bear the cost of subsidizing firms. The socially optimal number of firms (2.39, in the third column) is considerably higher than under the use of permits or subsidies (1.38) because the increase in external benefits (which increases from 1.16 to 1.41) outweigh the lost profit (which decreases from -0.03 to -0.27). Despite the welfare improvement in the subsidy equilibrium (moving from the first to second column), a single regulator coordinating policies would increase subsidies and entry considerably (moving from the second to third column).

2.0.4 Alternative Simulations

The model simulation results in section 4 show that the welfare gains of policy coordination increase as the environmental benefit increases. This section of the appendix shows that this result is qualitatively robust to changes in exogenous parameters. The model is simulated under the following scenarios: 1) the share of consumption in region A is greater than in B ($\gamma = 0.6$ instead of 0.5), 2) demand becomes more inelastic ($b = 2$ instead of 1), and 3) demand increases ($a = 2$ instead of 1).

Table S5 is presented in a format similar to Table 1 in the paper and contains the aggregate welfare from no regulation, uncoordinated regulation and coordinated regulation, and the welfare gains of moving from less regulation to more coordinated regulation. We simulate the model under low, moderate, and large external benefit values corresponding with the cutoffs intervals defined by endpoints $d^{SO}, \underline{d}^i, \hat{d}^i$. Because these cutoffs depend on the parameter values that we vary by scenario, the cutoffs change and the external benefit, d, must be chosen to fall in the interval defined by the cutoffs. Table S5 includes the cutoff values (column 1) and the external benefit values that fall within the cutoff interval. These results are comparable to those presented in Table 1 in the main text.

Table S5: Aggregate welfare ($W^A + W^B$) of each regulatory context: no regulation, uncoordinated regulation, and coordinated regulation under low, moderate, and large environmental benefits. Welfare gains from moving between regulatory contexts are in parentheses.

	Cutoff	No Reg W^U	Uncoord W^{RO}	(% change) $(W^U \rightarrow W^{RO})$	Coord W^{SO}	(% change) $(W^{RO} \rightarrow W^{SO})$
Scenario 1: Region A consumption rises ($\gamma = 0.6$)						
Low Benefit ($d = 0.3$)		0.319	0.324	(1.57%)	0.325	(0.31%)
Moderate Benefit ($d = 1$)	$\underline{d}^A = 0.37$	0.706	-	-	0.722	(2.27%)
Large Benefit ($d = 2$)	$\hat{d}^A = 1.29$	1.258	1.335	(6.12%)	1.388	(3.97%)
Scenario 2: Demand becomes more inelastic ($b = 2$)						
Low Benefit ($d = 0.3$)		0.089	0.089	(< 0.01%)	0.089	(< 0.01%)
Moderate Benefit ($d = 1$)	$\underline{d}^A = 0.74$	0.218	-	-	0.238	(9.17%)
Large Benefit ($d = 2$)	$\hat{d}^A = 1.10$	0.401	0.461	(14.96%)	0.51	(10.63%)
Scenario 3: Demand doubles ($a = 2$)						
Low Benefit ($d = 0.3$)		1.671	1.747	(4.55%)	1.778	(1.77%)
Moderate Benefit ($d = 2$)	$\underline{d}^A = 1.55$	4.311	-	-	4.32	(0.21%)
Large Benefit ($d = 5$)	$\hat{d}^A = 4.65$	8.97	9.022	(0.58%)	9.33	(3.41%)

References

Markusen JR, Morey ER, and Olewiler N (1995) Competition in Regional Environmental Policies when Plant Locations are Endogenous. *Journal of Public Economics* **56**(1), 55–77.