International Coordination of Environmental Policies: Is it Always Worth the Effort?

Jude Bayham* Félix Muñoz-García† Ana Espínola-Arredondo‡

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Abstract

We study the use of entry subsidies as an alternative form of environmental policy. Given the strong political opposition to standard output subsidies, several countries have recently used entry policies to promote renewable energy technology, such as solar panels and biofuels. We study a two-stage game in which two regulators choose an entry policy (i.e., tax, subsidy, or permit) to maximize domestic welfare. Observing the policy, firms decide the region in which to enter and compete as Cournot oligopolists. We find that both chosen domestic (uncoordinated) policies and internationally coordinated policies increase welfare. However, the welfare gains from international policy coordination are only large when the product is extremely clean. These results indicate that the welfare gains of international policy coordination may only offset the costs of negotiation in relatively clean industries.

Keywords: Entry subsidy, Strategic environmental policy, Policy coordination, Imperfect competition

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*Address: 301 Prospect St. Yale University. New Haven, CT 06511 Email: jbayham@wsu.edu

†Address: 103G Hulbert Hall, Washington State University. Pullman, WA 99164-6210. E-mail: fmunoz@wsu.edu

‡Address: 111C Hulbert Hall, Washington State University, Pullman, WA 99164-6210. E-mail: anaespinola@wsu.edu

1 Introduction

Growing concern over climate change and energy security has led governments to provide a variety of subsidy instruments at multiple levels in the renewable energy industry. For instance, many developed countries offer feed-in tariffs to firms and consumers who generate energy from renewable sources, and direct capital subsidies for large-scale renewable energy projects (IEA, 2013). However, governments often face political opposition to output subsidies to renewable energy, especially during periods of low economic growth (Stokes, 2013; Cherry, Kallbekken, and Kroll, 2014). In such cases, policy-makers may alternatively pursue environmental goals through indirect means, such as entry policies (e.g., grants and low-interest loans), which facilitate development, increase competition, and drive the price of emerging technologies down.[1] Our paper examines the welfare benefits of entry policy as an indirect form of environmental policy, both when independently implemented by each region at the domestic level and when regions coordinate their policies. We show that domestic policies are welfare improving, and international policy coordination across countries yields a further increase in welfare. More surprisingly, however, we demonstrate that the welfare gain from promoting international policy coordination is, in certain contexts, so small that it may not offset the costs from negotiating international agreements. This result suggests that, in some cases, countries should avoid international treaties that try to harmonize environmental entry subsidies.

We analyze environmental entry policy by studying a two-stage game where, in the first stage, two regulators (one in each region) choose an entry policy to maximize domestic welfare. In the second stage, observing the entry policy, firms choose whether to enter and, if so, the region in which to enter and subsequently compete as Cournot oligopolists. Entering firms produce a relatively clean good, which can exhibit different degrees of environmental benefits. In this context, we consider two forms of entry policy: a permit restriction policy that acts like a quota on entry, and an entry tax or subsidy. In addition, we analyze each policy under three different scenarios: (1) both regions are unregulated; (2) each region autonomously regulates firms located within its jurisdiction; and (3) both regions coordinate regulation (social optimum). We then evaluate the stability of each equilibrium under the permit and entry tax/subsidy policy, and compare the welfare implications of the different regulatory structures.

First, we show that, while entry policy can be used to achieve environmental goals in a closed economy, free-riding and business-stealing effects arise under an international setting, thus precluding each regulator from reaching the social optimum when it independently sets its own subsidy policy. When environmental

[1]U.S. government policies such as the Department of Energy's SunShot initiative promote solar industry development by funding the development of new technologies and the expansion of pilot-scale operations to commercial scale (Castelazo, 2012). China has aggressively promoted entry by providing generous grants and no-interest loans to new firms producing solar technologies (Tracey, 2012). These entry policies are currently at the root of several trade disputes between U.S. and Chinese solar panel manufacturers (Simmons, 2014).

benefits are small, regulators would each prefer to restrict excessive entry (and thus capital investments in a closed economy, but they tend to relax entry when operating in an open economy in order to "steal business" from the rival region. In contrast, when environmental benefits are large, a single regulator subsidizes a fraction of the socially optimal entry while its rival enjoys the benefits without subsidizing entry itself. We nonetheless demonstrate that, in both contexts, international policy coordination solves the business-stealing and free-rider problem that results from each regulator strategically setting entry policy.

Second, we find that the welfare gains of policy coordination critically depend on the product's environmental benefit. This result is particularly important since policy coordination requires costly negotiation of international agreements (Hovi, Ward, and Grundig, 2014). In particular, we show that when environmental benefits are low, domestic (uncoordinated) regulation yields large welfare gains, whereas international policy coordination produces relatively small welfare gains. By contrast, when environmental benefits are large, both domestic policies and international policy coordination entail large welfare gains; and the latter may exceed the former.

As a consequence, our findings predict large welfare benefits from international agreements that harmonize subsidy policy in extremely clean industries, such as solar panels and wind turbines.[2] In contrast, our results show small welfare gains from coordinating policies in less clean industries, such as the production of corn-based ethanol.[3] If international negotiations are particularly costly, the welfare benefits of policy coordination in these industries may not justify the effort. Furthermore, our results suggest that, while international treaties are not necessarily desirable in certain contexts, the welfare gains of domestic (uncoordinated) policies are yet sufficiently large to recommend their introduction under a large set of parameter conditions.

Related literature. Over the past several decades, the WTO has actively discouraged countries from using strategic trade policies to promote domestic firms. As environmental policy begun to gain acceptance, concern over the strategic use of environmental policy grew (Whalley, 1991; Barrett, 1994). A large literature has since analyzed the strategic use of emission standards and fees and the subsequent welfare impacts of such policies (for a review see Ederington and Minier (2003)). Most recently, Mason, Barbier, and Umanskaya (2014) explore the use of feed-in tariffs and border taxes as an indirect form of environmental regulation. While this literature has considered environmental policies under both exogenous and endogenous market structures, no studies have analyzed the strategic use of entry policies in a multi-region open economy with an endogenous market structure.[4]

[2]Life-cycle analysis shows that solar and wind energy technologies produce less than 10% of the GHG emissions generated by conventional coal and natural gas technologies (Dolan and Heath, 2012; Hsu et al., 2012). While US regulators initially responded to competition from subsidized Chinese manufacturers with import tariffs, many are now calling for policy coordination citing the environmental benefits of inexpensive solar technologies (Hart, 2012).

[3]Life-cycle analysis of corn-based ethanol generates approximately 60% of the GHG emissions generated by conventional gasoline (Liska et al., 2009).

[4]Reitzes and Grawe (1999) study a multi-region model in which entry in one region is exogenous. Our model considers

This paper lies at the intersection of a literature on strategic environmental policy, and tax competition. The early literature on strategic policy demonstrates that governments may promote the competitiveness of domestic firms in imperfectly competitive international markets with R&D subsidies (Spencer and Brander, 1983) export subsidies (Brander and Spencer, 1985), import tariffs (Brander and Spencer, 1981) and domestic taxes and subsidies (Eaton and Grossman, 1986). Afterwards, Barrett (1994), Ulph (1996), and Kennedy (1994), among others, extended the analysis to include environmental policy in an open economy. The common theme in this literature suggests that environmental policy in an open economy is likely not first-best because regulators internalize market power as well as environmental externality.

Several studies have since extended the literature on strategic environmental and trade policy to include endogenous entry in response to changes in policy (Katsoulacos and Xepapadeas, 1995; Bhattacharjea, 2002; Greaker, 2003; Bayındır-Upmann, 2003; Fujiwara, 2009; Haufler and Wooton, 2010; Etro, 2011). This literature focuses almost exclusively on pollution externalities in production and the emission fees and standards used to control them. In contrast, we investigate an indirect environmental policy that nonetheless affects industry structures and welfare; entry subsidies and taxes.

In a closely related literature on tax competition, geographically distinct governments compete over the foreign direct investment and associated tax revenue from domestically located firms (Zodrow and Mieszkowski, 1986; Wilson, 1999). Janeba (1998) develops a two-region model without environmental externality to show that even small tax differentials between regions can impact tax revenues due to firm relocation. Markusen, Morey, and Olewiler (1995) studies this phenomenon in the context of environmental regulation of pollution externalities and find that each region relaxes regulation to attract entry. Our analysis also finds that welfare in each region is heavily dependent on firm location, which responds to differentials in entry policy. We then take the analysis a step further and show that the welfare benefits of international regulatory coordination diminish as environmental benefits rise, and can become smaller than the welfare gain of introducing domestic (uncoordinated) regulation.

