Environmental policy helping antitrust decisions☆

Socially excessive and insufficient merger approvals

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Abstract

This paper considers firms' incentives to merge under duopoly, where we allow for product differentiation, cost asymmetries, and pollution intensities (green and brown goods). We first analyze mergers in the absence of environmental regulation, showing that mergers induce an output shift towards the lowest cost firm. When emission fees are introduced, however, firms also consider their relative pollution intensities, potentially reverting the above output shift. We show that socially excessive mergers can arise when firms shift output to the more cost-efficient firm which may cause more pollution. In contrast, socially insufficient mergers can arise if output shifts reduce pollution.

KEYWORDS: socially excessive/insufficient mergers, product differentiation, cost asymmetry, pollution intensity, emission fees, antitrust authorities, environmental regulation
JEL CLASSIFICATION: G34, H23, L41, Q50

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1. Introduction

Many industries nowadays include firms with different pollution intensities. The literature on environmental regulation, and mergers, however, mostly overlooks this feature by considering markets where firms are either all polluting or all green rather than a combination of both. In the energy sector, for instance, mergers are common between energy and utility service providers in which one firm is less polluting than its rivals (Creti and Sanin, 2017).[1]

Allowing for firm-level heterogeneities can help us better understand firm's behavior and predict the welfare effects from mergers. If the antitrust authority (AA) incorrectly assume that firms are symmetric, mergers may be blocked on the basis that they can lead to an output reduction. When differences in pollution intensities are taken into account, however, mergers could induce output shifts that mitigate environmental damages yielding an overall welfare gain in settings where mergers would have been blocked otherwise.

Our model considers an industry with a green and a polluting firm where we allow for cost asymmetries and product differentiation. In the first period, firms choose whether to file a merger to the AA for approval. In the second period, the AA approves or blocks the merger. In the third period, the environmental regulator (such as the Environmental Protection Agency, EPA) sets emission fees, observing whether the merger was approved or not. Finally, firms respond choosing their output levels either cooperatively as part of the merger or competing à la Cournot. This timing indicates that merger plans and the AA response, approving or blocking the merger, are often taken into consideration in a long-run horizon, and staying in place for years or decades before any revisions. In contrast, emission fees and firms' output decisions can be more easily revised after observing a change in merger decisions in the first stages of the game.[2]

[1]For example, Enbridge, a Canadian oil-pipeline operator, acquired the 50-megawatt Silver State North photovoltaic project from First Solar Inc., a Nevada-based solar power plant in 2012 to honor its neutral footprint commitment (Martin, 2012). Creti and Sanin (2017, Table 1) provide a list of mergers between renewable and non-renewable energy firms under the cap-and-trade program of the Regional Greenhouse Gas Initiative (RGGI). In addition, Hennessy and Roosen (1999) suggest that firms may have incentives to merge and aggregate pollution permits when emission is pooled within a certain attainment area under the "bubble" policy of the US Environmental Protection Agency (EPA).

[2]In addition, we consider the AA taking precedence over EPA in approving mergers when firms have incentives to merge in anticipation of more stringent environmental standards, such as in the energy sector (Creti and Sanin, 2017).

We first focus on the case of no environmental regulation. In this setting, mergers induce an output shift from the less to the more cost-efficient firm irrespective of pollution differentials. Such mergers can, however, yield a welfare loss if firms produce relatively homogeneous goods, as in standard merger models without environmental regulation (Kao and Menezes, 2010). Nevertheless, welfare-enhancing mergers can still arise when output shifts to a less polluting brown firm, or output of both green and more polluting brown firm reduces to mitigate severe environmental damage.[3]

We then consider environmental regulation in our analysis, examining under which conditions mergers entail a welfare loss, as in standard models of market power, and in which cases they yield a welfare gain. In this setting, emission fees generate incentives to shift their output after the merger from the polluting to the green firm –an incentive that did not exist in the absence of environmental regulation. More importantly, the increase in the green firm's output exceeds the reduction in the polluting firm's output, leading an overall decrease in pollution. Nonetheless, when firms are relatively homogenous and pollution is less severe, mergers' output reductions and price increases still decrease overall welfare, as in standard merger models (Salant et al., 1983).

We identify the welfare effects of mergers, finding that they can be welfare-reducing if the polluting firm generates significantly higher environmental damages than its green rival. Therefore, it is possible that AA which ignores environmental damages can approve welfare-reducing mergers, and we identify situations where those mergers should be blocked; specifically, when firms are relatively cost-symmetric, produce differentiated goods, and the polluting firm generates significantly higher environmental damages than its green rival.

Overall, we may observe the approval of welfare-reducing mergers or the blocking of welfare-enhancing mergers in equilibrium. When the AA ignores environmental damages, mergers can be approved (blocked) but they would have been blocked (approved) by the AA that also considers

[3]Monsanto, which manufactures Roundup™ weedkiller, is faced with multiple litigations for allegations of causing non-Hodgkin lymphoma (NHL) and multiple myeloma by its active ingredient glyphosate (Bayer AG, 2019, p.250). Bayer, which acquired Monsanto in 2018, manufactures Natria™ herbicide, an organic substitute for weed and broadleaf control that mitigates the environmental and health impacts associated with the use of chemical herbicides. Our model applies to a broad class of mergers between environmentally differentiated firms, such as the one above where an output shift from conventional to organic herbicides is predicted. Pelaez and Mizukawa (2017) identify a trend of agrochemical industry leaders, which face increasing regulatory costs, acquiring biopesticide companies, which produce more environmental-friendly pest control products.

environmental damages. However, the EPA has the ability, in the subsequent stage of the game, to correct any output (and pollution) inefficiencies that may arise from an incorrect merger approval decision made by the AA. This gives rise to another benefit of environmental policy, often overlooked in the literature, as it can correct output inefficiencies that would have not existed if the AA considered environmental damages when evaluating merger approvals. Our results then call for more concerted efforts between the AA and EPA in evaluating mergers, especially in industries where firms have different pollution intensities.

Our findings contribute to the debate about the factors that competition policy should consider when evaluating mergers. Antitrust authorities often focus on consumer surplus and firms' profits, without considering potential output shifts that, after the merger, decrease (increase) the production of the relatively polluting (green) good. European competition law explicitly considers environmental reasons (see articles 6 and 174 of the Treaty), but they have rarely been used to approve or block mergers.[4] In the case of the United States, the Horizontal Merger Guidelines (US Department of Justice and Federal Trade Commission, 2010) do not explicitly consider the broader impact of mergers on the environment, while the EPA does not actively monitor mergers.[5]

1.1 Related Literature

A large body of the literature analyzes horizontal mergers in oligopolistic markets with environmental externalities.[6] Specifically, Canton et al. (2012) consider the upstream ecoservice industry supplying pollution abatement goods to the downstream polluting market. In this context, horizontal mergers in the ecoservice industry are profitable if a sufficient number of firms merge,

[4] See, for instance, Martinez-Lopez (2000) for a discussion about the agreement between European appliances manufacturers to limit their production of energy-inefficient machines. While this agreement entailed an increase in prices, as the discontinued appliances were the most inexpensive, the European Commission considered that it would help address the environmental externalities that consumers did not take into account in their purchasing decisions.

[5] If the emission fees are administratively costly, or if they require a close monitoring of firms' production decisions, then the AA which considers environmental externalities may help the EPA's task by approving (blocking) mergers that (do not) contribute to an overall welfare improvement.

[6] Our analysis focuses on non-cumulative pollutants, such as carbon dioxide, sulphur dioxide, and suspended particulate; see Benchekroun and Ray Chaudhuri (2008) for an overview of studies on cumulative pollutants.

as in Salant et al. (1983), or if costs are relatively convex, as in Perry and Porter (1985).[7] In addition, mergers are welfare-improving when emission fees are intermediate; that is, fees are not too high (low) to yield insufficient output (abatement). Lambertini and Tampieri (2012, 2014) seek to understand mergers of Cournot triopolists under environmental regulation, and show that firm incentives and social objectives align if output reduction, which increases profits and decreases pollution, more than offsets consumer welfare losses. Our paper differs from the previous literature by considering endogenous emission fees and allowing for asymmetric firms. We show that mergers in a two-firm context can be both profitable and welfare-improving under different forms of asymmetries, and how the EPA can strategically use emission fees to facilitate or hinder mergers between the firms.

A branch of literature in industrial organization analyzes differentiated oligopolies with asymmetric costs. Zanchettin (2006) extends Singh and Vives (1984)'s model of differentiated duopoly and Fauli-Oller (2002)'s model of asymmetric costs to consider pricing strategies and equilibrium profits in a setting of differentiated and asymmetric firms. Unlike our paper, however, these studies do not consider firms' incentives to merge. Kao and Menezes (2010) show that welfare-enhancing mergers can arise for output shifts from the less to the more cost-efficient firm, and the same result holds in our model without environmental damages. However, our model also shows that mergers can be welfare-improving if output shifts mitigate environmental damages. Gelves (2014) considers two-firm mergers in an oligopolistic setting with N firms similar to that in Salant et al. (1983), but allowing for cost asymmetries and product differentiation, suggesting that welfare-enhancing mergers are more likely when products become more differentiated.

The closest articles to our paper are Fikru and Gautier (2016, 2017), who examine mergers in Cournot markets with product differentiation and emission fees but assuming symmetric costs and no pollution differentials between firms. We show that mergers can be welfare-improving when costs are asymmetric even in the absence of environmental externalities, since output shifts from

[7] A recent example in the pollution abatement industry is the acquisition of Auburn FilterSense LLC, a US provider of particulate emissions monitors and intelligent controls for industrial particulate/dust filtration systems, by Nederman, the Swedish environmental technology company (Filtration + Separation, 2018). Another example in the waste management industry is the acquisition of Quantex Environmental Inc., an Ontario based company, by Covanta Environmental Solutions, a New Jersey based environmental services provider (Waste 360, 2018).

the less efficient to the more cost-efficient firm help save production costs. When externalities are present, however, we propose another channel of welfare gains. Specifically, emission fees on the polluting firm induce this firm to reduce its output even when firms do not merge. Our research then complements Fikru and Gautier (2017, 2020), since we also find that regulation should be more stringent in markets with homogeneous goods and high pollution intensities. However, we demonstrate that stringent regulation is required when firms are relatively cost-asymmetric. In addition, we identify under which conditions welfare-enhancing (welfare-reducing) mergers are blocked (approved) by the AA, leading to an overall welfare loss.

The remainder of this paper is organized as follows. Section 2 develops the model. Section 3 examines merger incentives and welfare effects without environmental regulation, when the AA considers pollution (in section 3.2) or not (in section 3.2.1). Section 4 evaluates these effects when emission fees are present, when the AA considers pollution (in section 4.3) or not (in section 4.5). Section 5 compares output and welfare across different regulatory regimes, and finally, section 6 concludes. The following table summarizes the different regulatory settings in our paper.

