Are big mergers welfare enhancing when there is environmental externality?

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Abstract

Previous studies find that horizontal merger deals that consolidate a majority of firms in the market are likely to reduce welfare. This study provides an in-depth analysis of the relationship between the size of a merger and welfare in industries with environmental externality. In an international framework we show that in a market where more than 50-percent of firms have merged, a further increase in the size of the merger could increase or decrease welfare depending on two previously unexplored factors: (i) a given threshold of size of a merger and (ii) the pollution intensity of firms. Furthermore, we show that the relationship between welfare and size of merger can be affected by an exogenous change in emission tax at home and in a foreign country.

JEL Classification: Q5; G34

Keywords: anti-trust agency, merger and acquisition, emission tax, transboundary pollution, pollution damages, product differentiation

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1 Introduction

Several studies have examined the welfare effects of a multi-firm horizontal merger in markets with imperfect competition (e.g., Qiu and Zhou, 2006; Mazzeo et al., 2012; Saggi and Yildiz, 2006). The general consensus is that the 'bigger' the merger, the less likely is the increase in welfare post-merger. This is because a merger consolidating either a number of firms or those with large market share, is more prone to restricting output and lowering consumer surplus.

For example, Farrell and Shapiro (1990) show that a merger among a given number of firms raises welfare if those merging firms initially had market shares not larger than a given threshold. Under general conditions Levin (1990) finds that this threshold is 50%. Likewise, Barros and Cabral (1994) examine the impact of a multi-firm merger on welfare in an open economy and show that domestic welfare increases only if the combined share of merging firms and foreign firms is less than a weighted share of the local non-merging firms. These studies examine welfare impacts by making comparisons of welfare (the sum of profits and consumer surplus) before and after the merger.

However, less is understood about the welfare impact of mergers in industries with environmental externalities. Empirical evidence and market signals show that merger deals, in pollution-intensive sectors in particular, are becoming a frequently observed strategy among corporate managers. For example, Berchicci, Dowell and King (2012) examine over 2,000 merger deals in the period 1991- 2005 among firms regulated for the disclosure of toxic chemical releases. This study finds evidence that managers in such industries are strategically choosing merger partners with certain environmental capabilities, among other things. Likewise, several mergers are taking place among firms in the energy sector all of which require approval by anti-trust agencies (Kumar, 2012). Recent studies shows that firms in environmentally sensitive industries such as the energy sector could benefit from acquiring similar firms that own eco-friendly technologies (Kwon et al., 2018).

According to Creti and Sanin (2017) recent big mergers in the utility, energy and power sectors are believed to have been triggered by uncertainty about tightening environmental regulation. Another signal for the rise of merger deals among polluting firms comes from new insurance products that are designed to cover environmental liability resulting from a merger deal and include environmental risk assessment to value merger deals (PWC website, 2016). Despite such evidences, there are not many theoretical set-ups that examine the welfare impact of mergers among polluting firms. Fikru and Gautier (2016, 2017) are the only merger models which incorporate environmental externality where both studies examine the special case of a two-firm merger in a closed economy. Fikru and Gautier (2016) examine the profitability of a two-firm merger while Fikru and Gautier (2017) examine the optimal policy response when two firms merge under different scenarios. Neither examine the impact of a multi-firm merger on welfare or consider aspects of merger deals in an international context. The contribution of this study is to provide a more general framework to evaluate multi-firm mergers and examine the welfare consequences of big mergers in polluting sectors.

Given the recent rise in merger activities within polluting industries, it is important to revisit current procedures used to evaluate the welfare impact of mergers. This is because when a negative externality is present, the welfare components change compared to welfare in non-polluting markets. Furthermore, a market with a regulated negative externality likely has lower production levels compared to a pollution-free market and this has important implications for further changes in output and resulting welfare. The presence of a negative externality affects how (and to what extent) firms respond to a change in a given market condition or a change in policy.

The primary objective of this study is to provide an in-depth examination of the relationship between the size of a merger and welfare in an oligopoly market with environmental externality. The framework adopted in this study shows that the relationship between the size of a merger and welfare is not straightforward, and not always negative. We derive conditions under which "big" mergers are not always prone to reducing welfare, where the pollution intensity of competing firms and initial merger size in an industry are key factors new to the merger literature. Specifically, in a market where more than 50% of firms have merged, a further increase in the size of the merger increases welfare if firms are not too pollution-intensive and the merger size is relatively small (but still above the 50% mark). This is because of the positive consumer surplus effects created via the oligopolistic interdependence between non-merging and merging firms, which results from a bigger merger. However, results are reversed if firms are sufficiently pollution intensive. Our findings thus suggest that existing models of horizontal mergers would not yield accurate welfare analysis for pollution-intensive industries since they implicitly assume that pollution intensities and resulting damages are absent.

Results in the merger literature often times rely on cost savings/synergies to argue for welfare-enhancing effects from mergers (e.g., Davidson and Mukherjee 2007), or derive results in a closed-economy setting absent environmental considerations (e.g., Barros and Cabral 1994). We argue, in contrast, that welfare-enhancing effects may take place with bigger mergers even when cost synergies/savings are not present. This is because we explicitly account for the oligopolistic interdependence of firms arising from potential changes in the merger size, which opens the door for higher output even when mergers are big. Furthermore, the environmental literature has, surprisingly, assumed away aspects of mergers even as merger deals increasingly take into account changes in environmental policy. Our modelling strategy incorporates environmental externalities, where we argue that environmental policy can be consistent with anti-trust policy, but also taxation in the cooperative equilibrium. The reasoning is that environmental policy may offer incentives to generate size of mergers consistent with the need to control pollution, but also consistent with the goal of anti-trust policy of increasing consumer surplus.

The findings of this study have important policy implications. Given anti-trust agencies' role in accepting (rejecting) welfare-increasing (-reducing) merger proposals, we propose simpler decision-rules to accurately reflect welfare changes. We derive a threshold merger size which anti-trust agencies may use as a reference point to make such decisions. And such a reference point may depend on environmental policies at home and in other countries, but also the pollution intensity of production. This element of analysis is important because it allows to analyze anti-trust and environmental policy in a unified and flexible framework.

Section 2 builds a general post-merger model, derives first order conditions and lays the foundation for the comparative statics exercise. Our framework is used to examine the effect of a change in the size of a merger on production and welfare. In Section 3 we perform a welfare analysis to study the overall effect of a change in the size of a merger on welfare. Section 4 concludes by discussing policy implications and addressing questions for future research.

2 The Model

2.1 General set-up

Consider two countries, namely, a home and foreign country represented by superscripts h and f, respectively. Suppose there are n (m) fixed number of firms operating in the home (foreign) country. In the post-merger equilibrium k^h (k^f) number of firms merge in the home (foreign) country such that $n - k^h$ ($m - k^f$) number of firms remain independent in the home (foreign) country. Salant et al. (1983) refers to the subset of firms that merge as "insiders" and those firms that continue to be independent post-merger are "outsiders".

Each firm j that merges ($j = 1, 2, \ldots, k^v$) in each country exhibits a cost function $c^{vj}(q^{vj}, e^{vj})$, where q^{vj} denotes output of each firm j in country $v = h, f$ and e^{vj} denotes emissions. Each outsider i ($i = k^v + 1, \ldots, l;\ l = n, m$) in each country exhibits costs $\tilde{c}^{vi}(\tilde{q}^{vi}, \tilde{e}^{vi})$, where $\tilde{q}^{vi}$ and $\tilde{e}^{vi}$ denote, respectively, output and emissions of each outsider firm i in country $v = h, f$. We shall follow Requate (2006) and assume that the cost function satisfies (dropping country and firm superscripts for notational simplicity) $c_e < 0$, $c_q > 0$, $c_{qq} > 0$, $c_{qe} = c_{eq} < 0$, $c_{ee} > 0$, $c_{qq}c_{ee} - c_{qe}c_{eq} \geq 0$, where subscripts denote partial derivatives.

Additionally, emission taxes are set by each country's government where the tax rate in the home (foreign) country is t^h (t^f).