2 Model

Consider a model of a two-region economy in which goods and services flow freely between regions A and B. Entry is endogenous and, upon entry, firms pay a region-specific fixed irrecoverable cost $F^k > 0$, where $k = \{A, B\}$. This cost represents research and development as well as administrative costs necessary to enter the market and operate in region k. Each firm in regions A and B face a world inverse demand $P(Q) = a - bQ$, where Q denotes total output. All firms have symmetric marginal production costs, c.

endogenous entry and policy in both regions.

Output is either sold in region A, $Q^A = \gamma Q$, or in region B, $Q^B = (1-\gamma)Q$, where γ represents the share of output sold in region A.[5] Firms in each region simultaneously and independently choose output to maximize profits given the behavior of other firms within the region and those operating within the other jurisdiction, $q^k(x,y) = \frac{a-c}{b(1+x+y)}$ for $k = \{A, B\}$ where x and y denote the number of firms in regions A and B, respectively. The number of firms is continuous to facilitate comparison with previous results. We adopt the post-entry assumptions in Mankiw and Whinston (1986), which ensure that additional entry reduces individual firm output, increases aggregate industry output, and the market price is greater than or equal to marginal cost. The equilibrium profits of a representative firm located in any region $k = \{A, B\}$ are $\pi^k(x,y) = \frac{(a-c)^2}{b(1+x+y)^2}$, which are also decreasing in the number of entrants.[6] Therefore, a firm enters if $\pi^k(x,y) - F^k \geq 0$.[7]

2.1 Unregulated Equilibrium

When regulation is absent (henceforth refereed to as the "unregulated equilibrium" and indicated by U), firm location is determined solely by the fixed entry cost, since there are no transportation costs and consumers perceive the goods to be perfect substitutes. If entry costs are lower in region A (B), all firms enter region A (B, respectively). If the entry cost coincides in regions A and B, firms are indifferent between operating in either region, as the next lemma describes.

Lemma 1. *The unregulated equilibrium number of entrants in regions A and B solves $\pi^k(x,y) - F^k = 0$ where $k = \{A, B\}$, and is given by the (x,y)-pair*

$$(x^U, y^U) = \begin{cases} x = n^U, y = 0 & \text{if } F^A < F^B \\ (x,y) \text{ s.t. } x + y = n^U & \text{if } F^A = F^B \\ x = 0, y = n^U & \text{if } F^A > F^B \end{cases} \tag{1}$$

where $n^U \equiv \frac{a-c}{\sqrt{b \min\{F^A, F^B\}}} - 1$.

When the entry costs are symmetric across regions (i.e., $F^A = F^B$), every (x,y)-pair that satisfies $x + y = n^U$ is a possible equilibrium (see A.2 for details). For simplicity, we focus on the symmetric equilibrium in which $x^U = y^U = \frac{1}{2}n^U$. When entry costs are lower in one country, all n^U firms enter the low-cost region.

[5] Production cost is invariant to regional destination of output as in Janeba (1998) and Bayındır-Upmann (2003).

[6] In addition, individual profits rise as demand increases (higher a), or as demand becomes less elastic (lower b), and fall as own production costs, c, increase.

[7] In order to guarantee the entry of at least one firm, we assume that the fixed entry cost is not prohibitive, i.e., $\pi^k(1) \equiv F_{max} \geq F^k$.

2.2 Regulation - Coordinated Regional Policies

Consider a regulator whose jurisdiction spans regions A and B, i.e., an international organization coordinating region A's and B's policies. The regulator chooses the number of entrants, x and y, to maximize aggregate welfare[8]

$$W(x,y) \equiv CS(Q(x,y)) + \sum_{i}^{x}\{\pi_i^A(x,y) - F^A\} + \sum_{j}^{y}\{\pi_j^B(x,y) - F^B\} + D(Q(x,y)), \tag{2}$$

where CS is total consumer surplus between both regions and $D(Q(x,y)) = dQ(x,y) = d(Q^A(x,y) + Q^B(x,y))$ is the benefit of consuming clean products and d is the marginal benefit i.e., positive externality. In the case of energy, d represents the marginal benefits of installing renewable energy technologies, i.e., solar panels and wind turbines. Alternatively, these benefits arise from the substitution away from technologies that create environmental damage.

The first-order conditions are

$$[x] \quad CS_x + (\pi^A - F^A) + dQ_x^A + dQ_x^B = x\pi_x^A + y\pi_x^B \tag{3}$$

$$[y] \quad CS_y + (\pi^B - F^B) + dQ_y^B + dQ_y^A = y\pi_y^B + x\pi_y^A. \tag{4}$$

where the subscripts denote partial derivatives. The left hand side of (3) and (4) represents the benefit of an additional entrant including: the increased consumer surplus due to a larger aggregate output, CS_x and CS_y, the net profits of the new entrant, $\pi^k - F^k$ for $k = \{A, B\}$, and the benefits associated with an increase in the domestic consumption of clean goods. Each of these three terms is positive, but diminishing in x and y. In contrast, the right hand side of the first order condition represents the dissipation of aggregate profits in regions A and B due to new entry, which is positive and decreasing in x and y. The socially optimal (SO) level of entry in regions A and B solves (3) and (4) and is given by (x^{SO}, y^{SO}).[9]

The single regulator, who coordinates entry in both regions, is indifferent between entry in regions A and B because they are symmetric and transportation costs are zero. If the entry costs are lower in one region, welfare maximizing entry requires that all firms enter into the low-cost region. Alternatively, if entry costs are equal, the regulator allocates firms to both regions evenly. For simplicity, let n^{SO} be the aggregate

[8] The social planner could alternatively provide an entry tax or subsidy. To show that the problems are equivalent, consider an alternative welfare function: $W(x,y) \equiv CS(Q(x,y)) + \sum_i^x\{\pi_i^A(x,y) - (F^A + z)\} + \sum_j^y\{\pi_j^B(x,y) - (F^B + z)\} + (x+y)z + D(Q(x,y))$ where z is the entry tax or subsidy, and $\sum_i^x z + \sum_j^y z = (x+y)z$. This welfare function simplifies to $W(x,y) \equiv CS(Q(x,y)) + \sum_i^x\{\pi_i^A(x,y) - F^A\} + \sum_j^y\{\pi_j^B(x,y) - F^B\} + D(Q(x,y))$, and thus is equivalent to equation (2) (Janeba, 1998).

[9] The explicit solution to (3) and (4) requires solving a third-order polynomial and provides little intuition beyond that in the first-order conditions. However, we know that a a unique equilibrium for (x^{SO}, y^{SO}) exists since the welfare functions in each region are locally concave in x and y. See A.3 for details.

number of firms that solves

$$CS_n + (\pi - F) + dQ_n = n\pi_n \tag{5}$$

where $n^{SO} = x^{SO} + y^{SO}$, $CS_n = CS_x = CS_y$, $\pi = \pi^A = \pi^B$, $F = \min\{F^A, F^B\}$, $Q_n = Q_x^k = Q_y^k$, and $n\pi_n = x\pi_x^A = y\pi_x^B = y\pi_y^B = x\pi_y^A$. Lemma 2 compares the socially optimal number of firms, n^{SO}, (arising from the presence of a regulator coordinating entry policies across regions) against the unregulated equilibrium number of firms, n^U.

Lemma 2. *The unregulated level of entry exceeds the socially optimal level of entry, $n^U > n^{SO}$ (or $x^U + y^U > x^{SO} + y^{SO}$), if and only if $n\pi_n(n^U) > CS_n(n^U) + D_n(n^U)$, or alternatively, when goods are not sufficiently clean, i.e., $d < d^{SO}$ where $d^{SO} \equiv a - c - \sqrt{bF}$.*

See A.4 for proof of Lemma 2 and derivation of cutoff d^{SO}. If the unregulated and socially optimal level of entry do not coincide ($n^U \neq n^{SO}$), the regulator can use entry policy to induce the socially optimal level of entry. In particular, the regulator may set a tax, z, which solves $\pi(n^{SO}) = F + z$, where $z > 0$ as long as unregulated entry is excessive, $n^U > n^{SO}$, or when $d < d^{SO}$. This occurs, for instance, when no environmental benefit arises from the domestic consumption of the good, i.e., $d = 0$, which is consistent with the results in Mankiw and Whinston (1986) whereby the regulator limits entry by increasing entry costs.[10] By contrast, when private entry is insufficient, $n^U < n^{SO}$ or $d \geq d^{SO}$, the regulator may offer an entry subsidy $z < 0$, which again solves $\pi(n^{SO}) = F + z$, inducing additional entry.[11]

We illustrate the result of Lemma 2 in Figure 1 based on a stylized model.[12] Figure 1 depicts a cutoff (isocline), d^{SO}, in (F, d)-space, where the unregulated and socially optimal entry correspond, i.e., $n^U = n^{SO}$. When the environmental benefit is below d^{SO} for a given value of F, unregulated entry exceeds the socially optimal entry because profit dissipation decreases welfare more than the environmental benefits of increased production. Therefore, the regulator limits entry through taxation or permit restriction. In contrast, environmental benefits above d^{SO} increase the social value of output relative to dissipated profits, which lead the regulator to subsidize entry, $z < 0$.