	EPA is absent	*EPA is present*
AA considers pollution	Section 3.2	Section 4.3
AA ignores pollution	Section 3.2.1	Section 4.5
AA is absent	Section 5	Section 5

Table 1: Different regulatory settings

2. Model

Consider a market with two firms, i and j, where $i, j = \{B, G\}$ stands for the polluting and the green firm, respectively. The brown (green) firm has lower (higher) marginal production cost c_B (c_G), where $0 \leq c_B \leq c_G \leq 1$, since the green firm has additional abatement costs. However, the brown firm pollutes the environment more (less) than its rival, that is, environmental damages are $Env(q_G, q_B) = d_B q_B^2 + d_G q_G^2$, where $d_B \geq d_G \geq 0$. For simplicity, we normalize the green firm's production cost to $c \equiv c_G - c_B$, which can be interpreted as its cost disadvantage relative to the brown firm. Analogously, we normalize the pollution parameter of the brown firm to $d \equiv d_B - d_G$, which represents its pollution intensity differential relative to the green firm. Therefore, environmental damages can be expressed as $Env\left(q_B\right) = dq_B^2$, which are increasing and convex in the brown good (as in Lambertini and Tampieri, 2012; and Espínola-Arredondo and Muñoz-García, 2015).[8]

We consider firm i's inverse demand function of $p_i\left(q_i, q_j\right) = 1 - q_i - \beta q_j$, where $\beta \in [0,1]$ represents the degree of product differentiation. When $\beta = 0$, goods are completely differentiated and when $\beta = 1$, goods are perfect substitutes; see Singh and Vives (1984). For simplicity, we assume that $\beta < \overline{\beta} \equiv 2\left(1 - c\right)$, which guarantees that both firms are active without the merger. Otherwise, the brown firm will be the only active firm, and, hence, oppose any merger with its green rival.

The timing of the game is as follows:

(1) Every firm i decides whether to merge with firm j or not. If one or both firms oppose, the merger does not ensue. If both firms approve, the proposed merger is evaluated by the antitrust authority.

(2) If both firms choose to merge, the antitrust authority decides whether to approve or block the merger.

(3) The regulator sets an emission fee t_i^k for each firm, which depends on its type $i \in \{B, G\}$ and the industry structure $k \in \{M, NM\}$, where *M (NM)* denotes merger (no-merger), respectively.

(4) If firms merge, they jointly choose output pair $\left(q_B^M, q_G^M\right)$. If the merger does not ensue, every firm i independently selects its output level q_i^{NM} and engages in Cournot competition.

As a benchmark, we first examine a setting with no environmental regulation (where stage 3 is absent), and find the equilibrium output, profits, and welfare with and without the merger. We next evaluate how these equilibrium results are affected by the emission fees. Appendix 1 considers a setting where, instead, the green firm enjoys a cost advantage relative to its brown rival, showing

[8]Our model is similar in construct to Denicolò (2008) in assuming that the green (brown) technology has no (negative) externalities but is more (less) costly, in which the green firm has incentives to go beyond the minimum standard to induce the regulator to set more stringent environmental regulation at the expense of the brown firm. Also, when $d_B = d_G$, $d = 0$ that condenses to a model with only cost asymmetry and product differentiation (Gelves, 2014).

that, while output levels and emission fees are affected, firms' merger decisions and the AA's merger approvals are not affected.

3. Equilibrium analysis without regulation

3.1 Third stage - output decisions

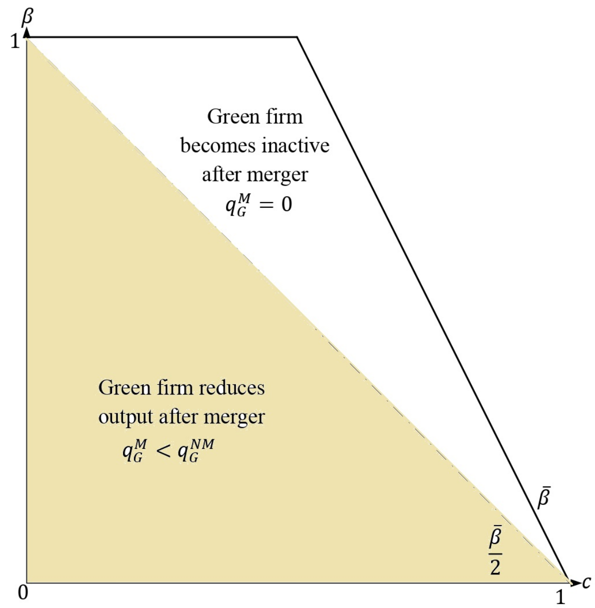
Operating by backwards induction, we begin our analysis with the third stage of the game[9]

Lemma 1. *Under a merger, the green firm reduces its output when* $\beta < \frac{\overline{\beta}}{2}$ *and stops production otherwise. The brown firm reduces output when* $\beta < \beta_B^{NR}$*, increases output when* $\beta_B^{NR} \leq \beta < \frac{\overline{\beta}}{2}$*, where* $\beta_B^{NR} \equiv \overline{\beta}^{-1}(3 - \sqrt{9 - 2\overline{\beta}^2})$*, and monopolizes the market otherwise.*

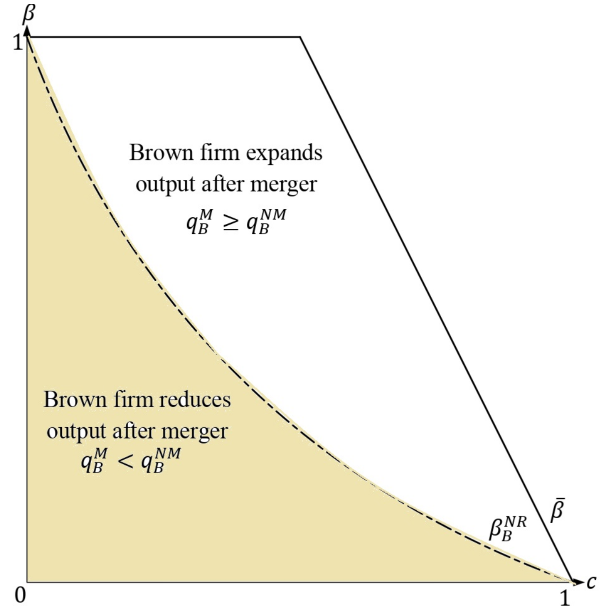
Figures 1a and 1b illustrate this result. When firms are relatively differentiated (low β) or cost-symmetric (low c), the green (brown) firm reduces output after the merger, which occurs below cutoff $\frac{\overline{\beta}}{2}$ (cutoff $\beta < \beta_B^{NR}$, where *NR* stands for "no-regulation") in the left (right) panel; otherwise, this firm ceases (expands) production, with respective output levels provided in the Appendix. Overall, when β is relatively low, $\beta < \beta_B^{NR}$, both firms reduce their output after the merger; when β is intermediate, $\beta_B^{NR} < \beta < \frac{\overline{\beta}}{2}$, the green firm reduces its output while the brown firm expands its output; and finally, when $\beta > \frac{\overline{\beta}}{2}$, the green firm shuts down while its brown rival increases its output.[10]

[9]Environmental regulation is absent in this section, implying that the game has only three stages.

[10]For example, Cathay Pacific acquired Dragon Air in 2006 and became the sole aviation company based in Hong Kong. In 2020, Cathay Pacific shut down Dragon Air in a corporate restructuring effort to keep cost down (Lee, 2020).



(a) Green firm



(b) Brown firm

Figure 1: Output change under no regulation

Let us define output change of firm i as $\Delta q_i^{NR} = q_i^{NM} - q_i^M$, where $i \in \{B, G\}$. Corollary 1 identifies this output change across green and brown firms.

Corollary 1. *The green firm reduces output more than the brown firm, that is,* $\Delta q_G^{NR} > \Delta q_B^{NR}$*, and output reduction due to merger is more significant for firms producing more homogeneous goods.*

The green firm's cost inefficiency relative to the brown firm causes this firm to reduce output relative to its brown rival; a result that holds for all values of β and c. In addition, when goods becomes more differentiated (low β), both firms reduce their output, but the green firm does it more significantly than its brown rival. When goods are more homogeneous (high β), however, the green firm reduces its output as much as possible (producing zero units) while the brown firm increases its output, implying that $\Delta q_B^{NR} < 0$.

3.2 Second stage - merger approval

In the second stage, the AA anticipates the output level that every firm i produces in the third stage, and approves the merger if and only if it increases social welfare, defined as follows:

$$SW(q_G, q_B) = CS + PS - Env(q_B) \tag{1}$$

where $CS = \frac{1}{2}\left(q_B^2 + 2\beta q_B q_G + q_G^2\right)$ represents consumer surplus,[11] $PS = \pi_B + \pi_G$ (sum of profits) denotes producer surplus, and $Env\left(q_B\right) = dq_B^2$ captures environmental damages, as defined in Section 2. The following lemma characterizes the decision of the AA.

Lemma 2. *The AA approves the merger if and only if $\beta \leq \beta_1\left(d\right)$ or $\beta \geq \beta_2\left(d\right)$, where cutoffs $\beta_1\left(d\right)$ and $\beta_2\left(d\right)$ solve $SW\left(q_G^M, q_B^M\right) = SW\left(q_G^{NM}, q_B^{NM}\right)$. Otherwise, the merger is blocked.*

As a benchmark, Figure 2 depicts the case where environmental damages are symmetric ($d = 0$), in which mergers are approved if $\beta \geq \beta_2\left(0\right)$ as in the shaded region.[12] Starting with the standard duopoly (homogeneous goods and symmetric costs) at $\beta = 1$ and $c = 0$, as depicted at the top left-hand corner of the figure, the merger is welfare reducing. Intuitively, both firms decrease their output, yielding a loss in consumer surplus that offsets the gain in producer surplus, ultimately yielding a welfare decrease. However, when firms become more asymmetric (higher c, thus moving rightward along the horizontal line at the top of the figure), we find that the merger can become welfare enhancing. In this case, the merger of two cost-asymmetric firms leads to an output shift, from the least to the most efficient firm, yielding an overall efficiency improvement and a welfare increase. Finally, when products become more heterogeneous (lower β), the merger entails a smaller profit gain, ultimately making welfare-reducing mergers more likely; as depicted at the bottom of the figure.

[11] Our results do not suffer path dependence problem since our quasilinear-quadratic utility representation assumes away wealth effects (Johansson (1999, p.748), and Hsu and X. H. Wang (2005)).

[12] When $d < 1$, our results show that there are no (β, c)-pairs below cutoff $\beta_1\left(d\right)$ that satisfy $SW^M > SW^{NM}$.