Demand faced by each firm j and i in each country is given, respectively, by

$$p^{vj} = p^{vj}(q^{h1} + \ldots + q^{hk^h}, \tilde{q}^{hk^h+1} + \ldots + \tilde{q}^{hn}, q^{f1} + \ldots + q^{fk^f}, \tilde{q}^{fk^f+1} + \ldots + \tilde{q}^{fm}) \quad (1)$$

$$\tilde{p}^{vi} = \tilde{p}^{vi}(q^{h1} + \ldots + q^{hk^h}, \tilde{q}^{hk^h+1} + \ldots + \tilde{q}^{hn}, q^{f1} + \ldots + q^{fk^f}, \tilde{q}^{fk^f+1} + \ldots + \tilde{q}^{fm}) \quad (2)$$

where the first argument, $q^{h1} + \ldots + q^{hk^h}$, denotes output of the merged entity in the home country. The second argument, $\tilde{q}^{hk^h+1} + \ldots + \tilde{q}^{hn}$, represents output of outsiders in the home country. The third and fourth terms denote analogous levels of output for firms operating in the foreign country. Further properties of the demand functions are spelt out later on.

We define profit for the merged entity and each outsider firm as follows:

$$\sum_{j=1}^{k^h} \pi^{vj} = \sum_{j=1}^{k^h} [p^{vj} q^{vj} - c^{vj}(q^{vj}, e^{vj}) - t^v e^{vj}] \quad where \quad j = 1, \ldots, k^v \quad (3)$$

$$\tilde{\pi}^{vi} = \tilde{p}^{vi} \tilde{q}^{vi} - \tilde{c}^{vi}(\tilde{q}^{vi}, \tilde{e}^{vi}) - t^v \tilde{e}^{vi} \quad where \quad i = k^v + 1, \ldots, l; l = n, m \quad (4)$$

where insiders in the home country maximize joint profit, $\sum_{j=1}^{k^h} \pi^{hj} = \pi^{h1} + \ldots + \pi^{hk^h}$, by choosing the level of output, q^{hj}, and emissions, e^{hj}, simultaneously in a Cournot-Nash fashion. The sum of the number of outsiders and insiders is equal to the total number of firms in each country.

The post-merger equilibrium is solved using backward induction. First, the government in each country simultaneously chooses the level of the tax taking the other country's tax as given. Second, firms in each country take policy as given in their profit-maximization behavior. Insiders choose the level of output and emissions which maximize *joint* profits, while outsiders choose the level of output and emissions to maximize *each* firm's independent profits. Firms operating in the home and foreign country behave in a Cournot-Nash fashion. We shall assume interior solutions and a symmetric equilibrium within each set of firm in each country. In what follows we present the maximization problem and assumptions for firms operating in the home country. An analogous framework applies to firms in the foreign country.

The insiders' maximization problem yields $2k^h$ first-order conditions. That is,

$$\frac{\partial \sum_{j=1}^{k^h} \pi^{hj}}{\partial q^{h1}} = p^{h1} + q^{h1}\frac{\partial p^{h1}}{\partial q^{h1}} + q^{h2}\frac{\partial p^{h2}}{\partial q^{h1}} + \ldots + q^{hk^h}\frac{\partial p^{hk^h}}{\partial q^{h1}} - \frac{\partial c^{h1}}{\partial q^{h1}} = 0 \tag{5}$$

$$\frac{\partial \sum_{j=1}^{k^h} \pi^{hj}}{\partial e^{h1}} = -\frac{\partial c^{h1}(\cdot)}{\partial e^{h1}} - t^h = 0 \tag{6}$$

$$\vdots$$

$$\frac{\partial \sum_{j=1}^{k^h} \pi^{hj}}{\partial q^{hk^h}} = p^{hk^h} + q^{hk^h}\frac{\partial p^{hk^h}}{\partial q^{hk^h}} + q^{h1}\frac{\partial p^{h1}}{\partial q^{hk^h}} + \ldots + q^{hk^h-1}\frac{\partial p^{hk^h-1}}{\partial q^{hk^h}} - \frac{\partial c^{hk^h}}{\partial q^{hk^h}} = 0 \tag{7}$$

$$\frac{\partial \sum_{j=1}^{k^h} \pi^{hj}}{\partial e^{hk^h}} = -\frac{\partial c^{hk^h}(\cdot)}{\partial e^{hk^h}} - t^h = 0 \tag{8}$$

Assumption 2.1. *(i) $p_1^h \equiv \partial p^{hs}/\partial q^{hr} < 0 \quad \forall$ firms $s = r$; and (ii) $p_1^{h-} \equiv \partial p^{hs}/\partial q^{hr} < 0 \quad \forall$ firms $s \neq r$.*

Assumption 2.1(i) says that the own-effect in demand for all insiders is identical within the home country; and 2.1(ii) indicates that the cross-effect in demand, *across firms which merge*, is identical within the home country.

Assumption 2.2. *Within each country $p_1^h \equiv p_1^{h-}$ and $p_3^f \equiv p_3^{f-}$.*

Assumption 2.2 says that for insiders the effects on demand *within* each country is identical thus ruling out the possibility of product differentiation within countries. This assumption does not restrict cross-country effects on demand thus allowing for product differentiation across countries.

Thus, under Assumption 2.1 and 2.2, and under symmetry ($q^{h1} = \ldots = q^{k^h} = q^h$, $e^{h1} = \ldots = e^{hk^h} = e^h$) the first-order conditions for insiders in the home country reduce to

$$p^h + q^h k^h p_1^h - c_1^h = 0 \tag{9}$$

$$-c_2^h - t^h = 0 \tag{10}$$

where $p^{h1} = \ldots = p^{hk^h} = p^h$. The terms c_1^h, c_2^h denote, respectively, the partial derivative of $c^h(q^h, e^h)$ with respect to the first and second argument.

Each outsider firm, i, chooses the level of output, $\tilde{q}^{hi}$, and emissions, $\tilde{e}^{hi}$, simultaneously in a Cournot-Nash fashion. Under symmetry ($\tilde{q}^{hk^h+1} = \ldots = \tilde{q}^{hn} = \tilde{q}^h$, $\tilde{e}^{hk^h+1} = \ldots = \tilde{e}^{hn} = \tilde{e}^h$), we have the following first-order conditions:

$$\tilde{p}^h + \tilde{q}^h \tilde{p}_2^h - \tilde{c}_1^h = 0 \quad (11)$$

$$\tilde{c}_2^h - t^h = 0 \quad (12)$$

where $\tilde{p}^{hk^h+1} = \ldots = \tilde{p}^{hn} = \tilde{p}^h$, $\tilde{c}^{hk^h+1} = \ldots = \tilde{c}^{hn} = \tilde{c}^h$. The term $\tilde{p}_2^h$ denotes the partial derivative of $\tilde{p}^h$ with respect to the second argument of the demand function (i.e., own effect). $\tilde{c}_1^h$, $\tilde{c}_2^h$ represent the partial derivative of $\tilde{c}^h(\cdot)$ with respect to the first and second arguments, respectively.

An analogous set of equations for insiders and outsiders applies to the foreign country:

$$p^f + q^f k^f p_3^f - c_1^f = 0 \quad (13)$$

$$-c_2^f - t^f = 0 \quad (14)$$

$$\tilde{p}^f + \tilde{q}^f \tilde{p}_4^f - \tilde{c}_1^f = 0 \quad (15)$$

$$-\tilde{c}_2^f - t^f = 0 \quad (16)$$

The demand functions, (1)-(2), under symmetry are given by

$$p^v = p^v(k^h q^h, (n - k^h)\tilde{q}^h, k^f q^f, (m - k^f)\tilde{q}^f) \quad (17)$$

$$\tilde{p}^v = \tilde{p}^v(k^h q^h, (n - k^h)\tilde{q}^h, k^f q^f, (m - k^f)\tilde{q}^f) \quad (18)$$

for country $v = h, f$. Equations (9)-(16) implicitly determine the post-merger equilibrium vector q^h, $\tilde{q}^h$, q^f, $\tilde{q}^f$, e^h, $\tilde{e}^h$, e^f, $\tilde{e}^f$. Second-order conditions ensure stability and uniqueness of the equilibrium.