[10] Alternatively, the regulator may require a permit to enter, offering only n^{SO} permits to induce the socially optimal level of entry. Because the tax policy amounts to a revenue neutral transfer, both policies are equivalent to the regulator whose jurisdiction spans regions A and B.

[11] In this case, the permit policy is immaterial because even if the number of permits available increases, firms do not enter because they would earn negative profits.

[12] Figure 1 considers $a = b = 1$ and $c = 0$ for $F \in [0, F_{max}]$ where $F_{max} = \frac{(a-c)^2}{4b} = \frac{1}{4}$. F_{max} is the entry cost that would prevent all but one entrant.

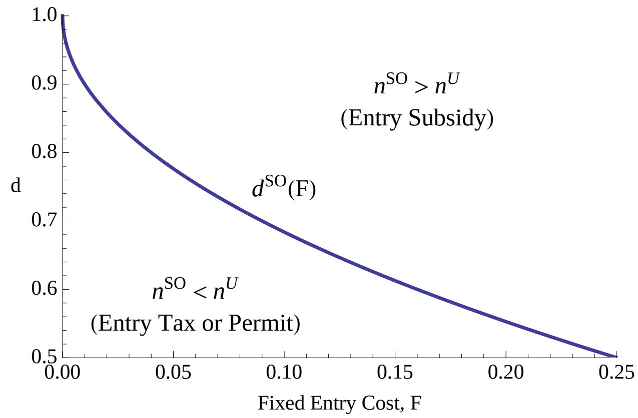

Figure 1: Comparing socially optimal and unregulated entry.

2.3 Regulation - Uncoordinated Regional Policies

This section examines the regulatory inefficiency that arises when regulators in region A and B independently set entry costs to promote domestic welfare. We consider two regions that are still symmetric in production, entry costs, and marginal benefit of consuming clean products to facilitate the comparison of uncoordinated and coordinated entry policy in both regions. If each regulator could choose the number of firms within its jurisdiction conditional on the number of firms in the rival region, they would solve

$$\text{[Regulator } A\text{]} \quad \max_{x} \quad W^A(x,y) \equiv \gamma CS(Q(x,y)) + x(\pi^A(x,y) - F) + dQ^A(x,y) \tag{6}$$

$$\text{[Regulator } B\text{]} \quad \max_{y} \quad W^B(x,y) \equiv (1-\gamma)CS(Q(x,y)) + y(\pi^B(x,y) - F) + dQ^B(x,y) \tag{7}$$

Thus, the first-order conditions of regulator A and B are

$$\text{[Regulator } A\text{]} \quad \gamma CS_x(x,y) + \pi^A(x,y) - F^A + dQ^A_x(x,y) = x\pi^A_x(x,y) \tag{8}$$

$$\text{[Regulator } B\text{]} \quad (1-\gamma)CS_y(x,y) + \pi^B(x,y) - F^B + dQ^B_y(x,y) = y\pi^B_y(x,y) \tag{9}$$

The first-order conditions implicitly characterize the regulator's best response functions, $x(y)$ and $y(x)$, which are illustrated in Figure 2.[13] Region A's best response function is decreasing in y, which implies that regulator A perceives entry in region B as a strategic substitute for domestic entry, i.e., he would promote a smaller number of domestic firms as more firms enter the foreign region. The rationale behind such strategy is the well-known free-riding argument across jurisdictions. As more firms enter region B, the increase in aggregate production benefits consumers in region A, despite eroding domestic profit. Hence, the

[13]For consistency, Figure 2 still uses parameter values: $a = b = d = 1, c = 0, F = 0.2$, and now assume that each region consumes half of total production (i.e., $\gamma = 0.5$).

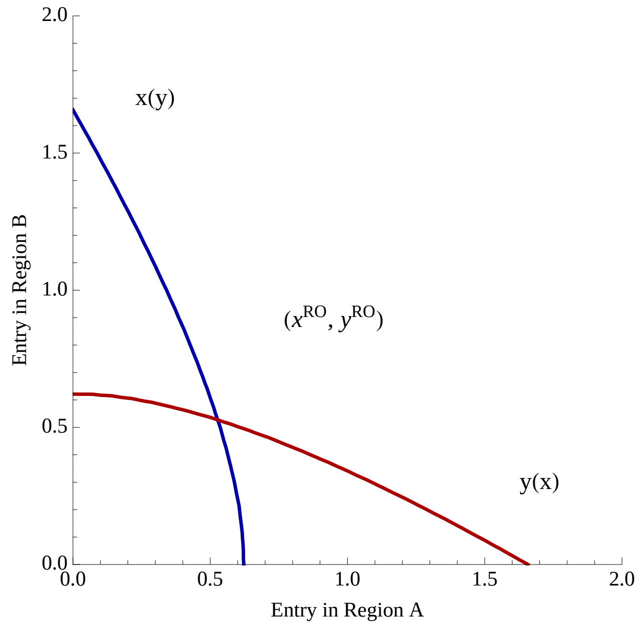

Figure 2: The regulators' best response functions in regions A and B.

regulator in region A can free-ride off of these benefits, ultimately supporting the entry of fewer firms into his own jurisdiction. Since regions are symmetric, the results hold for region B as well.[14] The intersection of the best response functions in Figure 2 indicates the regionally optimal (RO) level of entry, (x^{RO}, y^{RO}). If both regulators can induce the regionally optimal level of entry using taxes, subsidies, or permits, then the intersection becomes a candidate for the two-region regulated equilibrium. We further investigate this equilibrium in section 3.

2.3.1 Entry Externalities

The regionally optimal entry from Subsection 2.3, (x^{RO}, y^{RO}), does not necessarily coincide with the unregulated entry (x^{SO}, y^{SO}) of Subsection 2.2. Specifically, entry in region $k = \{A, B\}$ creates two forms of externality in region $\ell \neq k$: on one hand, it increases competition among firms, thus decreasing aggregate profits (negative pecuniary externality); but it also increases consumer surplus (positive pecuniary externality).[15] Conventional positive externalities arise from the increased production of clean products in the foreign region, which benefits all regions when consumed (or installed in the case of solar panels). These externalities are evident when comparing the first-order conditions of the single regulator in Section 2.2 (in

[14] In addition, the best response function of region A, $x(y)$, shifts outward as the share of region A's consumption, γ, increases. Intuitively, for a given number of foreign firms, the regulator in region A would optimally induce a larger number of firms as γ increases. Bayındır-Upmann (2003) circumvents the complication of two regions who simultaneously use policy in order to achieve a regionally optimal level of entry by assuming that the number of foreign firms is exogenous. Unlike this paper, that approach neglects the strategic response of each regulator to the others' policy.

[15] Note that these externalities were absent when regulators coordinated entry policies across jurisdictions (section 2.2), but are present when each regulator simultaneously and autonomously sets entry policy (section 2.3).

Equations (3) and (4)) to those of the two separate regulators in Section 2.3 (in equations (8) and (9)). If regulator A increases entry in region A, it does not account for the positive externalities $(dQ_x^B + (1-\gamma)CS_x)$ or negative externalities $(y\pi_x^B)$ it imposes on region B's welfare. Similar to cutoff d^{SO} in Lemma 2, the next lemma evaluates the range of environmental benefit, d, for which the regionally optimal number of firms is larger than the unregulated number of firms for each region, i.e., $x^{RO} > x^U$ and $y^{RO} > y^U$.

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., $d^k > \underline{d}^k$, where $\underline{d}^A \equiv \frac{b(1-\gamma)}{\gamma} d^{SO}$ for region A ; and $\underline{d}^B \equiv \frac{b\gamma}{1-\gamma} d^{SO}$ for region B. Finally, $\underline{d}^A < \underline{d}^B$ if and only if $\gamma < 1/2$.*

See A.5 for proof of Lemma 3 and derivation of cutoffs $\underline{d}^A$ and $\underline{d}^B$. Figure 3 depicts cutoffs $\underline{d}^A$ and $\underline{d}^B$ as a function of the share of consumption in region A, γ. For completeness, the figure also includes cutoff d^{SO} from Lemma 2. Recall that when the environmental benefit exceeds the socially optimal threshold $d \geq d^{SO}$, socially optimal entry exceeds the unregulated entry. Cutoff d^{SO} is constant in γ because the geographic distribution of consumption, γ, is irrelevant to aggregate welfare when regulators jointly coordinate their entry policy.[16] In contrast, cutoffs $\underline{d}^A$ and $\underline{d}^B$ are inversely related to their respective shares of domestic consumption (γ in region A and $1-\gamma$ in region B) and divide the parameter space (γ, d) into four partitions that provide a comparison of unregulated entry relative to two regulatory benchmarks: socially optimal entry (coordinated policies) and regionally optimal entry (uncoordinated policies).