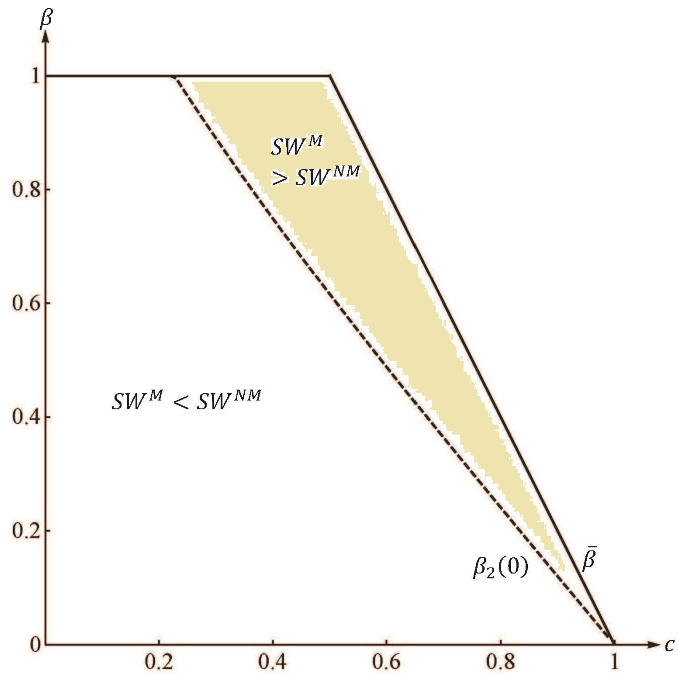


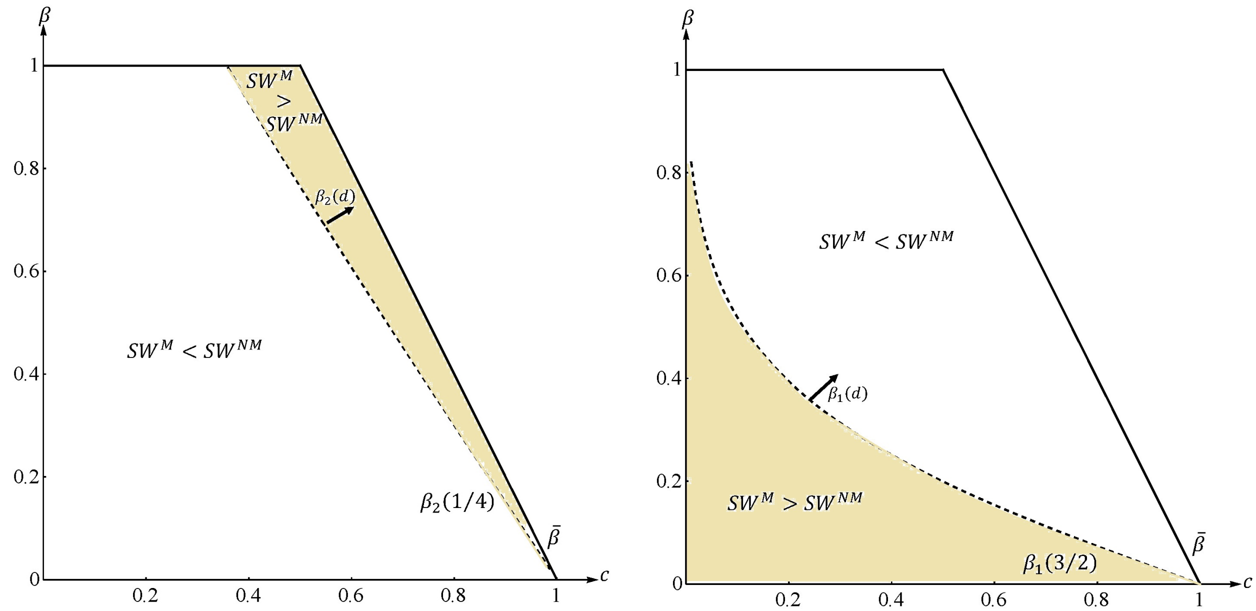
Figure 2: Symmetric environmental damages, ($d = 0$).

Figure 3a depicts the case where environmental damages slightly increase to $d = \frac{1}{4}$. Relative to Figure 2, the merger induces both firms to reduce their output when β is low, as depicted in the shaded areas of Figure 1, yielding a new positive effect on welfare (pollution decrease). In this context (figure 3a), this positive effect is small and, as a consequence, not significantly changing our results from Figure 2, where mergers are welfare reducing when β is low. However, when β increases, the merger entails that an output shift from the green to the brown firm, which can lead to the green firm becoming inactive while the brown rival increases its output. In this case, the merger generates a new, but negative, welfare effect when $d > 0$ relative to $d = 0$, explaining why welfare improving mergers (shaded area) are more restrictive in Figure 3a than in Figure 2.[13]

Figure 3b depicts the case of relatively severe environmental damages at $d = \frac{3}{2}$. When β is low, the above positive effect from mergers becomes more significant, altering our results from Figure 2, so the merger is now welfare-improving. Intuitively, the output reduction that both firms experience after the merger yields lower environmental damages, which offset the welfare loss from the merger identified in Figure 2 (where $d = 0$). However, when β increases, the merger makes the green

[13] Further increases in environmental damages, however, rotate cutoff $\beta_2(d)$ clockwisely at $(c, \beta) = (1, 0)$, shrinking the shaded region representing welfare-enhancing mergers. This cutoff is to the right of $\overline{\beta}$ when $d > 1/2$.

firm inactive while the brown firm increases its output, yielding a negative welfare effect, which is relatively severe in this case given that $d = \frac{3}{2}$. As a result, mergers become welfare reducing.



(a) Low environmental damages

(b) High environmental damages

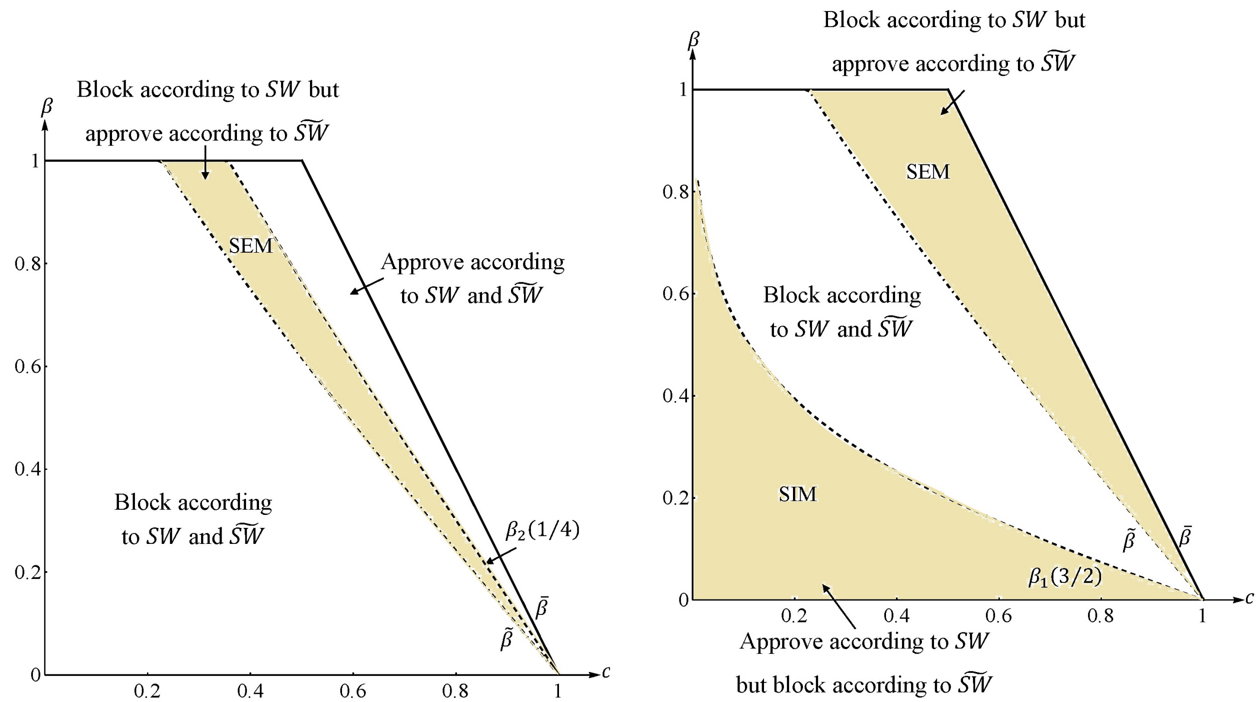
Figure 3: Welfare under no regulation

3.2.1 Antitrust which overlooks environmental effects

If the AA ignores environmental damages, his welfare function becomes

$$\widetilde{SW}\left(q_G, q_B\right) = CS + PS \tag{2}$$

When environmental damages are symmetric, $d = 0$, welfare in expressions (1) and (2) coincides, implying that the AA approves mergers under the same (β, c)-pairs. For mild environmental damages ($d = 1/4$), the AA that considers these damages behaves as in Figure 3a while that ignoring them behaves as in Figure 2. Comparing these two figures, we obtain Figure 4a. The shaded area above cutoff $\widetilde{\beta}$, which solves $\widetilde{SW}\left(q_G^M, q_B^M\right) = \widetilde{SW}\left(q_G^{NM}, q_B^{NM}\right)$, and below cutoff $\beta_2(1/4)$, indicates socially excessive mergers (SEM) because the AA approves mergers while overlooking their associated environmental damages. Figure 4b, which compares Figure 2 and 3b, shows that both SEM and socially insufficient mergers (SIM) are present when environmental damages become more severe $(d = 3/2)$. This happens because the AA approves mergers between relatively homogeneous and cost-asymmetric firms that reduce welfare (SEM) and blocks mergers between relatively differentiated and cost-symmetric firms that could have improved social welfare (SIM).[14]



(a) Superimposing cutoffs when $d = 1/4$

(b) Superimposing cutoffs when $d = 3/2$

Figure 4: Socially excessive and insufficient mergers

3.3 First stage - merger vote

Let us conclude our analysis in this section by studying merger incentives in the first stage. Define the firms' sum of profits as $\pi^k \equiv \pi^k_B + \pi^k_G$, where $k = \{M, NM\}$.

Lemma 3. *Under no environmental regulation, both firms have incentives to merge under all parameter conditions, whether the merger keeps both firms active or shuts down the green firm.*

When firms merge and coordinate output, the merged firm obtains larger profits than competing à la Cournot, that is, $\Delta\pi^{NR} \equiv \pi^M - \pi^{NM} > 0$, so every firm i has incentives to merge and produce

[14]While parameter $d > 0$ measures the brown firm's pollution differential, it could alternatively capture the difference between the EPA and AA's welfare function (e.g., their preference divergence). When $d = 0$, both agencies have the same welfare function. When $d > 0$, the EPA assigns a weight to environmental damages but the AA does not.

positive units; and this holds even when the brown firm acquires and shuts down its green rival since now the brown firm dominates the market.[15]

4. Equilibrium analysis with environmental regulation

In this section, we introduce the regulator, which, observing whether firms merge, sets emission fees.

4.1 Fourth stage - output decisions

In the fourth stage, every firm *i* observes the emission fees set by the regulator in the third stage, that is, $\left(t_B^M, t_G^M\right)$ if the merger is approved or $\left(t_B^{NM}, t_G^{NM}\right)$ if the merger is blocked, and responds with the following output decisions.

Lemma 4. *Under regulation, the green firm's equilibrium output is* $q_G^{NM,R} = \frac{2\left(1-c-t_G^{NM}\right)-\beta\left(1-t_B^{NM}\right)}{4-\beta^2}$ *without and* $q_G^{M,R} = \frac{\left(1-c-t_G^M\right)-\beta\left(1-t_B^M\right)}{2(1-\beta^2)}$ *with the merger. Similarly, the brown firm's equilibrium output is* $q_B^{NM,R} = \frac{2\left(1-t_B^{NM}\right)-\beta\left(1-c-t_G^{NM}\right)}{4-\beta^2}$ *without and* $q_B^{M,R} = \frac{\left(1-t_B^M\right)-\beta\left(1-c-t_G^M\right)}{2(1-\beta^2)}$ *with the merger. Whereas, when only the brown firm is active, its output is* $q_B^R = \frac{1-t_B}{2}$ *with and without the merger. In addition, firms' output is more responsive to emission fees under merger than under no merger.*

In words, firm *i* responds negatively (positively) to emission fees charged to this (the other) firm, and firms' output is more responsive to emission fees when they merge. In contrast, when the regulator shuts down one firm and only keeps the other firm active, this firm's output is decreasing in its costs and emission fees, as expected, and does not depend on the industry structure.