2.2 Comparative statics with linear demand

In this sub-section, we consider the case of linear demand where the effects within each country are identical but there is product differentiation across countries. In particular, the second-order derivative of the inverse demand function with respect to output is zero for all firms, and $p_1^h = p_2^h = \tilde{p}_2^h = \tilde{p}_1^h = -\beta$ and $p_3^h = p_4^h = \tilde{p}_3^h = \tilde{p}_4^h = -\gamma$ where $\gamma \in [0, \beta]$ denotes the degree of product differentiation. Similarly, $p_4^f = p_3^f = \tilde{p}_3^f = \tilde{p}_4^f = -\beta$ and $p_1^f = p_2^f = \tilde{p}_1^f = \tilde{p}_2^f = -\gamma$ apply for the foreign country. We consider symmetric cost functions *within* countries, i.e., $c^v(\cdot, \cdot) = \tilde{c}^v(\cdot, \cdot)$ for country $v = h, f$. The assumption of symmetry in pollution intensities and cost functions within countries (but not necessarily across countries) helps avoid concerns of efficiency gains and cost savings in influencing production decisions and welfare effects. This set-up captures the effect of the size of the merger (i.e., changes in k^h, k^f for given tax) both via the oligopolistic interdependence *across* countries (i.e., product differentiation) and *within* each country, while making connections with the literature. Modelling multi-firm mergers with no cost savings in an international context allows us to compare the implications of our result with the open-economy literature. This is because our model allows for the free flow of goods and services across the two countries.

We use equations (9)-(18) for the comparative statics analysis, which is presented in the Appendix. Results are consistent with the existing literature such as Farrell and Shapiro (1990) and Collie (2007). Consistent with the merger literature we also find that in equilibrium the output of each outsider is greater than the output level of each insider where $q^v < \tilde{q}^v$ for $v = h, f$. Further, we define the output gap between each insider and each outsider, $q^v - \tilde{q}^v$, as the output *'spread'*. It indicates how far apart each outsider's output is relative to the output of each insider.

Assumption 2.3. *The cost function is of the end-of-pipe type* $c^v(q^v, e^v) = c^v q^v + (\delta^v q^v - e^v)^2/2$.

To keep the analysis tractable and facilitate the analysis of second-order derivatives we assume an end-of-the-pipe cost function, where δ^v denotes a constant pollution intensity, and $c^v > 0$ marginal costs. This type of cost function is widely used in the literature (e.g., Lahiri and Symeonidis, 2007). In what follows the analysis relies on assumption 2.3.

An exogenous decrease in the emission tax in the home country increases the output spread in the home country, keeping the foreign tax fixed. This is because a decrease in the tax increases the output level of each insider and each outsider (by rendering each of these more cost competitive), where the extent of the increase in each outsider's output is greater than the extent of the increase in each insider's output. This exacerbates the output gap between the two types of firms; formally, $|q^h_{th}| < |\tilde{q}^h_{th}|$, where subscripts denote partial derivatives. By joining multiple firms together, the merged entity has the ability to reduce the sensitivity of its insider's output to a change in tax. This ability directly depends on the number of merging firms, k^h. Analogously, changes in the foreign tax reduce the spread since outsider's output is more sensitive to taxation i.e., $q^h_{tf} < \tilde{q}^h_{tf}$. Home output rises with foreign taxation because foreign firms become less cost competitive.

2.3 Production effects

Total output in the home country is given by the sum of output of insiders and outsiders, $Q^h = k^h q^h + (n - k^h)\tilde{q}^h$. The effect of a change in the size of the merger in that country is examined using $\partial Q^h / \partial k^h$:

$$\begin{aligned} dQ^h &= k^h dq^h + (n - k^h) d\tilde{q}^h + (q^h - \tilde{q}^h) dk^h \\ \Delta dQ^h &= \left[-k^h A \beta^2 q^h + (q^h - \tilde{q}^h)\left(-k^h \beta C(n+1) + k^{h2}\beta C + 1\right)\right] dk^h \end{aligned} \tag{19}$$

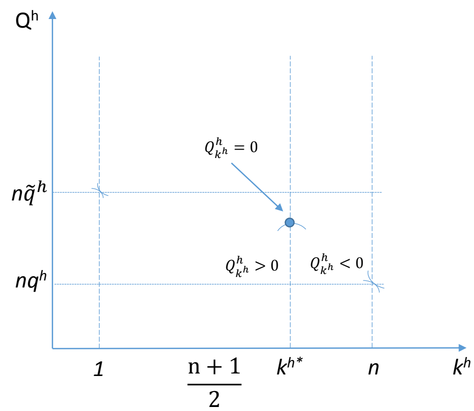
where $A > 0$, $C > 0$ are functions of k^v, β,γ, m, n as defined in the Appendix. $\Delta > 0$ denotes the determinant of the coefficient matrix in (A. 1). Due to the symmetric nature of the model an analogous expression applies to total output in the foreign country.

There are several opposing effects. First, an increase in k^h lowers total output, Q^h, via a reduction in q^h, because a larger merger implies lower output by each insider. But at the same time it increases total output of insiders via higher k^h (for given q^h). Second, total output increases via an increase in the output of each outsider, $\tilde{q}^h$, because the number of firms which remain outsiders falls. At the same time total output falls via the reduction in the number of outsiders, $n - k^h$. Thus, total output in the home country, Q^h, may fall or rise with an increase in the size of the merger. The direction and extent of the change depends on the size of the merger, k^h, and the spread. For example, with a large spread an increase in k^h could decrease Q^h because of the decrease in each insider's output; and if the spread is small (close to zero) an increase in k^h could increase Q^h because each outsider has sufficiently more output. Likewise, for a given spread, $\partial Q^h/\partial k^h$ is likely to be negative (positive) if k^h is very large (small).

We show there is at least a threshold size of merger, k^{h*}, such that (i) $\partial Q^h/\partial k^h = 0$, and (ii) $\partial^2 Q^h/\partial k^{h2} < 0$. This implies there is a certain range of size of merger for which total home output rises and falls with an increase in k^h. Figure 1 summarizes this result (see the appendix for a derivation of Figure 1).

In Figure 1 the lower bound for the size of the merger is one which indicates the no-merger equilibrium where all firms enjoy the same market power. The upper bound for the size of the merger indicates a multi-plant monopoly operating n plants. Figure 1 indicates that the threshold size of merger (k^{h*}) is greater than the midpoint. Thus, the analysis is relevant for big mergers consolidating over 50% of firms in the industry. Assuming Q^h is a continuous function of k^h, the implication is that for a range of size of merger $k_1^h < k^{h*}$ ($k^{h*} < k_2^h$), total home output rises (falls). The reason for this is that with a relatively larger (smaller) size of merger given by $k^{h*} < k^h < k_2^h$ ($k_1^h < k^h < k^{h*}$) reductions (increases) in output of each insider (outsider) induce a decrease (increase) in total output. We think of k^{h*} as size of merger consistent with stable total, industry output. The driver for this result is the oligopolistic interdependence, whereby changes in outsider and insiders' per-firm output

Figure 1: Threshold size of merger, k^{h*}



open the possibility for higher or lower industry output. When k^h is smaller than k^{h*}, there are several outsiders and the output increasing effect from outsiders dominates the reduction in output of each insider, leading to an increase in overall output. When k^h is larger than k^{h*}, there are only fewer outsiders and the output increasing effect from outsiders will be dominated by each insider's reduction in output, leading to a reduction in overall output.

Proposition 2.4. *There is at least a size of merger, $(n+1)/2 < k^{h*} < n$, which satisfies $\partial Q^h/\partial k^h = 0$, $\partial^2 Q^h/\partial k^{h2} < 0$. Thus, $\partial Q^h/\partial k^h > 0$ for $k_1^h < k^h < k^{h*}$ and $\partial Q^h/\partial k^h < 0$ for $k^{h*} < k^h < k_2^h$.*

Proof. See appendix. □

We now outline the connection between emission tax and the threshold size of merger (k^{h*}) derived in Figure 1, thus making the analysis of environmental policy relevant to mergers.

Since a change in the tax alters the gap between q^h and $\tilde{q}^h$ (i.e., the spread), it also affects $\partial Q^h/\partial k^h$ and hence the derivation of k^{h*}. Specifically, a tax reduction (for given t^f, k^f) raises each outsider and insider's output. But because the former is more sensitive to taxation the gap between the two rises, giving a new larger level k^{h*}. This is because the size of the spread is directly related to the size of the merger, since the latter captures the degree of market power of the merged firm. Given the range of k^h between k_1^h and k_2^h, a larger k^{h*} means the range for which $\partial Q^h/\partial k^h > 0$ is larger. Analogously, a tax increase lowers q^h and $\tilde{q}^h$, but because the latter falls relatively more the gap between the two becomes smaller. A smaller k^{h*} implies $\partial Q^h/\partial k^h < 0$ for most of the range of k^h within k_1^h and k_2^h. A reduction in tax in the home country encourages local production, and the range at which total output declines with an increase in merger size is lowered. On the other hand, a rise in the home tax discourages local production, and the range at which total output declines with an increase in merger size is larger.