Partition (1) represents the case in which environmental benefits are large enough that both regulators promote entry beyond the unregulated equilibrium ($x^{RO} > x^U$ and $y^{RO} > y^U$). This preference for increasing entry by each autonomous regulator coincides with their preferences when coordinating policies, i.e., $\max\{\underline{d}^A, \underline{d}^B\} \geq d^{SO}$. In partition (2), regulator A prefers to encourage entry ($x^{RO} > x^U$) while regulator B prefers to discourage entry ($y^{RO} < y^U$), given that $\underline{d}^B > d > \underline{d}^A$. Intuitively, region A benefits more from consumer surplus and clean products than the reduction in firm profits because $\gamma > 0.5$. Partition (2) is bisected by the isocline, d^{SO}, above which coordinated regulation calls for increased entry. In (2a), coordinated regulation encourages entry relative to the unregulated equilibrium, i.e., $x^{SO} > x^U$ and $y^{SO} > y^U$, whereas in (2b) the coordinated regulation limits entry. An opposite argument applies in partition (3), where only regulator B encourages entry ($y^{RO} > y^U$). As is the case in partition (2), the single regulator would increase entry in the region above cutoff d^{SO}, in partition (3a), and decrease entry below d^{SO}, in partition (3b). Finally, in partition (4), both regulators discourage entry ($x^{RO} < x^U$ and $y^{RO} < y^U$), since the benefits of

[16] Cutoffs $\underline{d}^A$ and $\underline{d}^A$ are functions of the cutoff a single regulator coordinating entry policies would identify, d^{SO}, and the elasticity of demand, b. Intuitively, as demand becomes more elastic (b decreases), more entry occurs without regulation because monopoly rents rise, which reduces the individual regulator's need to provide subsidies. The planner's cutoff d^{SO} only intersects $\underline{d}^A$ and $\underline{d}^B$ at $\gamma = 0.5$ when $b = 1$.

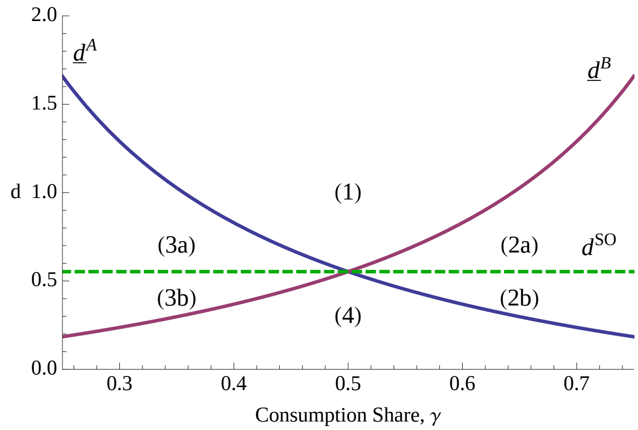

Figure 3: Cutoffs $\underline{d}^A$ and $\underline{d}^B$ divide the (d, γ)-space into four partitions. Regulator $k = \{A, B\}$ encourages entry above $\underline{d}^k$ and discourages entry below $\underline{d}^k$.

consuming clean goods are relatively low. The single regulator would also restrict entry in all of partition (4), i.e., $x^{SO} < x^U$ and $y^{SO} < y^U$.

While our previous discussion compares unregulated entry against two regulatory benchmarks (SO and RO), we have not yet examined whether entry under uncoordinated regional policies (RO) is insufficient (relative to the social optimum, SO). We confirm this result in Lemma 4.

Lemma 4. *The socially optimal level of entry exceeds the regionally optimal level of entry in region A, $x^{SO} > x^{RO}$ (in region B, $y^{SO} > y^{RO}$), when the marginal pecuniary benefits of entry exceed the marginal pecuniary costs $(1-\gamma)CS_x + dQ_x^B > y\pi_x^B$ in region A ($(1-\gamma)CS_y + dQ_y^A > x\pi_y^A$ in region B), respectively, which holds for all $d > d^{SO}$.*

See A.6 for details. When the benefits of clean goods are sufficiently large (high d), entry increases welfare in the opposing region despite the dissipation of firm profits. Regionally optimal entry is smaller than the socially optimal entry because output is consumed in both regions, which implies that the benefits of larger output are not completely internalized. Figure 4 depicts the difference between the socially optimal and regionally optimal aggregate level of entry, $(x^{SO} + y^{SO}) - (x^{RO} + y^{RO})$ in $(x + y, d)$-space when $\gamma = .5$. The figure shows that for $d > d^{SO}$, the socially optimal entry exceeds the regionally optimal entry.

3 Entry Policies

Throughout Section 2.3 we have taken the regulators' ability to induce the regionally optimal level of entry as a given. We now explore whether the regionally optimal level of entry (x^{RO}, y^{RO}) can be implemented using either a quantity-based policy (i.e., entry permits) and a price-based entry policy (i.e., entry tax or subsidy). Price- and quantity-based instruments alter the incentives of potential entrants in different ways.

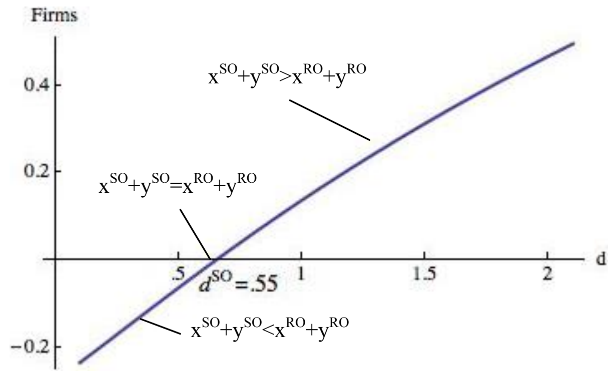

Figure 4: Difference between the socially optimal (SO) and regionally optimal (RO) aggregate entry as a function of d.

Our discussion will focus on the incentive structure created when regulators are restricted to one of these policy types.

3.1 Quantity-Based Entry Policy

Consider the case in which both regulators use a quantity-based entry policy such as permit restrictions. A permit policy allows regulator k to directly restrict entry in region k, but cannot restrict entry in region $\ell \neq k$, where $k = \{A, B\}$.

Proposition 1. *Under a quantity-based entry policy, both regulators limit the number of entrants and induce the regionally optimal level of entry, (x^{RO}, y^{RO}), if $d \leq \min\{\underline{d}^A, \underline{d}^B\}$; but do not limit the number of entrants allowing for the unregulated level of entry to arise, (x^U, y^U), otherwise.*

The proof of Proposition 1 is in A.7. The limitation of the permit policy to only restrict entry implies that it is only effective in partition (4) of Figure 5. Partition (4) represents the (d, γ)-pairs where the RO policy calls for both regulators to restrict entry, i.e., $(x^{RO}, y^{RO}) < (x^U, y^U)$. Therefore, regulator A (B) sets a permit limit equal to x^{RO} (y^{RO}, respectively). Neither regulator has incentive to deviate from this strategy because x^{RO} (y^{RO}) maximizes the welfare in region A (B, respectively) and thus, relaxing the policy to encourage entry would decrease welfare. In partitions (1-3), at least one regulator would like to encourage entry, which implies that they would not restrict entry by limiting available permits. If regulator A does not use permits to restrict entry, regulator B cannot benefit by restricting entry because the firms that would have been prevented from entering region B locate in region A instead.

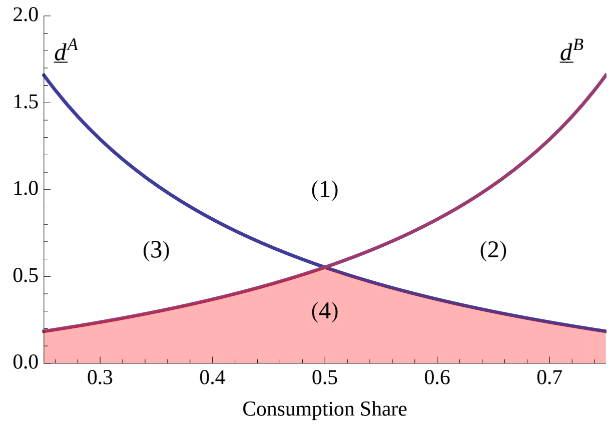

Figure 5: Cutoffs $\underline{d}^A$ and $\underline{d}^B$ divide the (d, γ)-space into four partitions characterized by the regulators preference for entry. The shaded area indicates the conditions under which the regionally optimal level of entry, (x^{RO}, y^{RO}), can be implemented with a quantity-based entry policy.