4.2 Third stage - emission fees

In the third stage of the game, the regulator finds the emission fees that induce socially optimal output levels, solving

$$\max_{q_G, q_B \geq 0} SW\left(q_G, q_B\right) = CS + PS + Tax - Env\left(q_B\right) \tag{3}$$

[15] This follows the standard result in the literature, which suggests that the merger of duopolistic firms into a monopoly is always profitable if side payments are allowed (Salant et al., 1983).

where *Tax* represents the regulator's tax revenue from emission fees. The following lemma identifies first-best output levels that maximize social welfare, which apply to whether firms merge or not.

Lemma 5. *The socially optimal output for green and brown firms are*

$$\left(q_G^{SO}, q_B^{SO}\right) = \begin{cases} \left(\frac{(1+2d)(1-c)-\beta}{1+2d-\beta^2}, \frac{1-\beta(1-c)}{1+2d-\beta^2}\right) & \text{if} \quad \beta < \beta^R(d) \\ \left(0, \frac{1}{1+2d}\right) & \text{otherwise}. \end{cases}$$

where cutoff $\beta^R(d) \equiv (1+2d)(1-c)$.

When both firms generate the same pollution per unit of output $(d = 0)$, the green firm stops production for all $\beta \geq \beta^R(0) = \frac{\overline{\beta}}{2}$. Intuitively, the green firm exhibits a relatively large cost disadvantage, and no pollution advantage, so that the regulator only assigns output to the brown firm. When environmental damages are positive, however, the regulator only assigns output to the brown firm when $\beta \geq \beta^R(d)$, which is more restrictive since cutoff $\beta^R(d)$ increases in d, so that the regulator assigns a positive output to both green and brown firm under larger parameter conditions. Figure 5 shows the clockwise rotation of cutoff $\beta^R(d)$ when environmental damages increase (from $d = 0$ to $d = \frac{1}{4}$, for instance), ultimately shrinking the (β, c)-pairs between cutoffs $\beta^R(d)$ and $\overline{\beta}$ (the shaded region) where the brown firm is the only firm being assigned output by the regulator. A comparison of output levels across regulatory regimes is provided in Appendix 2.

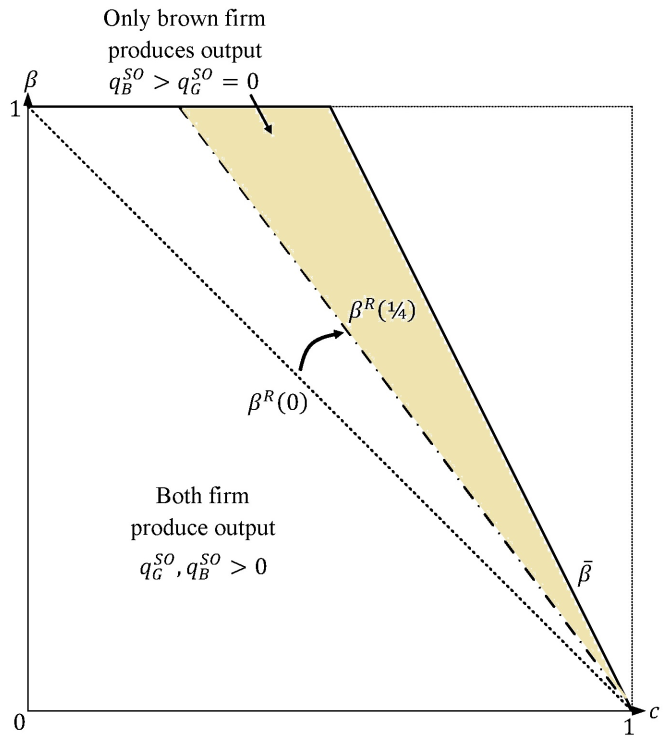


Figure 5: Symmetric environmental damages, (d = 0).

The following corollary depicts how socially optimal output changes in the parameter values.

Corollary 2. *When both firms are active, q_G^{SO} (q_B^{SO}) decreases in β if $\beta < \min\left\{\frac{1}{2(1-c)}, \frac{(1+2d)(1-c)}{2}\right\}$, increases in d (c) but decreases in c (d), respectively. When only the brown firm is active, q_B^{SO} decreases in d but does not change with β and c.*

When goods become more differentiated (low β), the regulator seeks more units of both goods, but fewer units of the green good if it becomes more costly and, similarly, fewer units of the brown good if it becomes more polluting.

We next identify the emission fees that induce socially optimal output found in Lemma 5.

Proposition 1. *When $q_G^{SO} > 0$ and $q_B^{SO} > 0$, the regulator sets emission fees of*

$$t_G^{NM} = -\frac{(1+2d)(1-c)-\beta}{1+2d-\beta^2} \quad \text{and} \quad t_B^{NM} = \frac{(2d-1)[1-\beta(1-c)]}{1+2d-\beta^2}$$

$$t_G^{M} = -(1-c) \quad \text{and} \quad t_B^{M} = \frac{2d[1-2\beta(1-c)]-(1-\beta^2)}{1+2d-\beta^2}$$

Otherwise, the regulator sets $t_G = 0$ and $t_B = -\frac{1-2d}{1+2d}$ to achieve $q_G^{SO} = 0$ and $q_B^{SO} = \frac{1}{1+2d}$.

For comparison purposes, the next lemma ranks taxes for each firm type and industry structure.

Corollary 3. *Emission fees satisfy* $t_G^M < t_G^{NM} < 0$ *and* $t_B^M < t_B^{NM}$ *if any only if* $\beta < \beta^R(d)$.

From Lemma 5, the regulator seeks a positive output from both firms when $\beta < \beta^R(d)$, and the green firm receives a subsidy when firms do not merge. In this setting, the subsidy becomes more generous if firms merge ($t_G^M < t_G^{NM} < 0$) to offset the output-reduction effect of market monopolization; as in Collie (2003) and Huck and Konrad (2004). Whereas, the brown firm is taxed to internalize the externalities when it becomes more polluting (e.g., $d > 1/2$), and emission fees are more stringent before than after the merger ($t_B^{NM} > t_B^M > 0$, respectively). In contrast, when $d \leq 1/2$ and $\beta \geq \beta^R(d)$, the regulator seeks output from the brown firm alone, offering a subsidy, $t_B < t_G = 0$, to align this firm's relatively less polluting output to the socially optimal level.[16]

4.3 Second stage - merger approval

In the second stage, we evaluate the AA's decisions.

Lemma 6. *Mergers are approved by the AA under all parameter conditions.*

The AA's objective function coincides with expression (1) under no regulation. The AA anticipates that the regulator in the third stage will respond by setting emission fees that align the firms' output to the respective first-best levels, both when firms merge and when they do not. In this context, expecting that social welfare with and without the merger coincides, the AA does not block the merger under any parameter conditions.

4.4 First stage - merger vote

In the first stage, we analyze the firms' incentives to merge.

Lemma 7. *Under environmental regulation, both firms have incentives to merge under all parameter conditions, whether the merger keeps both firms active or shuts down the green firm.*

[16] For instance, when $d = 0$, $t_G = 0$ and $t_B = -1$, which, inserted in q_B^R from Lemma 4, induces the brown firm to produce the socially optimal output, $q_B^{SO} = 1$.

When environmental damages are relatively symmetric, firms merge to receive production subsidies and increase output to the socially optimal level. When goods become more homogeneous ($\beta^R(d) \leq \beta < \overline{\beta}$), the brown firm still has incentives to acquire and shut down its green rival since the brown firm now receives production subsidies to increase its output to the socially optimal level that covers for the loss of the green firm in producing zero units. When environmental damages become more severe, however, the green firm has more incentives to merge with its brown rival to benefit from output shifts and production subsidies provided by the merger; however, the brown firm's incentives to merge weaken as it is subject to higher emission fees to produce fewer units.

4.5 Antitrust which overlooks environmental effects

Suppose the AA, because of its directives, focuses on consumer and producer surplus, overlooking environmental damages. In this context, we consider two cases: (1) the AA anticipating emission fees that the regulator sets in the third stage; and (2) the *naïve* AA which does not anticipate those fees in the third stage.

In case (1), the AA expects that firms, because of emission fees, will produce a socially optimal output whether they merge or not. In this setting, the AA adopts a "hands-free approach" and does not block the merger under any parameter conditions since approving or blocking it yields the same welfare. Interestingly, this happens because the AA anticipates that the regulator will, in the third stage, design emission fees to induce socially optimal output regardless of the market structure.[17] This outcome is independent of the specific welfare function of the AA and whether it differs from the EPA's. If their welfare functions differ, the AA can anticipate that the EPA will set emission fees that induce a welfare level that it, according to the AA, suboptimal; but this welfare level occurs regardless of whether the AA approves or blocks the merger. In case (2), however, the AA naïvely assumes that firms are not subject to emission fees in the third stage, so that the AA approves (blocks) the merger if $\beta \geq \widetilde{\beta}$ ($\beta < \widetilde{\beta}$) following the same decision rule as the one considered in Section 3.2.1.

[17]Since aggregate output coincides with and without the merger, consumer surplus also coincides. In addition, producer surplus is in one case subject to emission fees while in the other case is not. Recalling that total tax collection is returned to the firms in the form of a lump-sum transfer, so emission fees are revenue-neutral, and we obtain that social welfare coincides in both settings.

In both cases, since the AA's imperfect merger approval only affects industry structure but not output levels, the regulator can subsequently charge different emission fees (following those in Proposition 1 to induce socially optimal output from both firms). In this setting, even if the AA overlooks environmental effects, or whether it ignores EPA's activity in subsequent stages altogether, output levels are eventually corrected via environmental regulation. In this regard, the AA's "mistakes" can be rectified by the environmental agency. However, if the administration of emission fees is costly, or if the EPA does not perfectly observe firms' output levels, then the fees may fall short of inducing first-best output levels. In these contexts, it becomes more necessary for the AA to also consider the environmental effects of mergers.

5. Discussion

5.1 Welfare gains from the antitrust authority

In this section, we discuss the welfare gains of having an AA under different contexts. When the EPA is present, this welfare gain, as captured by the difference in welfare levels when both the AA and the EPA are active and that when only the EPA is active, $WG^{EPA} = SW_{AA,EPA} - SW_{EPA}$, is nil because the EPA induces a socially optimal output in both settings (when the AA is present and absent).