Lemma 2.5. *An increase (decrease) in the home tax renders the threshold size of merger, k^{h*}, smaller (larger) i.e., $dk^{h*}/dt^h < 0$.*

Proof. See appendix. □

The change in Q^h resulting from an increase in the size of the merger in the foreign country, k^f, is positive because of the oligopolistic interdependence across countries, where q^h and $\tilde{q}^h$ are positively related to k^f. That is, an increase in k^f lowers per-firm output (both insider and outsider's in that country) and, therefore, home insider and outsider's firms react strategically by raising output. In particular,

$$\Delta dQ^h \quad = \quad \gamma\beta^2 k^f \beta k^h \tilde{q}^f \left(1 + n - k^f\right) dk^f \tag{20}$$

Due to the symmetric nature of the model an analogous result applies to the foreign country (i.e., $\partial Q^f/\partial k^h > 0$).

Lemma 2.6. *An increase in the size of the merger in one country raises total output in the other country.*

We conclude this section by noting the effect of k^v on global emissions. A change in k^v affects emissions only via changes in output. Thus, any changes in global emissions, due to changes in k^v, depend exclusively on asymmetries in pollution intensities across countries and changes in output within and across countries (Lahiri and Symeonidis, 2007; Gautier, 2013, 2014, 2017).

3 Welfare Effects

3.1 The welfare function

This section examines the welfare effects of changing the size of a merger for a given tax. Welfare in each country is defined as the sum of consumer surplus, profits of local firms (insiders and outsiders), tax revenue and damages from global pollution. Except for Fikru and Gautier (2016, 2017) damages from pollution is a previously unexplored aspect in the merger literature, and a factor seldom considered by anti-trust agencies. As damages from pollution become increasingly important, we argue that the presence of damages may reverse recommendations as to whether reject or accept a merger proposal. In the home country we have,

$$\begin{aligned} W^h &= CS + k^h\pi^h + (n-k^h)\tilde{\pi}^h + t^h e^h k^h + t^h(n-k^h)\tilde{e}^h - \varphi^h \\ &= CS + k^h(p^h q^h - c^h) + (n-k^h)(\tilde{p}^h\tilde{q}^h - \tilde{c}) - \varphi^h \end{aligned} \tag{21}$$

where $CS = CS(k^h q^h, (n-k^h)\tilde{q}^h, k^f q^f, (m-k^f)\tilde{q}^f)$, $\varphi^h = \varphi^h(E)$ where $E = E^h + E^f$, and $E^h = e^h k^h + \tilde{e}^h(n-k^h)$, $E^f = e^f k^f + \tilde{e}^f(m-k^f)$. The damage function φ^h is assumed to be increasing and strictly convex in emissions. Emissions from each country affect the home country equally: marginal damages arising from changes in total (transboundary) emissions from the foreign country is equal to marginal damages arising from total emissions from the home country. We examine the effects of k^h and k^f on welfare in the home country by first differentiating (21) with respect to k^h keeping tax and k^f fixed. Although a change in k^h changes optimal taxes t^h and t^f (envelope theorem), we assume this effect to be negligible. In other words, our analysis in this section can be thought of as a case where governments do not adjust environmental policy as a result of changes in k^h. In particular,

$$\frac{\partial W^h}{\partial k^h} = Q^f\left(\gamma\frac{\partial Q^h}{\partial k^h} + \beta\frac{\partial Q^f}{\partial k^h}\right) + L(k^h) + (t^h - \varphi^{h'})\frac{\partial E^h}{\partial k^h} - \varphi^{h'}\frac{\partial E^f}{\partial k^h} + \pi^h - \tilde{\pi}^h \quad (22)$$

where $\partial Q^f/\partial k^h > 0$ and $\partial E^f/\partial k^h > 0$ from lemma 2.6. In the Appendix we show that the non-cooperative tax satisfies $t^h - \varphi^{h'} < 0$. The Appendix also defines the expression $L(k^h)$. The expression in (22) is generally consistent with Collie (2007) if we allow for $q^h = \tilde{q}^h$ and $\beta = \gamma$.

There are five broad effects. The first term in (22) denotes consumer surplus effects, the sign of which depends on the size of the merger. The second term, $L(k^h)$, captures profit effects. That is, the extent to which profits of insiders and outsiders change as a result of a change in k^h depends on the size of the merger (i.e., whether k^h is higher or lower than k^{h*}). The third term captures changes in welfare via damages from local pollution. The fourth term damages from transboundary pollution. The last term, $\pi^h - \tilde{\pi}^h$, captures the change in welfare for a given level of firm-level profit. We find $\pi^h - \tilde{\pi}^h > 0$ and consistent with the range $k^h > (n+1)/2$.[1]

In the remainder of this section we examine the previously unexplored role of pollution intensities and size of merger in the extent to which a merger should be rejected or accepted by a regulatory agency. In open economies, it is generally believed that the effect of a domestic merger on welfare depends on merger induced cost savings and whether the response from foreign competition offsets output restrictions. For example, Chaudhuri and Benchekroun (2012) find that with free trade a domestic merger with low (high) cost savings

[1] $\pi^h/\tilde{\pi}^h > 1 > (n+1)/k^h - 1$. The second inequality arises from $k^h > (n+1)/2$ *if and only if* $1 > (n+1)/k^h - 1$. The first inequality arises from $\pi^h - \tilde{\pi}^h > 0$ *if and only if* $\pi^h/\tilde{\pi}^h > 1$.

will reduce (enhance) welfare. The driving force behind their result is that with no cost savings a merger induces a larger reduction in production which reduces consumer surplus (even if the free trade offsets some of these reductions it will not be enough to completely offset loss in welfare). Our model allows us to show that the effect of a domestic merger on welfare (in an open economy) depends on the size of the merger and the pollution intensity of firms.

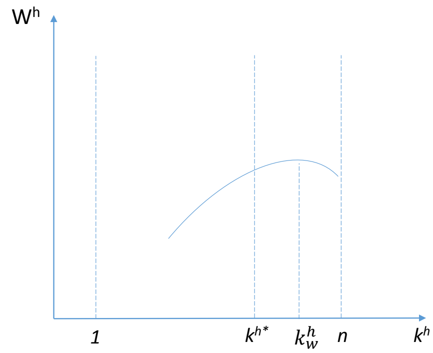
The analysis considers mergers which consolidate over 50% of the firms in the market and the role of the regulatory agency is to examine the impact of proposed mergers on welfare. We proceed for sufficiently "large" or "small" k^h relative to the threshold level k^{h*} defined in Proposition 2.4.

Definition 3.1. *A relatively small size of merger at home,* k^h*, satisfies* $\partial Q^h/\partial k^h > 0$ *for* $k_1^h < k^h < k^{h*}$*. A relatively large size of merger at home satisfies* $\partial Q^h/\partial k^h < 0$ *for* $k^{h*} < k^h < k_2^h$*.*

3.2 Welfare effects with small pollution intensity

As a benchmark, consider the case where damages from pollution are small (i.e., small pollution intensities for the home and foreign country, δ^h and δ^f, respectively) and the government puts a relatively large weight on consumer surplus effects. We regard this case as a benchmark because currently anti-trust agencies put a very small weight on damages from pollution in their decision-making process. Figure 2 illustrates our benchmark case (see appendix for a derivation of Figure 2), where k_w^h denotes the level of size of the merger at home which maximizes welfare in that country. For instance, with k^h initially small (i.e., $k_1^h < k^h < k^{h*}$) an increase in k^h raises welfare. This is because an increase in k^h raises consumer surplus via the increase in home and foreign output, but also raises profits even as each insider's output falls and each outsider's output rises (see appendix for analysis on change in profits, $L(k^h)$). Overall, welfare rises if damages from local and transboundary emissions are

Figure 2: Home welfare and size of merger in the home country



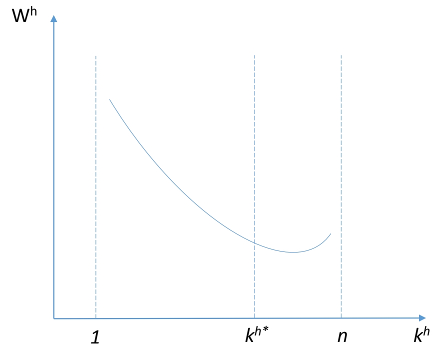
small. In sharp contrast to the view that multi-firm mergers cause welfare losses, our results suggest that an increase in the size of mergers may be welfare-enhancing. This welfare-enhancing effect occurs even when such mergers do not cause operational efficiency gains. Furthermore, we find that the welfare maximizing level k_w^h is higher than the 50% benchmark suggested by Levin (1990) and subsequent studies.