3.2 Price-Based Entry Policy

Regulators may instead promote RO with entry taxes or subsidies. As described in Lemma 3, the regionally optimal entry is less than the unregulated number of firms, $(x^{RO}, y^{RO}) < (x^U, y^U)$, when the benefit of clean products is low, which suggests that regulators could hinder entry with a tax. In contrast, the regionally optimal number of firms exceeds the unregulated number of firms, $(x^{RO}, y^{RO}) > (x^U, y^U)$, when the benefits of clean products are sufficiently high suggesting the use of subsidies to encourage entry. However, price-based entry policies pose an administrative challenge in a strategic context because both regulators have an incentive to deviate from the strategy that induces (x^{RO}, y^{RO}). Proposition 2 describes the equilibrium under a tax/subsidy policy as a function of the environmental benefit, d.

Proposition 2. *Under a price-based entry policy, both regulators set a zero tax, $z^A = z^B = 0$, and thus induce the unregulated equilibrium level of entry (x^U, y^U) if $d < \min\{\hat{d}^A, \hat{d}^B\}$; and only regulator A (B) sets a subsidy $\hat{z}^A < 0$ ($\hat{z}^B < 0$) to induce n^R entrants in region A (B) if $d \geq \hat{d}^A$ and $\gamma \geq 0.5$ ($d \geq \hat{d}^B$ and $\gamma < 0.5$, respectively).*

The proof of Proposition 2 is in A.8. Price-based entry policies threaten the implementation of RO by creating the incentive to deviate from the conditionally optimal strategy. We characterize the regulator's incentive to deviate over three distinct ranges of environmental benefit, each depicted in Figure 6: 1) $d \leq \min\{\underline{d}^A, \underline{d}^B\}$, 2) $\min\{\hat{d}^A, \hat{d}^B\} \geq d > \min\{\underline{d}^A, \underline{d}^B\}$, and 3) $d > \min\{\hat{d}^A, \hat{d}^B\}$.

Partition (4) in Figure 6 depicts the case where environmental benefits are low, i.e., $d \leq \min\{\underline{d}^A, \underline{d}^B\}$, and both regulators would prefer to deter entry by setting an entry tax to achieve $(x^{RO}, y^{RO}) < (x^U, y^U)$. However, each regulator knows that they can relax their own entry tax thereby attracting all firms into their own region and increasing welfare through additional domestic firm profits. This result embodies a feature commonly noted in the literature on tax competition (Janeba, 1998; Wilson, 1999), which assumes no environmental benefit, i.e., $d = 0$. The incentive of both regulators to reduce entry taxes for any $d \leq \min\{\underline{d}^A, \underline{d}^B\}$ implies that they both set an entry tax equal to zero and the unregulated equilibrium prevails.

Partitions (1) - (3) in Figure 6 depict the case where environmental benefits are moderate, $\min\{\hat{d}^A, \hat{d}^B\} \geq d > \min\{\underline{d}^A, \underline{d}^B\}$, and both regulators would now encourage entry by setting a entry subsidy to achieve (x^{RO}, y^{RO}) where $(x^{RO}, y^{RO}) > (x^U, y^U)$. Despite the welfare gains from setting a subsidy to encourage (x^{RO}, y^{RO}), both regulators have the incentive to free-ride off of the other regulator's subsidy. If regulator A can reduce its subsidy, all firms enter into region B. Since total entry depends on the lowest entry cost (inclusive of the subsidy), and providing the subsidy is costly, region A enjoys the same level of benefit and incurs no cost. By symmetry, regulator B faces the same incentive. Therefore, regulators set a subsidy of zero when environmental damages are moderate resulting in the unregulated equilibrium, (x^U, y^U).

The shaded region in Figure 6 depicts the case where environmental benefits are large, $d > \min\{\hat{d}^A, \hat{d}^B\}$. In contrast to the case where free-riding prevents either regulator from providing subsidies, environmental benefits are high enough that at least one regulator subsidizes all entry. However, the fact that a portion of output is exported (i.e., $\gamma \in [0, 1]$) implies that the subsidizing region receives only a fraction of the benefits, which diminishes the incentive to subsidize. Therefore, the regulator who benefits the most (region A when $\gamma \geq 0.5$, and region B when $\gamma < 0.5$) subsidizes entry to maximize domestic welfare conditional on zero entry in the other region.[17] Note that a price-based entry policy does not allow both regulators to reach the regional optimum (x^{RO}, y^{RO}), but instead, $(x^{RO}, 0), (0, y^{RO})$, or (x^U, y^U) arise.

Our analysis examines an indirect form of regulation, i.e., entry policies. This form of regulation nonetheless relates to more direct forms of regulation such as output-based emission fees and subsidies. Consider a simple production subsidy that augments the marginal cost of production. Beyond increasing the output of all firms, a reduction in marginal cost raises the cutoff above which unregulated entry is socially inefficient, i.e., $d^{SO} \equiv a - \hat{c} - \sqrt{bF}$ where $\hat{c} = c - s$ and $s > 0$ is a subsidy. That is, the environmental benefit would need to be higher for the planner to encourage entry. Therefore, entry policy is an imperfect substitute for a direct policy designed to promote production. Indeed, increasing the output subsidy s increases the cutoff d^{SO} and, as a result, the regulator can reduce the amount of entry subsidy necessary to achieve the socially optimal entry.

[17] For instance, region A sets a subsidy $\hat{z}^{A,R}$ that solves $\pi^A(n^R, 0) - F = z$, where $n^R = \{\max_n \; W^A(n, 0; d)\}$. The equilibrium number of firms under the entry subsidy when $d > \min\{\hat{d}^A, \hat{d}^B\}$ exceeds the unregulated equilibrium but is less than both the regionally optimal and socially optimal entry, i.e., $n^U < n^R < n^{RO} < n^{SO}$.

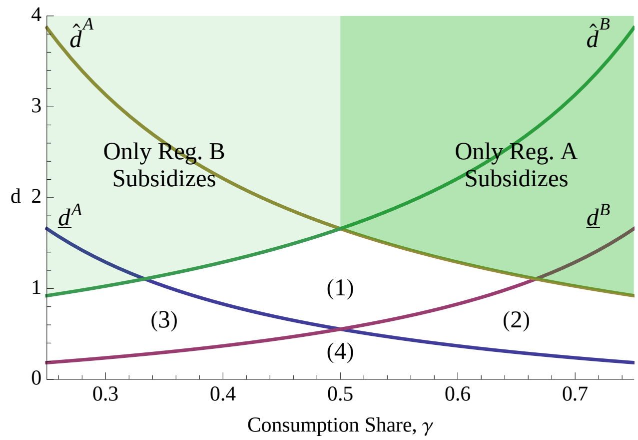

Figure 6: Cutoffs $\underline{d}^A$ and $\underline{d}^B$ divide the (d, γ)-space into four partitions. Cutoffs $\hat{d}^A$ and $\hat{d}^B$ are defined in A.8 and further divide the conditions under which regulators promote entry into conditions that sustain an entry subsidy equilibrium (when $d > \hat{d}^k$).

4 Welfare

We now investigate the welfare implications of the model by simulating the entry game. We compare the welfare 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 1, 2, and 3 contain the aggregate welfare ($W^A + W^B$), number of firms ($x + y$), equilibrium price ($P(Q)$), aggregate output (Q), total net profits $(x + y)\left(\sum_i^n \pi_i - F\right)$, and aggregate environmental benefits (dQ) for a series of simulations.[18]

Table 1: 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

[18]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.

4.1 Low Benefit

The low benefit case, described in Table 1, 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.[19] When entry permits are the regulatory tool (second column of Table 1), 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 to 0.324 from 0.32 in the unregulated equilibrium. The very small increase in welfare results from the lost environmental benefit offsetting the additional profits (0.02).

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).[20]

Table 2: 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

4.2 Moderate Benefit

Table 2 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

[19]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, Morey, and Olewiler (1995) for a detailed discussion on the role of tax competition in regulating polluting firms who choose where to operate.

[20]Note that the socially optimal number of firms is smaller than under entry permits because a single regulator internalizes the impact of entry on profits of firms in both regions whereas independent regulators in each region only consider domestic profits.

provided by firms in the other region. Therefore, the equilibrium under a subsidy (first column in Table 2) implies a zero subsidy by both regulators, which results in the unregulated equilibrium. Aggregate welfare in this equilibrium is 0.71, which is larger than the unregulated equilibrium welfare in the low benefit case because the environmental benefit is now 0.55.[21]

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.

Table 3: 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

4.3 Large Benefit

Table 3 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 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 (A when $\gamma \geq 0.5$, and B when $\gamma < 0.5$) 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

[21] If each regulator were able to subsidize entry but also use a permit policy to prevent subsidizing the entire industry, each regulator would have the incentive to decrease their own subsidy and benefit from the increased output of the other region. Therefore, the unregulated equilibrium, n^U, prevails when benefits are moderate regardless of the policies at the disposal of the regulator.

considerably (moving from the second to third column).