When the EPA is absent, however, the welfare gain of having an AA may be positive or negative, as suggested in Section 3. In particular, when the AA is absent, we assume that firms can merge when they experience a profit gain from it –that is, mergers are allowed under all parameter values. However, when the AA is present, it may allow or block mergers under different settings. Therefore, the AA yields no welfare gain when approving mergers, as they would have happened anyway in its absence. In other words, the AA only gives rise to a welfare gain when it blocks a merger, yielding $SW_{AA}^{NM} - SW^{M}$. In this context, we must separately consider the following scenarios.

5.1.1 AA considers environmental damages

Graphically, the AA blocks mergers, and thus yields a welfare gain, in the white-shaded regions of Figures 2, 3a, and 3b. Otherwise, the AA produces no welfare gain relative to a setting without this government agency, as depicted in the grey-shaded areas of these three figures. In addition, welfare gain $SW_{AA}^{NM} - SW^{M}$ is particularly large, suggesting that the AA's presence is more necessary, when: (i) firms sell differentiated products (low β), their costs are relatively symmetric (low c), and they produce similar environmental damages (low d); and when (ii) firms sell relatively homogeneous products (high β), costs are asymmetric (high c) and firms generate different environmental damages (high d).

5.1.2 AA ignores environmental damages

In this context, as analyzed in subsection 3.2.1, the AA considers welfare function $\widetilde{SW}$ rather than SW, and may allow mergers that should have been blocked according to SW (which we referred as SEM) and, similarly, it may block mergers that should have been allowed (denoted as SIM). For simplicity, let us start with the cases in which no regulatory mistakes occur. First, when the AA approves a merger according to both SW and $\widetilde{SW}$, the presence of the AA yields no welfare gains since, as discussed above, the merger would have ensued even when the AA was absent, generating the same social welfare. Second, when the AA blocks a merger according to both SW and $\widetilde{SW}$, the presence of the AA yields the same welfare gain as when the AA considers environmental damages, $SW_{AA}^{NM} - SW^{M}$, capturing the difference in welfare when the merger is prevented (with the AA) and when it ensued (without the AA).

SEM settings. When SEMs can be supported, however, the merger is approved when the AA is present, which would have happened in the absence of the AA anyway, yielding no welfare gains, i.e., $\widetilde{SW}_{AA}^{M} - SW^{M} = 0$. According to this welfare measure, the presence of an AA that ignores environmental damages seems to yield no benefit or harm. Nonetheless, we know from Section 3 that such a merger would have been blocked if the AA took into account the environmental effects that arise after the merger, implying that this type of AA gives rise to a welfare loss, captured by $SW_{AA}^{NM} - SW^{M}$. As discussed above, this welfare loss is particularly large in one of the regions where SEM can be sustained, namely, when firms sell relatively homogeneous products (high β), costs are asymmetric (high c), and firms generate different environmental damages (high d); see top right-hand area in Figure 4b.

SIM settings. Finally, when SIMs can be sustained, the AA blocks a merger that would have occurred in its absence, yielding a welfare loss $\widetilde{SW}_{AA}^{NM} - SW^{M}$. However, if the AA considered the environmental effects from the merger, this difference would avoid a welfare loss since $SW^{NM}_{AA} - SW^{M} < 0$. This welfare loss is relatively large when firms sell differentiated products (low β), costs are symmetric (low c), and firms generate substantially different environmental damages (high d), as depicted at the bottom left area in Figure 4b. Therefore, in industries with these parameter conditions, we can expect SIM decisions by the AA that yield particularly large welfare losses, implying that the AA's consideration of environmental damages is especially urgent in this type of markets.

Alternatively, the presence of an AA that ignores environmental damages is, in this setting, welfare reducing, which entails that society would be better off if the AA was absent. This result suggests that either the AA considers the environmental effects that ensue from the merger or, instead, simply allows all merger requests from firms satisfying the above parameter conditions.

5.2 Welfare gains from the EPA

In the absence of the AA, the introduction of the EPA yields an unambiguous welfare gain since the latter induces firms to produce socially optimal output levels. When the AA is present, as discussed in Section 5, the EPA keeps inducing socially optimal output, thus yielding the first-best outcome. This holds when the AA considers environmental damages, where the merger approval decision is correct, but the EPA provides firms with incentives to increase or decrease their output to approach the social optimum, ultimately producing a welfare gain. Similarly, this result holds when the AA ignores the environmental effects from the merger because, while the merger approval decision may be incorrect, the EPA induces firms to produce the same socially optimal output, whether or not they should have merged according to welfare definition SW.

Therefore, the welfare gain attributed to the EPA is the largest when it needs to use emission fees to correct an incorrect merger approval decision by the AA (which occurs when SEM and SIM are sustained in equilibrium), second largest in those settings where the AA is absent, and followed by contexts where the AA is present and made a correct merger approval decision. In other words, the EPA's role is most important when the AA overlooks the environmental effects that ensue from the merger, but becomes less necessary when the AA considers these effects when evaluating merger requests.

6. Conclusion

Our results indicate that, while mergers of symmetric firms under no regulation can lead to a welfare loss, as in Tirole (1988) and Lambertini (2013), mergers can be welfare-improving especially if firms are asymmetric in their production intensities, that is, when the brown firm generates a more severe environmental damage than its green rival. In these settings, mergers should be promoted. Furthermore, if the regulator can charge emission fees according to the industry structure, then first-best outcomes can be achieved whether firms are allowed to merge or not. Our paper then sheds light on the Horizontal Merger Guidelines (US Department of Justice and Federal Trade Commission, 2010) by suggesting that the AA can approve mergers of differentiated duopolists if they lead to cost savings and pollution mitigation. These criteria may offset the anticompetitive effects of mergers, going beyond the conventional consideration of consumer surplus and cost savings in merger evaluation, as in the merger between Boeing Company and McDonnell Douglas Corporation. Examples where a broader perspective in merger evaluations may be useful include mergers between food processing companies Sysco and US Foods (Woodall and Shannon, 2018, p.220), and between nuclear waste disposal companies EnergySolutions and Waste Control Specialists (US Department of Justice, 2017).

Our results further describe that, when the AA fails to consider the environmental effects associated with mergers, socially excessive mergers can arise when relatively polluting firms expand their output after a merger, which offsets the cost efficiencies that arise from the merger. These occur when firms are relatively homogeneous and asymmetric in cost and environmental damages. In contrast, socially insufficient mergers that were originally blocked may be reconsidered in the light of their reduction of environmental externalities. These happen when firms are relatively differentiated, cost symmetric, and different in pollution intensities.

While this paper examines emission fees/subsidies on one brown firm and one green firm, our model can be generalized into settings with more firms to study the effect of environmental regulation on collusive behavior and welfare implications of an AA which only considers consumer and producer surplus when deciding whether to approve new mergers (Qiu and S. Wang, 2011). Our model can also be extended to allow for the AA, the environmental regulator, or both, not to observe firms' production costs, and how welfare is affected, when emission fees can be used to induce optimal abatement efforts and output levels (Sawaki, 2015).

7. Appendices

7.1 Appendix 1 - The green firm having dual advantages

In this section, we investigate firms' behavior under regulation but assuming now that the green firm enjoys a cost efficiency relative to its brown rival, that is, $c \equiv c_B - c_G$ and $d \equiv d_B - d_G$. As a reference, Lemma A1, A2, A3, A4, Corollary A1, and Proposition A1 follow through the proofs of Lemma 4, 5, 6, 7, Corollary 2, and Proposition 1, respectively.

In the fourth stage, every firm i observes $\left(t_B^M, t_G^M\right)$ if the merger is approved or $\left(t_B^{NM}, t_G^{NM}\right)$ if it is blocked in the third stage, and in response, produces the following output.

Lemma A1. *The green firm produces* $q_G^{NM,R} = \frac{2\left(1-t_G^{NM}\right)-\beta\left(1-c-t_B^{NM}\right)}{4-\beta^2}$ *without and* $q_G^{M,R} = \frac{\left(1-t_G^M\right)-\beta\left(1-c-t_B^M\right)}{2(1-\beta^2)}$ *with the merger. Similarly, the brown firm produces* $q_B^{NM,R} = \frac{2\left(1-c-t_B^{NM}\right)-\beta\left(1-t_G^{NM}\right)}{4-\beta^2}$ *without and* $q_B^{M,R} = \frac{\left(1-c-t_B^M\right)-\beta\left(1-t_G^M\right)}{2(1-\beta^2)}$ *with the merger.*

In the third stage, the regulator solves expression (3) for socially optimal output, as follows,

Lemma A2. *The socially optimal output for green and brown firms are*

$$\left(q_G^{SO}, q_B^{SO}\right) = \begin{cases} \left(\frac{1+2d-\beta(1-c)}{1+2d-\beta^2}, \frac{1-c-\beta}{1+2d-\beta^2}\right) & \textit{if} \quad \beta < \overline{\frac{\beta}{2}} \\ (1,0) & \textit{otherwise}. \end{cases}$$

Therefore, the regulator assigns more (less) output to the green (brown) firm than those in the Lemma 5 where the green firm suffers a cost disadvantage, since this firm now enjoys cost advantage (disadvantage) to the other firm. When the brown firm suffers a significant cost disadvantage, the green firm produces 1 unit which is costless to produce and does not pollute.

The following corollary depicts how socially optimal output changes in the parameter values.

Corollary A1. *When both firms are active,* q_G^{SO} (q_B^{SO}) *decreases in* β *if goods are sufficiently differentiated, where* $\beta < \min\left\{\frac{1-c}{2}, \frac{1+2d}{2(1-c)}\right\}$*, and in addition, increases (decreases) in* c *and* d*, respectively.*

Similar to Corollary 2, when goods become more differentiated (low β), the regulator seeks more units of both goods. However, when the brown good becomes more costly to produce or more polluting, the regulator seeks more (less) units of the green (brown) good.

In this context, the regulator sets the following emission fees to achieve socially optimal output.

Proposition A1. *When $q_G^{SO} > 0$ and $q_B^{SO} > 0$, the regulator sets emission fees of*

$$t_G^{NM} = -\frac{1+2d-\beta(1-c)}{1+2d-\beta^2} \quad \text{and} \quad t_B^{NM} = \frac{(2d-1)(1-c-\beta)}{1+2d-\beta^2}$$

$$t_G^{M} = -1 \quad \text{and} \quad t_B^{M} = \frac{(2d-1+\beta^2)(1-c)-4\beta d}{1+2d-\beta^2}$$

Otherwise, the regulator sets emission fees of $t_G = -1$ and $t_B = 0$ to achieve $q_G^{SO} = 1$ and $q_B^{SO} = 0$.

Comparing with Proposition 1, we see that the green firm receives a more generous subsidy while the brown firm is subject to a less stringent fee whether it merges with its rival or not. This happens because the cost disadvantage of the brown firm leads this firm to reduce its output, so that the green firm needs to be further subsidized to increase output to the socially optimal level.

The following lemma characterizes the AA's decisions in the second stage of the game.

Lemma A3. *Mergers are approved by the AA under all parameter conditions.*

Following Lemma 6, we obtain the same results because firms are induced by the emission fees to produce first-best output or to stop production whether they are merged or not. In this regard, the AA, which takes into account the environmental externalities, does not block the merger and lets the environmental regulator does its job in affecting firms' behavior in the subsequent stages.

Finally, the following lemma examines firms' incentives to merge in first stage of the game.