3.3 Welfare effects with large pollution intensity

To argue that damages from pollution play a role, consider the case where pollution intensities are large (Figure 3). In this case an increase in k^h may reduce welfare because an increase in the size of the merger generates sufficient damages from pollution, where damages from local and transboundary pollution take place for $k_1^h < k^h < k^{h*}$. This finding implies that when pollution is relevant, mergers made up of fewer and fewer firms are likely to be accepted as they enhance welfare. Hence, anti-trust agencies ought to consider the pollution intensity of an industry where big horizontal mergers are being proposed.

Proposition 3.2. *Assume the home tax is given. (i) Consider a range of k^h such that*

Figure 3: Home welfare and size of merger in the home country



$k^h < k^h_w$. An increase in k^h raises home welfare if damages from pollution are small. (ii) Consider a range of k^h such that $k^h < k^h_w$. A decrease in k^h raises home welfare if damages from pollution are large.

Proof. See appendix. □

The way anti-trust agencies view proposals for big horizontal mergers ought to consider the industry's pollution intensity. If the industry has low (high) pollution-intensity (a) a merger made up of k^h firms where $k^h < k^h_w$ should be accepted (rejected) if it proposes to buy out (or merge with) additional firms, and (b) a merger which combines over (fewer than) k^h_w number of firms and proposes to add more insiders should be rejected.

Generally speaking a domestic merger in an open economy is believed to raise fewer anti-competitive concerns and less likely to be rejected by the anti-trust agency (Gaudet and Kanouni, 2004). Our findings suggests there is a role for the anti-trust agency in open economies. On one hand with small pollution intensities, Figure 2 implies that a domestic merger made up of over k^h_w firm reduces welfare and thus should not be allowed to proceed.

On the other hand with larger pollution intensities, Figure 3 implies that a domestic merger made up of over k_w^h firms raises welfare and such mergers are environmentally-friendly as they reduce production related pollution.

3.4 Emission tax and anti-trust decisions

We argue that in markets with big mergers, environmental policy may serve a purpose for the anti-trust agency. We do this by showing that changes in the emission tax can adjust the threshold size of the merger, k^{h*}, in Figures 2 and 3, closer to the welfare-maximizing size of the merger, k_w^h. The driver here is that changes in the tax affect the output spread and thus k^{h*}. We consider policy changes by the government consistent with addressing the inefficiencies associated with the non-cooperative equilibrium e.g., Hatzipanayotou, et al. (2005), Kayalica and Lahiri (2005), Gautier (2019).

Consider $Q_{k^h}^h(k^{h*}, k^f, t^h, t^f) = 0$ and $Q_{k^f}^f(k^h, k^{f*}, t^h, t^f) = 0$ which characterize k^{h*} and k^{f*}, respectively. Differentiation yields changes in k^{h*} with respect to the home and foreign tax (analogous expression is obtained for k^{f*}):

$$\psi dk^{h*} = \left[\left(-\frac{t^h}{q^h}q_{t^h}^h + \frac{t^h}{\tilde{q}^h}\tilde{q}_{t^h}^h\right)\right]\frac{dt^h}{t^h} + \left[\left(-\frac{t^f}{q^h}q_{t^f}^h + \frac{t^f}{\tilde{q}^h}\tilde{q}_{t^f}^h\right)\right]\frac{dt^f}{t^f} \tag{23}$$

where $\psi > 0$. We assume that changes in the threshold size of mergers across countries do not affect each other (i.e., $dk^{h*}/dk^{f*} = 0$), and changes in taxation are independent from each other (i.e., $dt^h/dt^f = 0$). The first assumption implies that how big a size of merger is in one country is not going to affect the size of merger in the other country; the assumption on taxation is consistent with Cournot-Nash behavior of governments when setting policy.

Consider the reference case where pollution intensities are small (Figure 2). Starting at k^{h*}, equation (23) indicates that lower taxation at home (i.e., $dt^h < 0$, $dt^f = 0$) increases k^{h*} to be closer to the welfare-maximizing merger size (see Lemma 2.5). A decline in emission tax at home makes k^{h*} a relevant tool for the anti-trust agency. Anti-trust agencies could use k^{h*} as a policy tool to accept or reject big merger proposals. So, in industries with lower pollution intensity, anti-trust agencies may prefer a laxer local environmental policy because it is consistent with the welfare-maximizing size of merger.

Analogously, a reduction only in the foreign tax (i.e., $dt^h = 0$, $dt^f < 0$) lowers k^{h*} because lower foreign taxation closes the output spread at home. In this case however k^{h*} moves away from the welfare-maximizing level. The implication is that, a stricter foreign policy may be viewed favorably by the anti-trust agency at home, when using k^{h*} as a tool to guide decisions on accepting or rejecting local mergers.

A policy reform in both countries where $dt^h/t^h = dt^f/t^f < 0$ moves k^{h*} closer to k^h_w, if the elasticity of home output with respect to home taxation is sufficiently large. That is, *if and only if*

$$\left|\left(-\frac{t^f}{q^h}q^h_{t^f} + \frac{t^f}{\tilde{q}^h}\tilde{q}^h_{t^f}\right)\right| < \left|\left(-\frac{t^h}{q^h}q^h_{t^h} + \frac{t^h}{\tilde{q}^h}\tilde{q}^h_{t^h}\right)\right| \tag{24}$$

Similarly, in the case where pollution intensities are large we use Figure 3 to establish that stricter (laxer) environmental policy at home (in the foreign country) decreases k^{h*} and this leads to a threshold size of merger consistent with higher welfare. Analogously, stricter foreign environmental policy increases k^{h*} and this leads to lower welfare at home. Starting at k^{h*}, a policy reform $dt^h/t^h = dt^f/t^f > 0$ is consistent with a higher welfare at home if the effects from an increase in the home tax on home output are sufficiently large. i.e., inequality in (24) holds.

The implication is that if anti-trust agencies use k^{h*} as a tool to accept or reject merger proposals in pollution-intensive industries, this tool correctly reflects welfare changes when home country adopts stricter and foreign country adopts laxer environmental policy. This is relevant as new international environmental agreements are developed and countries undertake environmental policy reforms.

Proposition 3.3. *Policy reform of emission taxes can be consistent with anti-trust policy.*

4 Discussion and concluding remarks

The analysis suggests that there is room for improving current horizontal merger policies so as to prevent the approval (rejection) of welfare reducing (enhancing) merger proposals. Anti-trust agencies outline the basic analytical technique used to evaluate horizontal mergers in the US (US Department of Justice and the Federal Trade Commission, 2010). Mergers that are suspected to enhance market power (by eliminating competition among insiders and/or causing a change in how outsiders behave) are challenged by the agencies because they often raise price and reduce production. Basically the agencies currently look for evidence for the impact of the merger on consumer surplus. We recommend that anti-trust agencies use a broad range of information (e.g., the reaction of foreign firms and pollution intensity) to evaluate the welfare impact of mergers. Figures 2 and 3 offer examples of rubrics regulators may consult when they examine merger proposals.

Farrell and Shapiro (1990), Levin (1990) and subsequent studies argue that the agencies should look at the number of merging firms and their market share and use the 50% benchmark. If this is always the case, then over 50% of firms in a given market are less likely to propose to consolidate either simultaneously or one after the other since this would be rejected by the agencies. Our findings suggest that merge proposals that fall outside the 50% benchmark may or may not enhance welfare.

The findings of this paper also provide insight for corporate managers. If $k_1^h < k^h < k^{h*}$ and if pollution intensities are small, then merger participants may consider acquiring/merging with even more prospective firms up to the point where $k^h = k^{h*}$ in order to get a better chance of getting their merger proposal accepted since it may not cause adverse competitive concerns (Figure 3). This is because, with small pollution intensity, for this range of merger size, increasing the number of insiders would lead to higher total production at home.

The policy reforms examined in section 3.4 are not only consistent with anti-trust policy, but also consistent with addressing the inefficiencies of the non-cooperative tax. An established result in the literature is that under sufficiently large damages from pollution, the cooperative emission tax in the home country is greater than its non-cooperative counterpart. In other words, starting at the Nash equilibrium global welfare rises if home sets a higher tax. This is because the cooperative home tax accounts for the damages from pollution the home country has on the foreign country. Similarly, with small damages from pollution global welfare can rise if starting at the Nash equilibrium home sets a smaller tax to address inefficiencies associated with consumer surplus and output distortion effects.