4.4 Welfare Comparison

Coordination of policy, environmental or otherwise, across jurisdictions often involves costly negotiation. We compare the welfare gains of policy coordination to the uncoordinated policy equilibrium as well as the unregulated equilibrium to explore the merits of coordinated regulation. Table 4 contains the aggregate welfare benefits arising from the transition between regulatory settings i.e., from U to RO, and from RO to SO. The magnitude of the figures is intended to illustrate the qualitative implications of the model; namely, the welfare benefits of regulation. Appendix A.1 provides comparable results using different parameter combinations, and shows that our qualitative results are unaffected.

Policy coordination is always welfare improving because the external benefits of entry are internalized. The welfare gains of policy coordination increase as the environmental benefit rises. When the environmental benefits are low ($d = 0.3$), permit restrictions can be used to implement the uncoordinated equilibrium, (x^{RO}, y^{RO}), and capture a large share of the welfare gains resulting from policy coordination (1.57% increase versus 0.31%). As benefits rise to a moderate level, ($d = 1$), free-riding prevents any successful uncoordinated regulation (RO); however, coordinated regulation (SO) increases welfare by 2.27%. When environmental benefits are large ($d = 2$), uncoordinated regulation (one region subsidizes all entry) only achieves a welfare increase of 2.94% versus a 7.18% increase from policy coordination. Therefore, policy coordination yields large welfare gains when environmental benefits are large and may be less critical when environmental benefits are small.

Table 4: 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).

	No Reg W^U	Uncoord W^{RO}	(% change) $(W^U \to W^{RO})$	Coord W^{SO}	(% change) $(W^{RO} \to W^{SO})$
Low Benefit ($d = 0.3$)	0.319	0.324	(1.57%)	0.325	(0.31%)
Moderate Benefit ($d = 1$)	0.706	-	-	0.722	(2.27%)
Large Benefit ($d = 2$)	1.258	1.295	(2.94%)	1.388	(7.18%)

5 Discussion and Conclusion

Insufficient or excessive entry? We study the use of entry policy as a form of indirect environmental regulation in an imperfectly competitive, multi-region setting. Our results show that, in the absence of positive environmental externalities, entry is excessive (relative to the social optimum) both when entry is left unregulated and when it is independently regulated within each jurisdiction. Hence, entry subsidies are too generous when environmental benefits of the good are small. In contrast, when environmental benefits are present, entry is insufficient under the unregulated and autonomously regulated contexts; thus implying that entry subsidies are insufficient. As a consequence, the coordination of entry policies across regions can help approach entry patterns to the social optimum.

Policy coordination: Not always recommended. While international policy coordination is welfare improving, its size crucially depends on the environmental benefit of the good. We find that, when the environmental benefit of the product is small, policy coordination yields a relatively negligible welfare increase; but a significant welfare gain otherwise.[22] Specifically, when environmental benefits are large, policy coordination helps regions set more generous entry subsidies, thus promoting more entry than when each region independently sets its own policy. In contrast, when benefits are small, policy coordination helps regions avoid excessive entry and costly capital investments.

Therefore, our findings indicate that, while introducing domestic regulation yields unambiguous welfare gains (relative to unregulated settings), investing a large amount of resources to achieve international policy coordination is not necessarily beneficial. Specifically, countries should coordinate their subsidy policies in industries with large environmental benefits, such as solar panels and wind turbines, but should actually avoid costly negotiations in industries with relatively small environmental benefits, such as biofuels. This result argues against promoting policy coordination between the U.S. and Europe, as the U.S. is claimed to provide generous entry subsidies to its biofuel industry (e.g., loans for starting up companies). Intuitively, promoting further entry in this industry yields a small environmental benefit which, after a sufficient number of firms enter (either domestically or overseas), is offset by the profit dissipation incumbent firms suffer, ultimately yielding an overall welfare loss.

Do not overlook domestic policies. Our results also show that, in certain contexts, the percent increase in welfare arising from the introduction of domestic policy (i.e., from the U to RO setting) can be larger than that of further moving to international policy coordination (i.e., from RO to SO). Although both policy changes entail a welfare improvement, the latter is smaller under most parameter combinations; see Table 4 and its application to other parameters in Appendix 1. Intuitively, this indicates that, if international policy coordination is costly or politically difficult, countries can still accrue most of the policy benefits by at least introducing domestic policies, while avoiding international treaties.

Further research. Our stylized model could be extended by including a coefficient on domestic output that captures the regulators' marginal value of domestic employment. Regulators would then face more

[22] In particular, policy coordination ameliorates the free-riding and business-stealing incentives by ensuring that both conventional and pecuniary externalities are internalized.

incentive to promote entry, which could complement environmental goals when the environmental benefit is high. In addition, we simplify the trade interactions between the regions by modeling consumption in either region as a constant share of aggregate output. Modeling the underlying trade dynamics would allow us to study the interaction between restrictive trade policy and entry policy. Finally, we model a homogenous good produced in both regions; a plausible assumption for the manufacture of renewable energy technologies. In differentiated product markets, entry policies increase variety thereby increasing welfare (DeRemer, 2011). Differentiated products would make entry subsidies unambiguously welfare improving in the single region, but free-riding incentives would still preclude optimal entry subsidies in the multi-region case with autonomous regulation.

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A Appendix

A.1 Alternative Simulations

The model simulation results in section 4.4 show that the welfare gains of policy coordination increase as the environmental benefit increases. This 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 5 is presented in a format similar to Table 4 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 5 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 4.

Table 5: 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) $(W^U \to W^{RO})$	Coord W^{SO}	(% change) $(W^{RO} \to W^{SO})$
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%)

A.2 Proof of Lemma 1

Firms enter the region in which they earn the highest profit net of entry costs. Since firms compete in an interregional market, gross profits are independent of location in region A or B. Therefore, firms locate in the region with the lowest entry cost F^k where $k = \{A, B\}$. There are three possible entry cost cases in the absence of regulation: 1) $F^A < F^B$, 2) $F^B < F^A$, and 3) $F^A = F^B$. In case 1, all firms enter region A and the equilibrium number of firms x^U solves

$$\pi^A(x,0) - F^A = \frac{(a-c)^2}{b(1+x)^2} - F^A = 0.$$

The equilibrium number of firms is $x^U = \frac{a-c}{\sqrt{bF^A}} - 1$, and is equivalent to the equilibrium entry in a single region. Conversely, the equilibrium number of firms in case 2 solves an analogous equation where $A = B$ and $x = y$, which yields $y^U = \frac{a-c}{\sqrt{bF^B}} - 1$. In case 3, the entry cost in both regions are equal ($F \equiv F^A = F^B$) and entrants are indifferent between entry in regions A or B. Therefore, entry in regions A and B, i.e., (x, y) solves $n = x + y$. Equilibrium entry n^U solves

$$\pi(n) - F = \frac{(a-c)^2}{b(1+n)^2} - F = 0$$

and is $n^U = \frac{a-c}{\sqrt{bF}} - 1$. We confine our analysis to the nontrivial cases in which entry costs are not prohibitive (i.e., $0 \leq F < F_{max} \equiv \frac{(a-c)^2}{4b}$ where F_{max} is equal to the monopolist's gross profit). We summarize the three possible cases in a general representation of the unregulated equilibrium entry $n^U = \frac{a-c}{\sqrt{b\min\{F^A,F^B\}}} - 1$.

A.3 Uniqueness of Equilibrium

The number of entrants n^{SO} maximizes $W(n)$ if it solves $W'(n) = 0$ and $W''(n) < 0$. The second derivative of the welfare function is

$$W''(n) = -\frac{(a-c)^2(2n-1)\gamma}{b(n+1)^4} + \frac{6n(a-c)^2}{b(n+1)^4} - \frac{4(a-c)^2}{b(n+1)^3} - \frac{2(a-c)d\gamma}{b(n+1)^3}$$

where the first and last terms represent, respectively, the marginal effect of a new firm on consumer surplus and on the benefit of consuming clean goods; both effects are concave in $n > 1$. The middle terms come from the marginal effect of a new firm on producer surplus, and are only concave when $n < 2$. Hence, if $n > 2$, the concavity of consumer surplus and benefits of consuming clean products must outweigh the convexity of producer surplus. This occurs when

$$\gamma < \frac{2(a-c)(n-2)}{2d(1+n)+(a-c)(2n-1)}.$$

This condition holds throughout the paper, and is satisfied for all parameters used to generate Figures and simulations.

A.4 Proof of Lemma 2

Suppose that $n^R > n^U$ when $CS_n(n^U)+D_n(n^U) < n\pi_n(n^U)$. Then it must be the case that at n^U, a marginal increase in the number of entrants yields a larger welfare. However, we know that the social marginal cost of entry is $n\pi_n(n^U)$, and the social marginal benefit of entry is $CS_n(n^U)+\pi_n(n^U)-F+D_n(n^U)$. By definition, $\pi(n^U)-F=0$, which implies that the social marginal benefit of entry at the unregulated equilibrium is $CS_n(n^U)+D_n(n^U)$. If a marginal increase in the number of entrants was welfare improving, the social marginal benefit of entry would exceed the social marginal cost: $CS_n(n^U)+D_n(n^U) > n\pi_n(n^U)$. This contradicts the original statement. Therefore $CS_n(n^U)+D_n(n^U) < n\pi_n(n^U)$.