Lemma A4. *Under environmental regulation, both firms have incentives to merge under all parameter conditions, whether the merger keeps both firms active or shuts down the brown firm.*

Similar to Lemma 7, in anticipation of the AA's merger approval in the second stage and the regulator's emission fees in the third stage, both firms will have incentives to merge.

7.2 Appendix 2 - Comparison across regulatory regimes

The next corollary illustrates firm i's output change due to regulation, $\Delta q_i^{NM} \equiv q_i^{NM,R} - q_i^{NM}$ when firms do not merge, and $\Delta q_i^{M} \equiv q_i^{M,R} - q_i^{M}$ when they do.

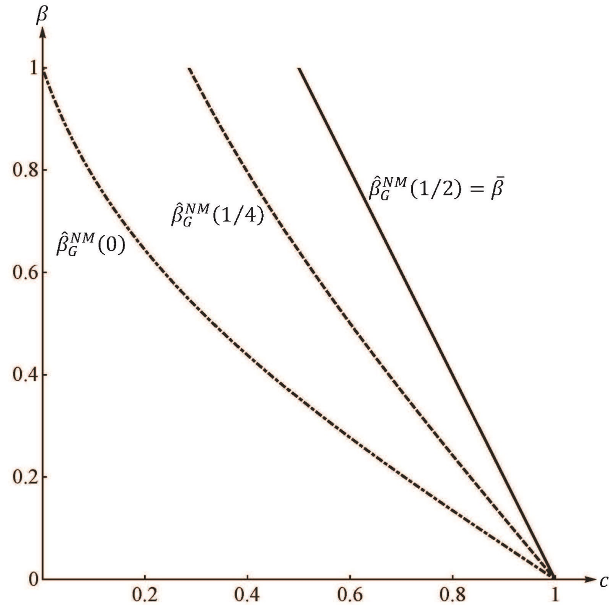
Corollary A2. *When firms do not merge, the green (brown) firm produces more (less) output with than without environmental regulation if $\beta < \widehat{\beta}_G^{NM}(d)$ $\left(\underline{\beta}_B^{NM}(d) < \beta < \overline{\beta}_B^{NM}(d)\right)$. In contrast, when firms merge, the green (brown) firm produces more (less) output with than without environmental regulation under all parameter values (when $\beta > \widehat{\beta}_B^{M}(d) \equiv \sqrt{1-2d}$, respectively). For compactness, cutoffs $\widehat{\beta}_G^{NM}(d)$, $\underline{\beta}_B^{NM}(d)$, and $\overline{\beta}_B^{NM}(d)$ are provided in the appendix.*

Figure A1a depicts the effect of regulation on the unmerged green firm. When $\beta < \widehat{\beta}_G^{NM}(d)$, this firm produces more units when regulated than otherwise, $q_G^{NM,R} > q_G^{NM}$. To understand this result, note that, when $d = 0$, the equilibrium output under no regulation is too low in the standard duopoly model where $c = 0$ and $\beta = 1$. When c (β) increases (decreases), equilibrium output under no regulation increases, and may become socially excessive, implying that regulation leads to an output reduction if $\beta > \widehat{\beta}^{NM}(0)$. When d increases, the (β, c)-pairs for which the green firm's output was insufficient under no regulation expands, as depicted by the upward shift in cutoff $\widehat{\beta}^{NM}(d)$. [18]

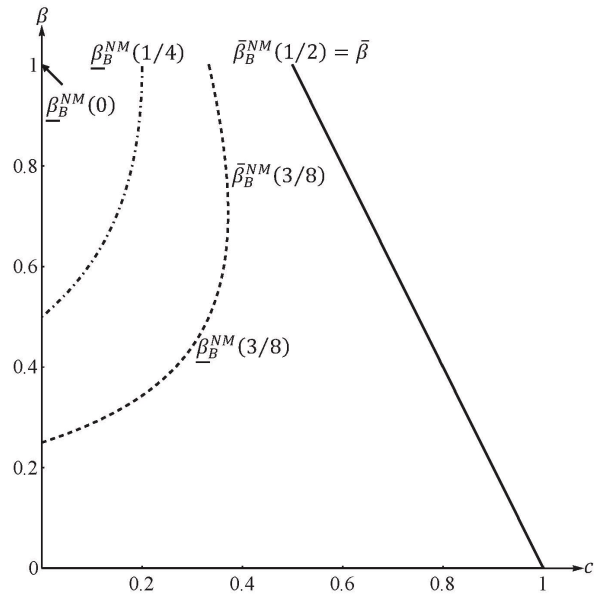
Figure A1b depicts the effect of regulation on the unmerged brown firm. When β lies below cutoff $\underline{\beta}_B^{NM}(d)$ or above cutoff $\overline{\beta}_B^{NM}(d)$, this firm produces more units under regulation than otherwise, $q_B^{NM,R} > q_B^{NM}$. Thus, regulation induces the brown firm to increase production only when its cost advantage and/or product heterogeneity widens. This advantage/heterogeneity must be more substantial when the brown firm becomes more polluting. However, when environmental damages satisfy $d \geq 1/2$, the regulator seeks less output from the relatively polluting brown firm by imposing emission fees.[19]

[18] In addition, cutoff $\widehat{\beta}_G^{NM}(d)$ satisfies $\widehat{\beta}_G^{NM}(d) < \beta^R(d)$ if and only if $(1-c)^2(1+2d) < 1$, simplifying to $\beta^R(d) < \frac{1}{1-c}$ which holds in this context.

[19] The regulator seeks an output increase from the brown firm when it generates the same environmental damage as the green firm, $d = 0$, under all parameter values. However, if this firm becomes more polluting (d increases), cutoff $\overline{\beta}_B^{NM}(d)$ bends away from point $(c, \beta) = (0, 1)$, so that the regulator reduces its output when firms produce more homogeneous goods (high β) and are relatively symmetric in costs (low c) satisfying $\underline{\beta}_B^{NM}(d) < \beta < \overline{\beta}_B^{NM}(d)$. When $d = 1/2$, cutoff $\overline{\beta}_B^{NM}(d)$ coincides with cutoff $\overline{\beta}$ so that the regulator seeks fewer units from this firm under all



(a) Unmerged green firm



(b) Unmerged brown firm

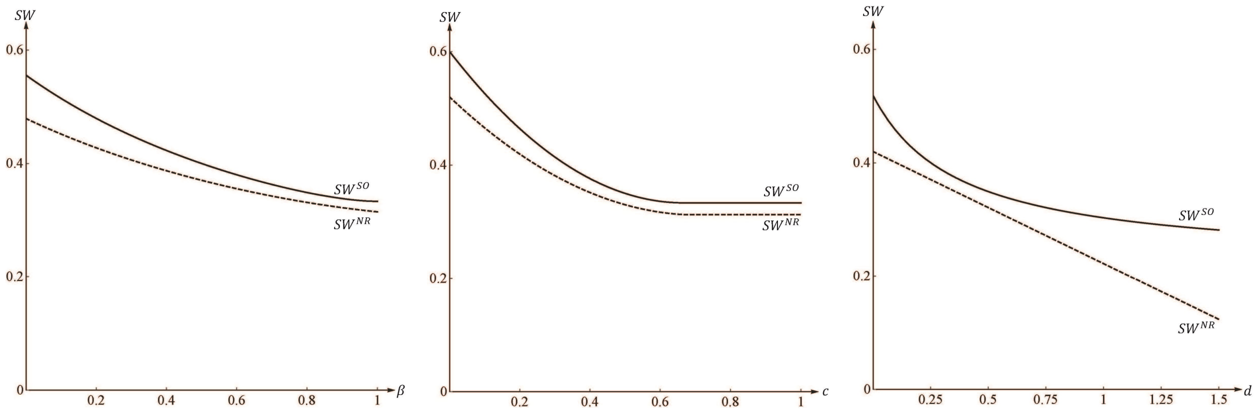
Figure A1: Output change

We next examine how social welfare (both with and without regulation) is affected by changes in the parameters.

Corollary A3. *When both goods are produced, social welfare decreases in β, c, and d. When only the brown good is produced, social welfare decreases in d but does not vary with β or c.*

Taking $\beta = 1/2$, $c = 1/3$, and $d = 1/4$ and varying one parameter at a time, Figures A2a to A2c depict that environmental regulation, which induces firms to produce socially optimal levels, unambiguously increases social welfare from SW^{NR} to SW^{SO}. Nonetheless, social welfare decreases if (i) goods become more homogenous (β increases), (ii) the green firm becomes less efficient (c increases), or (iii) the brown firm becomes more polluting (d increases) when $\beta < \beta^R(d)$.

parameter conditions. Note that cutoff $\hat{\beta}_B^M < \underline{\beta}_B^{NM}(d)$ if and only if $c > \frac{3\left(1-\sqrt{1-2d}\right)-2d}{3-2d}$.



(a) Variation in β (b) Variation in c (c) Variation in d

Figure A2: Social welfare

7.3 Appendix 3 - Technical proofs

7.3.1 Proof of Lemma 1

No merger. For $i = \{B, G\}$, every firm i chooses q_i to solve

$$\max_{q_i \geq 0} \pi\left(q_i\right) = \left(1 - q_i - \beta q_j - c_i\right) q_i$$

Taking the first order condition with respect to q_i, and assuming interior solutions,

$$q_i\left(q_j\right) = \frac{1 - \beta q_j - c_i}{2}$$

Suppose firm i dominates the market (which condition is provided thereafter), $q_j = 0$ yields $q_i = \frac{1-c_i}{2}$. Solving q_i and q_j simultaneously, we obtain the following equilibrium output.

$$q_i^{NM} = \begin{cases} \frac{2(1-c_i)-\beta(1-c_j)}{4-\beta^2} & \text{if} \quad \beta < \min\left\{\frac{2(1-c_i)}{1-c_j}, \frac{2(1-c_j)}{1-c_i}\right\} \\ \frac{1-c_i}{2} & \text{if} \quad \beta \geq \frac{2(1-c_j)}{1-c_i} \\ 0 & \text{otherwise.} \end{cases}$$

Substituting q_i^{NM} into the firm's profit function, equilibrium profits become

$$\pi_i^{NM} = \begin{cases} \left(\frac{2(1-c_i)-\beta(1-c_j)}{4-\beta^2}\right)^2 & \text{if} \quad \beta < \min\left\{\frac{2(1-c_i)}{1-c_j}, \frac{2(1-c_j)}{1-c_i}\right\} \\ \frac{(1-c_i)^2}{4} & \text{if} \quad \beta \geq \frac{2(1-c_j)}{1-c_i} \\ 0 & \text{otherwise.} \end{cases}$$

Merger. The joint profit maximization problem of the merged firm becomes

$$\max_{q_i, q_j \geq 0} \pi\left(q_i, q_j\right) = \left(1 - q_i - \beta q_j - c_i\right) q_i + \left(1 - q_j - \beta q_i - c_j\right) q_j$$

Taking the first order condition with respect to q_i, and assuming interior solutions,

$$q_i\left(q_j\right) = \frac{1 - 2\beta q_j - c_i}{2}$$

Solving q_i and q_j simultaneously, we obtain the following equilibrium output.