Addressing the impact of mergers involving polluting firms in an open economy has important policy implications especially when it comes to international and bi-lateral climate change negotiations. Our study suggests that a merger that takes place in one country has important policy and pollution effects in other countries. We show that as the size of a merger in one country increases, this could increase emissions in other countries by increasing their incentive to produce more. This in turn, may induce the affected country to set a stricter policy.

Moreover, our framework presents a general post-merger market in the following manner: while concurring with the existing literature in terms of showing that a plant owned by the merged entity is more likely to produce less than its outsider counterpart (e.g. Salant et al., 1983) it allows for this gap to be either larger or smaller. Existing studies establish results for a given gap or spread. Finally, our findings suggest that the effect of mergers on welfare depends on the initial size of the merger. This framework could be an important tool for merger policy making. Information on the 'optimal' size of mergers may help policy makers to devise tools that consider recent merger activities before accepting/rejecting merger proposals.

The analysis presented in this paper is not without limitations. Inevitably, the analysis relies on a set of assumptions which curtails the generality of results, but on the other hand it facilitates the analysis of second-order derivatives. This clearly points to an extension of the paper, particularly as it pertains to the derivation of threshold size of mergers. And key in this extension is the characterization of the cost function and elasticity of per-firm output with respect to the size of the merger. It is noteworthy however that, consistent with the literature, the comparative statics analysis on output and emissions, as well as the characterization of the optimal tax, holds under general demand and cost functions.

The current framework can be modified and extended to answer related questions like: what is the optimal size of the merger from the viewpoint of merging firms? For instance, merger participants can potentially include more target firms or exclude prospective ones depending on what is happening to their profit and how they interact with others in the post-merger market. Another question that could be addressed is: if pollution intensities are allowed to be different across firms within and across countries, what pool of firms would the most profitable merger include? This and related questions are important for companies contemplating to merge with several others with different pollution intensities.

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Appendix

Comparative statics

Differentiation of (9) - (16), along with (17) and (18), yields the following system:

$$A\vec{x} = \vec{y} \tag{A. 1}$$

where A is a 8x8 matrix, and $\vec{x}$, $\vec{y}$ are column vectors. In particular,

$$\vec{x} = \begin{bmatrix} dq^h \\ d\tilde{q}^h \\ dq^f \\ d\tilde{q}^f \\ de^h \\ d\tilde{e}^h \\ de^f \\ d\tilde{e}^f \end{bmatrix} \qquad \vec{y} = \begin{bmatrix} \left[-q^h(2p_1^h + k^h q^h p_{11}^h) + \tilde{q}^h(p_2^h + k^h q^h p_{12}^h)\right] dk^h + \left[-q^f(p_3^h + k^h q^h p_{13}^h) + \tilde{q}^f(p_4^h + k^h q^h p_{14}^h)\right] dk^f \\ dt^h \\ \left[-q^h(\tilde{p}_1^h + \tilde{q}^h \tilde{p}_{21}^h) + \tilde{q}^h(\tilde{p}_2^h + \tilde{q}^h \tilde{p}_{22}^h)\right] dk^h + \left[-q^f(\tilde{p}_3^h + \tilde{q}^h \tilde{p}_{23}^h) + \tilde{q}^f(\tilde{p}_4^h + \tilde{q}^h \tilde{p}_{24}^h)\right] dk^f \\ dt^h \\ \left[-q^h(p_1^f + k^f q^f p_{31}^f) + \tilde{q}^h(p_2^f + k^f q^f p_{32}^f)\right] dk^h + \left[-q^f(2p_3^f + k^f q^f p_{33}^f) + \tilde{q}^f(p_4^f + k^f q^f p_{34}^f)\right] dk^f \\ dt^f \\ \left[-q^h(\tilde{p}_1^f + \tilde{q}^f \tilde{p}_{41}^f) + \tilde{q}^h(\tilde{p}_2^f + \tilde{q}^f \tilde{p}_{42}^f)\right] dk^h + \left[-q^f(\tilde{p}_3^f + \tilde{q}^f \tilde{p}_{43}^f) + \tilde{q}^f(\tilde{p}_4^f + \tilde{q}^f \tilde{p}_{44}^f)\right] dk^f \\ dt^f \end{bmatrix}$$

And matrix A is given by

$$\begin{bmatrix} k^h(2p_1^h + k^h q^h p_{11}^h) - c_{11}^h & (n-k^h)(p_2^h + k^h q^h p_{12}^h) & k^f(p_3^h + k^h q^h p_{13}^h) & (m-k^f)(p_4^h + k^h q^h p_{14}^h) & -c_{12}^h & 0 & 0 & 0 \\ -c_{21}^h & 0 & 0 & 0 & -c_{22}^h & 0 & 0 & 0 \\ k^h(\tilde{p}_1^h + \tilde{q}^h \tilde{p}_{21}^h) & (n-k^h)(\tilde{p}_2^h + \tilde{q}^h \tilde{p}_{22}^h) + \tilde{p}_2^h - \tilde{c}_{11}^h & k^f(\tilde{p}_3^h + \tilde{q}^h \tilde{p}_{23}^h) & (m-k^f)(\tilde{p}_4^h + \tilde{q}^h \tilde{p}_{24}^h) & 0 & -\tilde{c}_{12}^h & 0 & 0 \\ 0 & -\tilde{c}_{21}^h & 0 & 0 & 0 & -\tilde{c}_{22}^h & 0 & 0 \\ k^h(p_1^f + q^f p_{31}^f) & (n-k^h)(p_2^f + q^f p_{32}^f) & k^f(2p_3^f + k^f q^f p_{33}^f) - c_{11}^f & (m-k^f)(p_4^f + q^f p_{34}^f) & 0 & 0 & -c_{12}^f & 0 \\ 0 & 0 & -c_{21}^f & 0 & 0 & 0 & -c_{22}^f & 0 \\ k^h(\tilde{p}_1^f + \tilde{q}^f \tilde{p}_{41}^f) & (n-k^h)(\tilde{p}_2^f + \tilde{q}^f \tilde{p}_{42}^f) & k^f(\tilde{p}_3^f + \tilde{q}^f \tilde{p}_{43}^f) & (m-k^f)(\tilde{p}_4^f + \tilde{q}^f \tilde{p}_{44}^f) + \tilde{p}_4^f - \tilde{c}_{11}^f & 0 & 0 & 0 & -\tilde{c}_{12}^f \\ 0 & 0 & 0 & -\tilde{c}_{21}^f & 0 & 0 & 0 & -\tilde{c}_{22}^f \end{bmatrix}$$

where p_g^v represents the partial derivative of the demand function in country $v = h, f$ with respect to argument $g = 1, 2, 3, 4$, and similarly for the cost function c_x^v denotes the partial derivative with respect to argument $x = 1, 2$.

Using the system in (A. 1) we examine the change in output of merged firms, q^v, and outsiders, $\tilde{q}^v$, for $v = h, f$ resulting from a change in the tax t^h, t^f. In particular,

$$\begin{aligned}\Delta \frac{dq^h}{c_{22}^{h2} c_{22}^{f2}} &= \frac{c_{12}^h}{c_{22}^h} \left(\eta^h + \beta\right) \left[\left(\eta^f + \beta(1 + k^f + m)\right) \eta^f + \beta^2 k^f (m + 2 - k^f)\right] dt^h \\ &\quad -\gamma \frac{c_{12}^f}{c_{22}^f} \left(\eta^h + \beta\right) [m\eta^f + \beta k^f (m + 1 - k^f)] dt^f\end{aligned}$$

$$\begin{aligned}\Delta \frac{d\tilde{q}^h}{c_{22}^{h2} c_{22}^{f2}} &= \frac{c_{12}^h}{c_{22}^h} \left(\eta^h + \beta k^h\right) \left[\left(\eta^f + \beta(1 + k^f + m)\right) \eta^f + \beta^2 k^f (m + 2 - k^f)\right] dt^h \\ &\quad -\gamma \frac{c_{12}^f}{c_{22}^f} \left(\eta^h + \beta k^h\right) [m\eta^f + \beta k^f (m + 1 - k^f)] dt^f\end{aligned}$$

where $\Delta > 0$ denotes the determinant of the coefficient matrix, and $\eta^v = (c_{11}^v c_{22}^v - c_{12}^{v2})/c_{22}^v > 0$, $v = h, f$, due the concavity of the cost function. $\eta^v = 0$, if the cost function is of the end-of-pipe. Intuitively, an increase in the tax in one country raises marginal cost thereby lowering output in that country (both merged and outsider firms). Furthermore, an increase in the tax in one country renders firms in the other country relatively more cost competitive thereby raising output in that country (both merged and outsider firms).