The result of Lemma 2 may be expressed as a threshold in terms of the benefit, d. Rearranging the first-order conditions of the regulator's welfare maximization problem we obtain

$$n^U\frac{(a-c)^2}{b(1+n^U)^3}+d\frac{a-c}{b(n^U+1)^2}=2n^U\frac{(a-c)^2}{b(1+n^U)^3}$$

and solving for the parameter d, we have

$$d=(a-c)\left(\frac{n^U}{n^U+1}\right)$$

which, evaluated at $n^U=\frac{a-c}{\sqrt{Fb}}-1$ yields

$$d^{SO}\equiv a-c-\sqrt{Fb}.$$

A.5 Proof of Lemma 3

Proof of Lemma 3 follows the same logic as the single-region counterpart in Lemma 2. Since any (x,y)-pair that satisfies $x+y=n^U$ is a single-region unregulated equilibrium as specified in Lemma 1, assume that $x^U=y^U=\frac{1}{2}n^U$ where n^U denotes the aggregate number of entrants when regulation is absent. Suppose that $(x^{RO}, y^{RO}) >> (x^U, y^U)$ when both

$$W_x^A(n^U) \equiv \gamma CS_x(n^U) + \pi_i^A(n^U) - F + D_x^A(n^U) - x\pi_{ix}^A(n^U) < 0$$
$$W_y^B(n^U) \equiv (1-\gamma)CS_y(n^U) + \pi_i^B(n^U) - F + D_y^B(n^U) - y\pi_{ix}^B(n^U) < 0$$

where $\pi_i^k(n^U) - F = 0$ by definition. If regulator A could increase welfare by inducing $x^{RO} > x^U$, marginal welfare at x^U would be positive, which contradicts the original statement. An analogous argument holds for regulator B. Therefore $(x^{RO}, y^{RO}) >> (x^U, y^U)$ if and only if $W_x^A(n^U) > 0$ and $W_y^B(n^U) > 0$.

These inequalities can then be used to derive a cutoff in terms of the benefit, d. The regionally optimal and unregulated level of entry coincide in region A when

$$\gamma \frac{n^U(a-c)^2}{b(1+n^U)^3} + d^A \gamma \frac{a-c}{b(b(1+n^U)^2} = \frac{n^U(a-c)^2}{b(1+n^U)^3}$$

and solving for d^A, we have

$$\underline{d}^A \equiv \left[\frac{n^U}{1+n^U}\frac{a-c}{b}\right]\frac{1-\gamma}{\gamma}$$

which, evaluated at $n^u = \frac{a-c}{\sqrt{Fb}} - 1$ is

$$\underline{d}^A \equiv \frac{b(1-\gamma)}{\gamma}\left(a-c-\sqrt{Fb}\right).$$

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

$$\underline{d}^B \equiv \frac{b\gamma}{1-\gamma}\left(a-c-\sqrt{Fb}\right)$$

A.6 Proof of Lemma 4

The socially optimal entry (x^{SO}, y^{SO}) solves the first-order conditions of the coordinated regulator's problem

$$[x] \quad \gamma CS_x + (1-\gamma)CS_x + (\pi^A - F^A) + dQ_x^A + dQ_x^B = x\pi_x^A + y\pi_x^B$$
$$[y] \quad \gamma CS_y + (1-\gamma)CS_y + (\pi^B - F^B) + dQ_y^B + dQ_y^A = y\pi_y^B + x\pi_y^A$$

whereas the regionally optimal entry (x^{RO}, y^{RO}) solves the first-order conditions of the independent regulator's problem

$$\begin{aligned}
&[\text{Region } A] \quad \gamma CS_x + \pi^A - F^A + dQ_x^A = x\pi_x^A \\
&[\text{Region } B] \quad (1-\gamma)CS_y + \pi^B - F^B + dQ_y^B = y\pi_y^B.
\end{aligned}$$

Therefore, by rearranging the identity

$$\gamma CS_x(x^{RO}, y^{RO}) + dQ_x^A(x^{RO}, y^{RO}) - x^{RO}\pi_x^A(x^{RO}, y^{RO}) \equiv -(\pi^A(x^{RO}, y^{RO}) - F^A)$$

we can show that the left hand side must be greater than zero. Then, by symmetry $CS_n = CS_x = CS_y$, $\pi = \pi^A = \pi^B$, $Q_n = Q_x^k = Q_y^k$ hold, which imply that pecuniary externalities must be positive in both regions at (x^{RO}, y^{RO}),

$$\begin{aligned}
(1-\gamma)CS_x(x^{RO}, y^{RO}) + dQ_x^B(x^{RO}, y^{RO}) - y^{RO}\pi_x^B(x^{RO}, y^{RO}) > 0 \\
\gamma CS_y(x^{RO}, y^{RO}) + dQ_y^A(x^{RO}, y^{RO}) - x^{RO}\pi_y^A(x^{RO}, y^{RO}) > 0
\end{aligned}$$

If the pecuniary externalities are positive, then $(x^{SO}, y^{SO}) > (x^{RO}, y^{RO})$ for all $d > \underline{d}^A = d^{SO}$.

A.7 Proof of Proposition 1

Our goal is to characterize the feasibility of the regionally optimal number of firms (x^{RO}, y^{RO}) under a permit policy. In section 2.3, we show that (x^{RO}, y^{RO}) maximize welfare in regions A and B, respectively. Our task is to show that when $d \leq \min\left\{\underline{d}^A, \underline{d}^B\right\}$, (x^{RO}, y^{RO}) is an equilibrium; and when $d > \min\left\{\underline{d}^A, \underline{d}^B\right\}$, (x^U, y^U), is an equilibrium.

We begin with the case where $d > \min\left\{\underline{d}^A, \underline{d}^B\right\}$. When environmental benefits are sufficiently high, the region consuming the most product has the highest welfare. For region A, welfare is increasing in the number of entrants at x^U since by Lemma 3, $x^{RO} > x^U$ when $d > \underline{d}^A$ and similarly for region B, $y^{RO} > y^U$ when $d \geq \underline{d}^B$. Therefore, at least one regulator would like to encourage entry and thus, does not restrict entry by limiting permits. If for instance, $\underline{d}^A > d \geq \underline{d}^B$ as in partition (3) in Figure 5, regulator B attempts to restrict entry to $\bar{y} < y^U$, potential entrants in region A earn positive profit (i.e., $\pi^A(x, \bar{y}) - F \geq 0$) until the entry condition holds with equality when $x = n^U - \bar{y}$ from Lemma 1, which is the unregulated equilibrium.

If on the other hand, $d \leq \min\left\{\underline{d}^A, \underline{d}^B\right\}$ as illustrated in the shaded region of Figure 5, both regulators increase welfare by restricting entry since $x^{RO} \leq x^U$ when $d \leq \underline{d}^A$, and similarly for region B $y^{RO} \leq y^U$

when $d \leq \underline{d}^B$, by Lemma 3. Intuitively, when d is sufficiently low, firm profits improve marginal welfare more than increased consumption. Consequently, neither regulator has the incentive to relax their permit restriction because doing so would decrease welfare. The resulting equilibrium is $(x^{RO}, y^{RO}) \leq (x^U, y^U)$

A.8 Proof of Proposition 2

Our goal is to characterize the feasibility of the regionally optimal number of firms (x^{RO}, y^{RO}) under a price policy (entry tax or subsidy). There are three relevant ranges for d over which the incentives of both regulators differ substantially: 1) $d \leq \min\left\{\underline{d}^A, \underline{d}^B\right\}$, 2) $\min\left\{\hat{d}^A, \hat{d}^B\right\} \geq d > \min\left\{\underline{d}^A, \underline{d}^B\right\}$, and 3) $d > \min\left\{\hat{d}^A, \hat{d}^B\right\}$. Cutoffs $\underline{d}^A$ and $\underline{d}^B$ are defined in A.5. Cutoffs $\hat{d}^A$ and $\hat{d}^B$ define the level of environmental benefit above which regulators A and B are willing to subsidize all entrants regardless of the other regulator's actions. In order to identify these cutoffs, note that in region A, the marginal welfare of an additional entrant is

$$W_1^A(n,0) \equiv n\gamma\frac{(a-c)^2}{b(1+n)^3} + \frac{(a-c)^2}{b(1+n)^2} - F^A + d\gamma\frac{(a-c)}{b(1+n)^2} = n\frac{2(a-c)^2}{b(1+n)^3}.$$

Evaluating $W_1^A(n,0)$ at $n^U = x^U + y^U = \frac{a-c}{\sqrt{bF}} - 1$ from Lemma 1 and solving for d yields $\hat{d}^A = \frac{2-\gamma}{\gamma}(a-c-\sqrt{bF})$. An analogous exercise provides the threshold in region B, $\hat{d}^B = \frac{1+\gamma}{1-\gamma}(a-c-\sqrt{bF})$. We show that when $d \leq \min\left\{\underline{d}^A, \underline{d}^B\right\}$, the unregulated equilibrium (x^U, y^U) prevails; and when $d \geq \min\left\{\hat{d}^A, \hat{d}^B\right\}$, only one of the regulators subsidizes entry up to $n^R < n^{RO} = x^{RO} + y^{RO}$. The following paragraphs describe the equilibrium for each range of environmental benefit d .