$$q_i^M = \begin{cases} \frac{(1-c_i)-\beta(1-c_j)}{2(1-\beta^2)} & \text{if} \quad \beta < \min\left\{\frac{1-c_i}{1-c_j}, \frac{1-c_j}{1-c_i}\right\} \\ \frac{1-c_i}{2} & \text{if} \quad \beta \geq \frac{1-c_j}{1-c_i} \\ 0 & \text{otherwise.} \end{cases}$$

Substituting q_i^M and q_j^M into the profit function, the merged firm i generates profits of

$$\pi_i^M = \begin{cases} \frac{1-c_i}{2} \cdot \frac{(1-c_i)-\beta(1-c_j)}{2(1-\beta^2)} & \text{if} \quad \beta < \min\left\{\frac{1-c_i}{1-c_j}, \frac{1-c_j}{1-c_i}\right\} \\ \frac{(1-c_i)^2}{4} & \text{if} \quad \beta \geq \frac{1-c_j}{1-c_i} \\ 0 & \text{otherwise.} \end{cases}$$

In this context, green and brown firms' equilibrium output under no merger are $q_G^{NM} = \frac{2-\beta-2c}{4-\beta^2}$ and $q_B^{NM} = \frac{2-\beta+\beta c}{4-\beta^2}$, respectively, both of which are positive since $\beta < \overline{\beta} \equiv 2\left(1-c\right)$ by definition. Under a merger, however, the green firm's output becomes $q_G^M = \frac{1-\beta-c}{2(1-\beta^2)}$ which is positive when $\beta < \frac{\overline{\beta}}{2}$, and the brown firm's output becomes $q_B^M = \frac{1-\beta+\beta c}{2(1-\beta^2)}$ which is positive for all parameter values. Otherwise, when $\frac{\overline{\beta}}{2} \leq \beta < \overline{\beta}$, the merged firm will set $q_G^M = 0$ and $q_B^M = \frac{1}{2}$.

For the green firm to reduce output after the merger, $q_G^M < q_G^{NM}$ entails $\frac{1-\beta-c}{2(1-\beta^2)} < \frac{2-\beta-2c}{4-\beta^2}$, simplifying to $\left(1-\beta\right)\left(2-\beta\right) + 3\beta c > 0$ that holds for all $\beta > 0$. In comparison, for the brown firm to reduce output after the merger, $q_B^M < q_B^{NM}$ implies $\frac{1-\beta+\beta c}{2(1-\beta^2)} < \frac{2-\beta+\beta c}{4-\beta^2}$, which holds for all values of $c < \frac{(1-\beta)(2-\beta)}{2+\beta^2} < 1-\beta$, or rearranged to yield $\beta < \beta_B^{NR} \equiv \frac{3-\sqrt{9-8(1-c)^2}}{2(1-c)} < \frac{\overline{\beta}}{2}$.

7.3.2 Proof of Corollary 1

When $\beta < \beta_B^{NR}$, the inequality $\Delta q_G^{NR} \equiv q_G^{NM} - q_G^M > q_B^{NM} - q_B^M \equiv \Delta q_B^{NR}$ is reduced to $\frac{\beta(1+\beta)(2+\beta)c}{2(1-\beta^2)(4-\beta^2)} > 0$, and $\frac{\partial q_G^M}{\partial \beta} = -\frac{(1-\beta)^2+2\beta c}{2(1-\beta^2)^2} < 0$ that holds for all $\beta > 0$ and $\frac{\partial q_B^M}{\partial \beta} = -\frac{(1-\beta)^2-\left(1+\beta^2\right)c}{2(1-\beta^2)^2} < 0$ if $\beta < \frac{1-\sqrt{c(2-c)}}{1-c} < \beta_B^{NR}$. In comparison, when $\beta \geq \beta_B^{NR}$, we obtain that $\Delta q_G^{NR} > 0 \geq \Delta q_B^{NR}$.

7.3.3 Proof of Lemma 2

Consumer surplus is consumers' utility net of the price paid on units purchased, as given by

$$\begin{aligned} CS\left(q_B, q_G\right) &= q_B + q_G - \frac{1}{2}\left(q_B^2 + 2\beta q_B q_G + q_G^2\right) - \left(1 - q_B - \beta q_G\right) q_B - \left(1 - q_G - \beta q_B\right) q_G \\ &= \frac{1}{2}\left(q_B^2 + 2\beta q_B q_G + q_G^2\right) \end{aligned}$$

When $\beta < \frac{\overline{\beta}}{2}$, both firms are active before and after the merger, yielding social welfare of

$$\begin{aligned} SW\left(q_B, q_G\right) &= \underbrace{\frac{1}{2}\left(q_B^2 + 2\beta q_B q_G + q_G^2\right)}_{CS} + \underbrace{p_B(q_B, q_G) q_B + \left[p_G(q_B, q_G) - c\right] q_G}_{PS} - \underbrace{d q_B^2}_{Env} \\ &= \left(1 - \frac{1}{2} q_G - c\right) q_G + \left(1 - \frac{1 + 2d}{2} q_B\right) q_B - \beta q_B q_G \end{aligned}$$

In contrast, when $\beta \geq \frac{\overline{\beta}}{2}$, the green firm is inactive after the merger, yielding social welfare of

$$SW\left(q_B^M, q_G^M\right) = \frac{1}{2}\left(\frac{1}{2}\right)^2 + \left(\frac{1}{2}\right)^2 - d\left(\frac{1}{2}\right)^2 = \frac{3 - 2d}{8}$$

Solving for $SW(q_B^M, q_G^M) > SW(q_B^{NM}, q_G^{NM})$, we obtain two cutoffs, one in which both firms remain in the market after the merger, $\beta < \beta_1\left(d\right) < \frac{\overline{\beta}}{2}$, which inverse function solves

$$d^{-1}\left(\beta\right) > \frac{4\left(1-\beta^2\right)^2\left[\left(4+\beta^2\right)\left(2-2c+c^2\right)-8\beta(1-c)\right]-\left(1-\beta^2\right)\left(4-\beta^2\right)(1-c)\left[\left(4+5\beta^2\right)(1-c)-6\beta\left(4-\beta^2\right)\right]}{2\left[6\beta(4-\beta^4)(1-c)-\beta^2(24-15\beta^2)-\beta^2(20-16\beta^2+5\beta^4)(1-c)^2\right]},$$

and one that only the brown firm is active after the merger, $\overline{\beta} > \beta_2\left(d\right) \geq \frac{\overline{\beta}}{2}$, solving

$$d^{-1}\left(\beta\right) < \frac{\left(4 - \beta^2\right)\left[3\left(4 - \beta^2\right) - 8\left(1 - c\right)^2\right] - 4\left[\left(4 + \beta^2\right)\left(2 - 2c + c^2\right) - 8\beta\left(1 - c\right)\right]}{2\beta\left[2\left(1 - c\right) - \beta\right]\left[8 - 2\beta\left(1 - c\right) - \beta^2\right]}$$

7.3.4 Proof of Lemma 3

Define $\Delta^{NR} \equiv \pi^M - \pi^{NM}$. When $\beta < \min\left\{\frac{1-c_i}{1-c_j}, \frac{1-c_j}{1-c_i}\right\}$, $\Delta^{NR} = \left(4 + 5\beta^2\right)\left(1 - c_i\right)^2 - 2\beta\left(8 + \beta^2\right)\left(1 - c_i\right)\left(1 - c_j\right) + \left(4 + 5\beta^2\right)\left(1 - c_j\right)^2$, which is symmetric and attains a minimum at $c_i = c_j$ given the positive semi-definite Hessian matrix $H\left(1 - c_i, 1 - c_j\right) = 2\left(4 - \beta^2\right)^2\left(1 - \beta^2\right) \geq 0$, simplifying the above results to $\Delta\pi^{NR} > \left(1 - \beta\right)\left(2 - \beta\right)^2\left(1 - c_i\right)^2 \geq 0$. Whereas, when $\frac{1-c_j}{1-c_i} \leq \beta < \frac{2(1-c_j)}{1-c_i}$, $\Delta^{NR} = -\beta^2\left(12 - \beta^2\right)\left(1 - c_i\right)^2 + 32\beta\left(1 - c_i\right)\left(1 - c_j\right) - 4\left(4 + \beta^2\right)\left(1 - c_j\right)^2 = \left[\beta\left(1 - c_i\right) - 2\left(1 - c_j\right)\right]\left[\beta^3\left(1 - c_i\right) + 2\beta^2\left(1 - c_j\right) - 12\beta\left(1 - c_i\right) + 8\left(1 - c_j\right)\right]$, which is positive because $\beta^3\left(1 - c_i\right) + 2\beta^2\left(1 - c_j\right) - 12\beta\left(1 - c_i\right) + 8\left(1 - c_j\right) < -4\left(1 - \beta^2\right)\left(1 - c_j\right) \leq 0$.

7.3.5 Proof of Lemma 4

No merger. For $i = \{B, G\}$, every firm i chooses q_i to solve

$$\max_{q_i \geq 0} \pi(q_i) = \left(1 - q_i - \beta q_j\right) q_i - (c_i + t_i)\, q_i$$

Taking the first order condition with respect to q_i, and assuming interior solutions,

$$t_i = 1 - 2q_i - \beta q_j - c_i$$

such that the best response function of firm i, in response to firm j's output, becomes

$$q_i\left(q_j\right) = \frac{1 - \beta q_j - c_i - t_i}{2}$$

Defining $x_i \equiv 1 - c_i - t_i$, firms' output are mutual best response to each other, yielding

$$q_i^{NM} = \frac{2(1 - c_i - t_i) - \beta\left(1 - c_j - t_j\right)}{4 - \beta^2} = \frac{2x_i - \beta x_j}{4 - \beta^2} \tag{A1}$$

Substituting q_i^{NM} into the profit function, equilibrium profits of firm i become

$$\pi_i^{NM} = \left(\frac{2(1 - c_i - t_i) - \beta\left(1 - c_j - t_j\right)}{4 - \beta^2}\right)^2 = \left(\frac{2x_i - \beta x_j}{4 - \beta^2}\right)^2$$

Merger. The joint profit maximization problem of the merged firm becomes

$$\max_{q_i, q_j \geq 0} \pi\left(q_i, q_j\right) = \left(1 - q_i - \beta q_j - c_i - t_i\right) q_i + \left(1 - q_j - \beta q_i - c_j - t_j\right) q_j$$

Taking the first order condition with respect to q_i, and assuming interior solutions,

$$t_i = 1 - 2q_i - 2\beta q_j - c_i$$

Solving q_i and q_j simultaneously, we obtain

$$q_i^M = \frac{(1 - c_i - t_i) - \beta\left(1 - c_j - t_j\right)}{2(1 - \beta^2)} = \frac{x_i - \beta x_j}{2(1 - \beta^2)} \tag{A2}$$

Substituting q_i^M and q_j^M into the profit function, the merged firm i generates profits of

$$\pi_i^M = \frac{1 - c_i - t_i}{2} \cdot \frac{(1 - c_i - t_i) - \beta\left(1 - c_j - t_j\right)}{2(1 - \beta^2)} = \frac{x_i^2 - \beta x_i x_j}{4(1 - \beta^2)}$$

In addition, we find that $\frac{\partial q_i^{NM}}{\partial t_i} = -\frac{2}{4-\beta^2} > -\frac{1}{2(1-\beta^2)} = \frac{\partial q_i^M}{\partial t_i}$ and $\frac{\partial q_i^{NM}}{\partial t_j} = \frac{\beta}{4-\beta^2} < \frac{\beta}{2(1-\beta^2)} = \frac{\partial q_i^M}{\partial t_j}$.