Next, we define the following terms in (19):

$$\mu^h = k^h \left(\frac{c_{11}^h c_{22}^h - c_{12}^{h2}}{c_{22}^h} + \beta \right) + (n - k^h) \left(\frac{c_{11}^h c_{22}^h - c_{12}^{h2}}{c_{22}^h} + \beta k^h \right) > 0 \tag{A.2}$$

$$A = \frac{(c_{11}^f c_{22}^f - c_{12}^{f2})^2}{c_{22}^{f2}} + \frac{(c_{11}^f c_{22}^f - c_{12}^{f2})}{c_{22}^f} (1 + k^f + m)\beta + \beta^2 k^f (2 + m - k^f) > 0 \tag{A.3}$$

$$B = m \frac{(c_{11}^f c_{22}^f - c_{12}^{f2})}{c_{22}^f} + \beta k^f (1 + m - k^f) > 0 \tag{A.4}$$

$$\begin{aligned}C &= \beta \frac{(c_{11}^f c_{22}^f - c_{12}^{f2})^2}{c_{22}^{f2}} + \frac{(c_{11}^f c_{22}^f - c_{12}^{f2})}{c_{22}^f} \left((1 + k^f + m)\beta^2 - \gamma^2 m\right) \\ &\quad + \beta k^f \left(\beta^2 (2 + m - k^f) - \gamma^2 (1 + m - k^f)\right) > 0\end{aligned} \tag{A.5}$$

Proof to Proposition 2.4

We derive the points illustrated in figure 1. Consider the definition of $Q^h = q^h k^h + (n - k^h)\tilde{q}^h$. Assume an end-of-pipe cost function. Hence, $\Delta \partial Q^h/\partial k^h = k^h[-\beta^2 q^h A - (q^h - \tilde{q}^h)\beta C(n+1)] + k^{h2}(q^h - \tilde{q}^h)\beta C + q^h - \tilde{q}^h$. First, at $k^h = 1$ no merger takes place (all firms compete as individual firms) so $q^h = \tilde{q}^h$, and consequently $Q^h(1) = n\tilde{q}^h$. Also, at $k^h = 1$, $\partial Q^h/\partial k^h = -\beta^2 q^h A < 0$ since $q^h = \tilde{q}^h$. Second, at $k^h = n$ all firms merge and maximize joint profits thereby restricting total output; therefore, $Q^h(1) = n\tilde{q}^h > nq^h = Q^h(n)$. Also, at $k^h = n$, $\tilde{q}^h = 0$ (no outsider output) and so $\Delta \partial Q^h/\partial k^h = k^h[-\beta^2 q^h A - q^h \beta C(n+1)] + k^{h2} q^h \beta C + q^h$ $= q^h(-k^h\beta^2 A - k^h \beta C(n+1) + k^{h2}\beta C + 1) = q^h(-n\beta^2 A - n\beta C(n+1) + n^2\beta C + 1) < 0$. Third, to derive $k^{h*} > (n+1)/2$ we impose the condition $\partial Q^h/\partial k^h = 0$ on the second order derivative $\partial^2 Q^h/\partial k^{h2}$. In particular, consider a point $k^h = (n+1)/\epsilon$, where $\epsilon > 1$. Then, at $\partial Q^h/\partial k^h = 0$, $\partial^2 Q^h/\partial k^{h2} < 0$ (we assume strictly concave function in k^h to obtain a threshold level such that total output rises/falls before/after threshold) yields

$$\begin{aligned} \partial^2 Q^h/\partial k^{h2} &< 0 \\ k^h[\beta^2 A(q^h \tilde{q}^h_{k^h} - \tilde{q}^h q^h_{k^h}) - 2\beta C(q^h - \tilde{q}^h)^2)] &< -(q^h - \tilde{q}^h)[\beta^2 A q^h + \beta C(n+1)(q^h - \tilde{q}^h)] \end{aligned}$$

where $[\beta^2 A(q^h \tilde{q}^h_{k^h} - \tilde{q}^h q^h_{k^h}) - 2\beta C(q^h - \tilde{q}^h)^2] < 0$ since $k^h > 0$ and, from $\partial Q^h/\partial k^h = 0$, the expression $[\beta^2 A q^h + \beta C(n+1)(q^h - \tilde{q}^h)] < 0$. And where $(q^h \tilde{q}^h_{k^h} - \tilde{q}^h q^h_{k^h}) > 0$. Then, simplification yields,

$$\begin{aligned} \left(\frac{n+1}{\epsilon}\right)[\beta^2 A(q^h \tilde{q}^h_{k^h} - \tilde{q}^h q^h_{k^h}) - 2\beta C(q^h - \tilde{q}^h)^2)] &< -(q^h - \tilde{q}^h)[\beta^2 A q^h + \beta C(n+1)(q^h - \tilde{q}^h)^2] \\ \frac{(n+1)[\beta^2 A(q^h \tilde{q}^h_{k^h} - \tilde{q}^h q^h_{k^h}) - 2\beta C(q^h - \tilde{q}^h)^2)]}{-(q^h - \tilde{q}^h)[\beta^2 A q^h + \beta C(n+1)(q^h - \tilde{q}^h)]} &> \epsilon \\ \frac{-(n+1)[\beta^2 A(q^h \tilde{q}^h_{k^h} - \tilde{q}^h q^h_{k^h}) - 2\beta C(q^h - \tilde{q}^h)^2)]}{(q^h - \tilde{q}^h)[\beta^2 A q^h + \beta C(n+1)(q^h - \tilde{q}^h)]} &> \epsilon \end{aligned}$$

Hence,

$$\frac{2(n+1)\beta C(q^h - \tilde{q}^h)^2}{(q^h - \tilde{q}^h)[\beta^2 A q^h + \beta C(n+1)(q^h - \tilde{q}^h)]} > \frac{-(n+1)[\beta^2 A(q^h \tilde{q}^h_{k^h} - \tilde{q}^h q^h_{k^h}) - 2\beta C(q^h - \tilde{q}^h)^2)]}{(q^h - \tilde{q}^h)[\beta^2 A q^h + \beta C(n+1)(q^h - \tilde{q}^h)]} > \epsilon$$

Therefore,

$$\frac{2}{\frac{(q^h-\tilde{q}^h)\beta^2 Aq^h}{\beta C(n+1)(q^h-\tilde{q}^h)^2}+1} > \epsilon \Rightarrow \epsilon < 2 \Rightarrow \frac{n+1}{\epsilon} = k^h \Rightarrow n+1 < \epsilon k^h < 2k^h \Rightarrow (n+1)/2 < k^h$$

where $-1 < [(q^h - \tilde{q}^h)\beta^2 Aq^h]/[\beta C(n+1)(q^h - \tilde{q}^h)^2] < 0$.

Derivation of Figures 2 and 3

We do this in two steps. First, we argue the conditions under which the function $W^h(k^h)$ is strictly convex or concave. Second, we evaluate the function (22) at k^{h*} in the cases where damages are large or small. We proceed under (i) the assumption of a unique $k^h > 0$ such that $W^h(k^h)$ is maximized or minimized, and (ii) a cost function of the end-of-pipe.

Then, at $k^h = 0$, (22) becomes, under assumption (ii), $\partial W^h/\partial k^h = [Q^f\gamma(q^h - \tilde{q}^h) + (t^h - \varphi^{h'})\delta^h(q^h - \tilde{q}^h)] - \tilde{\pi}^h > (<)0$, where the first and second terms are, respectively, negative and positive (note that at $k^h = 0$ no mergers take place so $\pi^h = 0$). Thus,the function $W^h(k^h)$ is strictly convex (concave) if damages from pollution are sufficiently large (small) i.e., the term δ^h is large (small). Then, at k^{h*}, where $\partial Q^h/\partial k^h = 0$, (22) becomes $\partial W^h/\partial k^h$ positive or negative. If the term δ^h is small, then the function $W^h(k^h)$ is strictly concave; and at k^{h*}, $\partial W^h/\partial k^h > (<)0$, if consumer surplus and profit effects are large (small) i.e., figure 2 illustrates the case where consumer surplus and profit effects are large. If the term δ^h is large, then the function $W^h(k^h)$ is strictly convex; and at k^{h*}, $\partial W^h/\partial k^h > (<)0$, if consumer surplus and profit effects are large (small) i.e., Figure 3 illustrates the case where consumer surplus and profit effects are small.