Case 1: $d \leq \min\left\{\underline{d}^A, \underline{d}^B\right\}$ (shaded region in Figure 5). The regionally optimal number of firms $(x^{RO}, y^{RO}) \leq (x^U, y^U)$ maximizes welfare in both regions as shown in Lemma 3. Under an entry tax, regulators can set an entry tax $\underline{z}^{RO}(d)$, which solves $\pi(\underline{x}^{RO}, \underline{y}^{RO}) - (F+z) = 0$. However, there exists an incentive for both regulators to deviate from an entry tax of $\underline{z}^{RO}(d) > 0$ since slightly relaxing one's entry tax "steals" all firms from the other region and thus, increases welfare by capturing all firm profit. Formally, regulator A can reduce their entry tax $z^A = \underline{z}^{RO} - \varepsilon$ where $\varepsilon \in (0, \underline{z}^{RO})$. Since $z^A < z^B = z^{RO}$, n^R firms enter region A where n^R solves $\pi^A(n^R, 0) - (F + z^A) = 0$. By lowering the entry tax, region A increases the number of entrants, $x^U + y^U > n^R > \underline{x}^{RO} + \underline{y}^{RO}$, and thus, decreases each firm's profit, $\pi(\underline{x}^{RO}, \underline{y}^{RO}) > \pi(n^R, 0) > \pi(x^U, y^U)$. However, aggregate profit in region A increases, $n^R\pi^A(n^R, 0) > \underline{x}^{RO}\pi^A(\underline{x}^{RO}, \underline{y}^{RO})$ which increases welfare since $\gamma CS(n^RO, 0) + dQ^A(n^R, 0) > \gamma CS(\underline{x}^{RO}, \underline{y}^{RO}) + dQ^A(\underline{x}^{RO}, \underline{y}^{RO})$. By symmetry, regulator B faces the same incentive to reduce their entry tax and encourage all entry into region B for all $d < \min\left\{\underline{d}^A, \underline{d}^B\right\}$ and all $z > 0$. The incentive for each regulator to reduce entry taxes to encourage domestic location of all potential entrants drives the entry tax in both regions to zero yielding the unregulated equilibrium (x^U, y^U). A similar result is described in Markusen, Morey, and Olewiler (1995) who model tax competition between two governments regulating a single firm who chooses to operate in one of the two regions.

Case 2: $\min\left\{\hat{d}^A, \hat{d}^B\right\} \geq d > \min\left\{\underline{d}^A, \underline{d}^B\right\}$ (partitions (1) - (3) in Figure 6). When $d > \min\left\{\underline{d}^A, \underline{d}^B\right\}$, the regionally optimal number of firms exceeds the unregulated number of firms $(x^{RO}, y^{RO}) > (x^U, y^U)$ from Lemma 3. Therefore, regulators can induce entry by using an entry subsidy, $\hat{z}^{RO}(d) < 0$, that solves $\pi(\hat{x}^{RO}, \hat{y}^{RO}) - (F + z) = 0$ and $d > \min\left\{\underline{d}^A, \underline{d}^B\right\}$. Recall that the entry policy variable z does not directly affect welfare; it only does so indirectly by altering firm entry behavior. If $z < 0$, then by rearranging the entry condition $\pi(x^{RO}, y^{RO}) - F = z$, net profits must also be negative when $(x^{RO}, y^{RO}) > (x^U, y^U)$. This implies that increasing the number of firms is only welfare improving if the environmental benefits exceed the negative net profit $\gamma CS(\hat{x}^{RO}, \hat{y}^{RO}) + dQ^A(\hat{x}^{RO}, \hat{y}^{RO}) > \hat{x}^{RO}\hat{z}^{RO}$ in region A (and similarly for region B, $(1-\gamma)CS(\hat{x}^{RO}, \hat{y}^{RO}) + dQ^B(\hat{x}^{RO}, \hat{y}^{RO}) > \hat{y}^{RO}\hat{z}^{RO}$), which holds for both regions by Lemma 3.

In contrast to case 1, both regulators have the incentive to free-ride on the environmental benefit provided by the entry subsidies in the other region. For instance, if the regulator in region A reduced the subsidy in region A, $z^A = \hat{z}^{RO} + \hat{\varepsilon}$, all potential entrants locate in region B, which increases welfare in region A since $\gamma CS(\hat{x}^{RO}, \hat{y}^{RO}) + dQ^A(\hat{x}^{RO}, \hat{y}^{RO}) = \gamma CS(0, \hat{x}^{RO} + \hat{y}^{RO}) + dQ^A(0, \hat{x}^{RO} + \hat{y}^{RO})$ and subsidy payments fall to zero because no firms enter into region A. However, the regulator in region B is not willing to subsidize all potential entrants since $(1-\gamma)CS(0, \hat{x}^{RO} + \hat{y}^{RO}) + dQ^B(0, \hat{x}^{RO} + \hat{y}^{RO}) < (\hat{x}^{RO} + \hat{y}^{RO})\hat{z}^{RO}$ for all $\min\left\{\hat{d}^A, \hat{d}^B\right\} \geq d > \min\left\{\underline{d}^A, \underline{d}^B\right\}$. Finally, region B would prefer the unregulated equilibrium to subsidizing all entry since $(1-\gamma)CS(\hat{x}^U, \hat{y}^U) + dQ^B(\hat{x}^U, \hat{y}^U) > (1-\gamma)CS(0, \hat{x}^{RO} + \hat{y}^{RO}) + dQ^B(0, \hat{x}^{RO} + \hat{y}^{RO}) - (\hat{x}^{RO} + \hat{y}^{RO})\hat{z}^{RO}$. By symmetry, both regions have the incentive to eliminate domestic entry subsidies when $\min\left\{\hat{d}^A, \hat{d}^B\right\} \geq d > \min\left\{\underline{d}^A, \underline{d}^B\right\}$, which results in the unregulated equilibrium.

Case 3: $d \geq \min\left\{\hat{d}^A, \hat{d}^B\right\}$ (shaded region in Figure 6). When $d \geq \min\left\{\hat{d}^A, \hat{d}^B\right\}$, $(x^{RO}, y^{RO}) > (x^U, y^U)$ as in case 2, which implies $\hat{\hat{z}}^{RO}(d) < 0$ is a subsidy. Also similar to case 2, each regulator has the incentive to free-ride on the policy of the other regulator. However, environmental benefits are large enough that one of the regions finds it optimal to subsidize all entry despite the other region's free-riding behavior. Suppose region B eliminates their subsidy causing all entrants to locate in region A. While region A is not willing to subsidize the regionally optimal entry since $\gamma CS(\hat{\hat{x}}^{RO} + \hat{\hat{y}}^{RO}, 0) + dQ^A(\hat{\hat{x}}^{RO} + \hat{\hat{y}}^{RO}, 0) < (\hat{\hat{x}}^{RO} + \hat{\hat{y}}^{RO})\hat{\hat{z}}^{RO}$, there exists a $\hat{\hat{n}}^R < \hat{\hat{x}}^{RO} + \hat{\hat{y}}^{RO}$ that solves $\pi(n, 0) - (F + \hat{\hat{z}}^R) = 0$ such that $\gamma CS(\hat{\hat{n}}^R, 0) + dQ^A(\hat{\hat{n}}^R, 0) > \hat{\hat{n}}^R\hat{\hat{z}}^{RO}$. Moreover, region B benefits from output $\hat{\hat{n}}^R > x^U + y^U$ since $(1-\gamma)CS(\hat{\hat{n}}^R, 0) + dQ^B(\hat{\hat{n}}^R, 0)$. When $\gamma \geq 0.5$, region A receives the largest welfare gains from entry and thus, subsidizes entry $\hat{z}^{A,R}$ providing a public good for region B. If $\gamma < 0.5$, region B receives the largest benefit and subsidizes entry at $\hat{z}^{A,R}$, which benefits region A. Whichever the case, at least one region sets a subsidy $\hat{\hat{z}}^R(d) < 0$ and $\hat{\hat{n}}^R$ firms enter the subsidizing region.