Proof of Lemma 2.5

Consider $Q^h_{k^h}(k^{h*}, t^h) = 0$, where subscripts denote partial derivative. Assume an end-of-pipe cost function. Dropping the "*" superscript differentiation gives $Q^h_{k^h k^h}dk^h + Q^h_{k^h t^h}dt^h = 0$, and hence $dk^h/dt^h = -Q^h_{k^h t^h}/Q^h_{k^h k^h}$. By proposition 2.4 $Q^h_{k^h k^h} < 0$. Then, consider

$$Q^h_{k^h} = -k^h\beta^2 A q^h + (q^h - \tilde{q}^h)\left(-k^h\beta C(n+1) + k^{h2}\beta C + 1\right)$$

where A and C are given by (A.3) and (A.5), and whence

$$\begin{aligned}
Q^h_{k^h t^h} &= -k^h\beta^2 A\frac{\partial q^h}{\partial t^h} + \left(\frac{\partial q^h}{\partial t^h} - \frac{\partial \tilde{q}^h}{\partial t^h}\right)\left(-k^h\beta C(n+1) + k^{h2}\beta C + 1\right) \\
&= -k^h\beta^2 A\frac{\partial q^h}{\partial t^h} + \left(\frac{\partial q^h}{\partial t^h} - \frac{\partial \tilde{q}^h}{\partial t^h}\right)\left(\frac{k^h\beta^2 A q^h}{q^h - \tilde{q}^h}\right) \\
&= -\frac{k^h\beta^2 A q^h \tilde{q}^h}{(q^h - \tilde{q}^h)t^h}\left(-\frac{t^h}{q^h}\frac{\partial q^h}{\partial t^h} + \frac{t^h}{\tilde{q}^h}\frac{\partial \tilde{q}^h}{\partial t^h}\right)
\end{aligned}$$

where $Q^h_{k^h}(k^{h*}, t^h) = 0$ implies $-k^h\beta C(n+1) + k^{h2}\beta C + 1 = k^h\beta^2 A q^h/(q^h - \tilde{q}^h) < 0$. As a result,

$$dk^{h*}/dt^h < 0 \Leftrightarrow \left|\frac{t^h}{q^h}\frac{\partial q^h}{\partial t^h}\right| < \left|\frac{t^h}{\tilde{q}^h}\frac{\partial \tilde{q}^h}{\partial t^h}\right| \tag{A.6}$$

since outsider output is more sensitive to changes in taxation.

Maximizing welfare with respect to emission tax

We show here how welfare is maximized in order to solve for the optimal tax in the home country. A similar analysis applies for optimal tax in the foreign country.

Home and foreign governments choose the tax, t^h and t^f, simultaneously taking the other country's tax as given. Consider the following welfare function for the home country, which consists of consumer surplus, profits of home firms (insiders and outsiders), tax revenue and damages from global pollution:

$$\begin{aligned}
W^h &= CS + k^h\pi^h + (n - k^h)\tilde{\pi}^h + t^h e^h k^h + t^h(n - k^h)\tilde{e}^h - \varphi^h \\
&= CS + k^h(p^h q^h - c^h) + (n - k^h)(\tilde{p}^h\tilde{q}^h - \tilde{c}) - \varphi^h
\end{aligned} \tag{A.7}$$

where $CS = CS(k^h q^h, (n - k^h)\tilde{q}^h, k^f q^f, (m - k^f)\tilde{q}^f)$, $\varphi^h = \varphi^h(E)$ where $E = E^h + E^f$, and $E^h = e^h k^h + \tilde{e}^h(n - k^h)$, $E^f = e^f k^f + \tilde{e}^f(m - k^f)$. The function φ^h is assumed to be increasing and strictly convex in emissions. Emissions from each country affect the home country equally: marginal damages arising from changes in total emissions from the foreign country (i.e., transboundary pollution) is equal to marginal damages arising from total emissions from the home country.

Due to the symmetric nature of the model, an analogous expression applies to the welfare function of the foreign country, W^f.

Differentiation of (21) with respect to t^h gives

$$\begin{aligned}\frac{\partial W^h}{\partial t^h} &= -k^f q^f \frac{\partial p^f}{\partial t^h} - (m-k^f)\tilde{q}^f \frac{\partial \tilde{p}^f}{\partial t^h} + \beta\left(k^{h2} q^h \frac{\partial q^h}{\partial t^h} + (n-k^h)\tilde{q}^h \frac{\partial \tilde{q}^h}{\partial t^h}\right) \\ &\quad + (t^h - \varphi^{h\prime})k^h \frac{\partial E^h}{\partial t^h} - \varphi^{h\prime}\frac{\partial E^f}{\partial t^h} \end{aligned} \tag{A.8}$$

An analogous expression applies to the foreign country, $\partial W^f/\partial t^f$. Setting (A.8) equal zero, and using the fact that $\partial p^f/\partial t^h = \partial \tilde{p}^f/\partial t^h$ and $Q^f = k^f q^f + (m-k^f)\tilde{q}^f$ gives

$$t^h = \varphi^{h\prime} - \frac{Q^f\left(\gamma \frac{\partial Q^h}{\partial t^h} + \beta \frac{\partial Q^f}{\partial t^h}\right) + \beta\left(k^{h2} q^h \frac{\partial q^h}{\partial t^h} + (n-k^h)\tilde{q}^h \frac{\partial \tilde{q}^h}{\partial t^h}\right) - \varphi^{h\prime}\frac{\partial E^f}{\partial t^h}}{k^h \partial E^h/\partial t^h} \tag{A.9}$$

where $\partial q^h/\partial t^h < 0$, $\partial \tilde{q}^h/\partial t^h < 0$, $\partial Q^h/\partial t^h < 0$, $\partial E^h/\partial t^h < 0$, $\partial Q^f/\partial t^h > 0$, $\partial E^f/\partial t^h > 0$ and $|\partial Q^h/\partial t^h| > |\partial Q^f/\partial t^h|$. An analogous expression applies to the tax of the foreign country, t^f. Throughout we shall assume that the optimal tax in each country is strictly positive.

The first, second and third term in (A.9) denote, respectively, the incentive to lower the tax to encourage output and thus raise consumer surplus (i.e., $\beta \partial Q^h/\partial t^h + \gamma \partial Q^f/\partial t^h < 0$), address the output distortion and attract profits via lower taxation, and reduction of transboundary pollution via lower taxation, $-\varphi^{h\prime}\partial E^f/\partial t^h < 0$, i.e., lower tax at home reduces output and thus emissions coming from the foreign country via the oligopolistic interdependence across countries. Equation (A.9) clearly indicates that the tax is set below the marginal damages in each country. This concurs with studies like Fikru and Gautier (2016, 2017).

The expression in (A.8), along with an analogous expression for the foreign country, implicitly determine the policy vector $t^h(k^h, k^f)$, $t^f(k^h, k^f)$.

The sign of profit change in equation (22)

$$L(k^h) = \left(k^h(p^h - c_1^h)\frac{\partial q^h}{\partial k^h} + (n - k^h)(\tilde{p}^h - \tilde{c}_1^h)\frac{\partial \tilde{q}^h}{\partial k^h} \right)$$

where $p^h - c_1^h = q^h k^h \beta$, $\tilde{p}^h - \tilde{c}_1^h = \beta \tilde{q}^h$. Assume end-of-pipe cost function and recall that in the case of linear demand, symmetric cost functions for home merged and outsiders first-order conditions imply $k^h q^h = \tilde{q}^h$. Then, $L(k^h) = \beta q^h k^h (k^h q^h_{k^h} + (n - k^h)\tilde{q}^h_{k^h})$. Thus, (i) $L(k^{h*}) > 0$ since at k^{h*} $\partial Q^h/\partial k^h = 0 \Leftrightarrow k^h q^h_{k^h} + (n - k^h)\tilde{q}^h_{k^h} = -(q^h - \tilde{q}^h) > 0$; (ii)$L(n) = n^2 q^h q^h_{k^h} \beta < 0$; and $L(k^h) > 0$ for range of k^h where $\partial Q^h/\partial k^h > 0$. Thus, for some range $k^h > k^{h*}$ profits increase at a diminishing rate and become zero/negative. And at k^{h*} profits rise at an increasing rate.