Monopoly. If instead, firm i monopolizes the market, then the monopolist solves

$$\max_{q_i \geq 0} \pi(q_i) = (1 - q_i) q_i - (c_i + t_i) q_i$$

Taking the first order condition with respect to q_i, and assuming interior solutions,

$$t_i = 1 - 2q_i - c_i$$

yielding output of firm i of

$$q_i = \frac{1 - c_i - t_i}{2}$$

with associated profits of

$$\pi_i = \frac{(1 - c_i - t_i)^2}{4}$$

7.3.6 Proof of Lemma 5

Social welfare is given by

$$\begin{aligned} &SW(q_i, q_j) \\ &= \underbrace{\frac{q_i^2 + 2\beta q_i q_j + q_j^2}{2}}_{CS} + \underbrace{[p_i(q_i, q_j) - c_i - t_i] q_i + [p_j(q_i, q_j) - c_j - t_j] q_j}_{PS} + \underbrace{t_i q_i + t_j q_j}_{Tax} - \underbrace{(d_i q_i^2 + d_j q_j^2)}_{Env} \\ &= \left(1 - \frac{1 + 2d_i}{2} q_i - c_i\right) q_i + \left(1 - \frac{1 + 2d_j}{2} q_j - c_j\right) q_j - \beta q_i q_j \qquad \text{(A3)} \end{aligned}$$

Total differentiation of expression (A3) yields

$$dSW(q_i, q_j) = (1 - q_i - \beta q_j - 2d_i q_i - c_i) dq_i + (1 - q_j - \beta q_i - 2d_j q_j - c_j) dq_j$$

The regulator, which takes the firms' responses to the emission fees into account, solves

$$\frac{\partial SW}{\partial t} = (1 - q_i - \beta q_j - 2d_i q_i - c_i) \frac{\partial q_i}{\partial t} + (1 - q_j - \beta q_i - 2d_j q_j - c_j) \frac{\partial q_j}{\partial t}$$

Differentiating expression (A1) with respect to t_i and t_j, the unmerged firm i's output changes in the regulator's emission fees for this and the rival firm are $\frac{\partial q_i^{NM}}{\partial t_i} = -\frac{2}{4-\beta^2}$ and $\frac{\partial q_i^{NM}}{\partial t_j} = \frac{\beta}{4-\beta^2}$, respectively. Similarly, differentiating expression (A2) with respect to t_i and t_j, the merged firm's output changes in the regulator's emission fees are $\frac{\partial q_i^M}{\partial t_i} = -\frac{1}{2(1-\beta^2)}$ and $\frac{\partial q_i^M}{\partial t_j} = \frac{\beta}{2(1-\beta^2)}$, respectively.

The regulator, which observes the merger was approved, solves

$$\frac{\partial SW^M}{\partial t_i} = -\frac{1 - q_i - \beta q_j - 2d_i q_i - c_i}{2\left(1-\beta^2\right)} + \frac{\beta\left(1 - q_j - \beta q_i - 2d_j q_j - c_j\right)}{2\left(1-\beta^2\right)}$$

Setting $\frac{\partial SW^M}{\partial t} = 0$, the pair of optimal emission fees, (t_i^M, t_j^M) under merger, satisfies

$$\left(1 - \beta^2 + 2d_i\right) q_i - 2\beta d_j q_j = (1 - c_i) - \beta\left(1 - c_j\right) \tag{A4}$$

The regulator, which observes the merger was blocked, solves

$$\frac{\partial SW^{NM}}{\partial t_i} = -\frac{2\left(1 - q_i - \beta q_j - 2d_i q_i - c_i\right)}{4-\beta^2} + \frac{\beta\left(1 - q_j - \beta q_i - 2d_j q_j - c_j\right)}{4-\beta^2}$$

Setting $\frac{\partial SW^{NM}}{\partial t} = 0$, the pair of optimal emission fees, (t_i^{NM}, t_j^{NM}) under no-merger, satisfies

$$\left(2 - \beta^2 + 4d_i\right) q_i + \beta\left(1 - 2d_j\right) q_j = 2(1 - c_i) - \beta\left(1 - c_j\right) \tag{A5}$$

Socially optimal output, which solves $dSW\left(q_i, q_j\right) = 0$ in (A4) and (A5) simultaneously, is

$$q_i^{SO} = \frac{\left(1+2d_j\right)(1-c_i) - \beta\left(1-c_j\right)}{(1+2d_i)\left(1+2d_j\right) - \beta^2}$$

Since output must be non-negative, setting the numerator of q_i^{SO} equal to zero, we obtain cutoff $\beta_i^R(d) = \frac{(1+2d_j)(1-c_i)}{1-c_j}$. When $\beta_i^R(d) \le \beta < \beta_j^R(d)$, $q_i^{SO} = 0$ and $q_j^{SO} = \frac{1-c_j}{1+2d_j}$ that solves $\max_{q_j \ge 0} SW\left(0, q_j\right) = \left(1 - \frac{1+2d_j}{2} q_j - c_j\right) q_j$. In this context, we obtain that $q_G^{SO} = 0$ and $q_B^{SO} = \frac{1}{1+2d}$ when $\beta \ge \beta^R(d) \equiv \beta_G^R(d) = (1+2d)(1-c)$ since the condition $\beta < \beta_B^R(d) = \frac{1}{1-c}$ always holds.

7.3.7 Proof of Corollary 2

When $\beta < \min\{\beta_i^R(d), \beta_j^R(d)\}$, $\frac{\partial q_i^{SO}}{\partial \beta} = \frac{(1+2d_j)[2\beta(1-c_i)-(1-c_j)(1+2d_i)]-\beta^2(1-c_j)}{[(1+2d_i)(1+2d_j)-\beta^2]^2}$, which sufficient condition for $\frac{\partial q_i^{SO}}{\partial \beta} < 0$ is $\beta < \frac{\beta_j^R(d)}{2}$. In this context, $\beta < \frac{1}{2(1-c)}$ is sufficient for $\frac{\partial q_G^{SO}}{\partial \beta} < 0$ and similarly, $\beta < \frac{(1+2d)(1-c)}{2}$ is sufficient for $\frac{\partial q_B^{SO}}{\partial \beta} < 0$. In addition, we obtain that $\frac{\partial q_i^{SO}}{\partial c_i} = -\frac{1+2d_j}{(1+2d_i)(1+2d_j)-\beta^2} < 0$, $\frac{\partial q_i^{SO}}{\partial c_j} = \frac{\beta}{(1+2d_i)(1+2d_j)-\beta^2} > 0$, $\frac{\partial q_i^{SO}}{\partial d_i} = \frac{-2(1+2d_j)[(1-c_i)(1+2d_j)-\beta(1-c_j)]}{[(1+2d_i)(1+2d_j)-\beta^2]^2} < 0$, and $\frac{\partial q_i^{SO}}{\partial d_j} = \frac{2\beta[(1-c_j)(1+2d_i)-\beta(1-c_i)]}{[(1+2d_i)(1+2d_j)-\beta^2]^2} > 0$. When $\beta_i^R(d) \le \beta < \beta_j^R(d)$, $\frac{\partial q_j^{SO}}{\partial \beta} = \frac{\partial q_j^{SO}}{\partial c_i} = \frac{\partial q_j^{SO}}{\partial d_i} = 0$, $\frac{\partial q_j^{SO}}{\partial c_j} = -\frac{1}{1+2d_j} < 0$, and $\frac{\partial q_j^{SO}}{\partial d_j} = -\frac{1-c_j}{(1+2d_j)^2} < 0$, and symmetric results apply to $\beta_j^R(d) \le \beta < \beta_i^R(d)$.

7.3.8 Proof of Proposition 1

When both firms are active, we set $q_i^{NM} = q_i^{SO}$ in expression (A1), the emission fees that align non-merger output with socially optimal levels satisfy $t_i^{NM} = 1 - 2q_i^{SO} - \beta q_j^{SO} - c_i$, yielding

$$t_i^{NM} = \frac{(1-2d_i)\left[\beta\left(1-c_j\right)-(1-c_i)\left(1+2d_j\right)\right]}{(1+2d_i)\left(1+2d_j\right)-\beta^2}$$

Similarly, we set $q_i^M = q_i^{SO}$ in expression (A2), the emission fees that align merger output with socially optimal levels satisfy $t_i^M = 1 - 2q_i^{SO} - 2\beta q_j^{SO} - c_i$, which, after rearranging, becomes

$$t_i^M = -\frac{\left[(1-2d_i)\left(1+2d_j\right)-\beta^2\right](1-c_i)+4\beta d_i\left(1-c_j\right)}{(1+2d_i)\left(1+2d_j\right)-\beta^2}$$

When only one firm is active in the market, the emission fee that solves $t_i = 1 - 2q_i^{SO} - c_i$ is

$$t_i = -\frac{(1-2d_i)(1-c_i)}{1+2d_i}$$

7.3.9 Proof of Lemma 6

Substituting (q_i^{SO}, q_j^{SO}) into expression (A3), social welfare under regulation becomes

$$SW^{SO} = \begin{cases} \frac{(1-c_i)^2(1+2d_j)+(1-c_j)^2(1+2d_i)-2\beta(1-c_i)(1-c_j)}{2[(1+2d_i)(1+2d_j)-\beta^2]} & \text{if} \quad \beta < \min\left\{\beta_i^R(d), \beta_j^R(d)\right\} \\ \frac{1}{2(1+2d_i)} & \text{if} \quad \beta \geq \beta_j^R(d) \\ \frac{1}{2(1+2d_j)} & \text{if} \quad \beta \geq \beta_i^R(d) \end{cases}$$

that coincides both when firms choose to merge and not merge in producing socially optimal output.

7.3.10 Proof of Lemma 7

Substituting $t_i^{NM} = 1 - 2q_i^{SO} - \beta q_j^{SO} - c_i$ into the profit function of firm i under no merger,

$$\pi_i^{NM,R} = \left(\frac{2(1-c_i-t_i)-\beta\left(1-c_j-t_j\right)}{4-\beta^2}\right)^2 = \left(q_i^{SO}\right)^2$$

Substituting $t_i^M = 1 - 2q_i^{SO} - 2\beta q_j^{SO} - c_i$ into the profit function of firm i under merger,

$$\pi_i^{M,R} = \frac{1-c_i-t_i}{2} \cdot \frac{(1-c_i-t_i)-\beta\left(1-c_j-t_j\right)}{2(1-\beta^2)} = q_i^{SO}\left(q_i^{SO}+\beta q_j^{SO}\right)$$

Substituting $t_i = 1 - 2q_i^{SO} - c_i$ into the profit function of firm i when it dominates the market,

$$\pi_i^R = \left[1 - q_i^{SO} - c_i - \left(1 - 2q_i^{SO} - c_i\right)\right] q_i^{SO} = \left(q_i^{SO}\right)^2$$

Therefore, we obtain that $\pi_i^{M,R} \geq \pi_i^{NM,R} = \pi_i^R$ for any $\beta \geq 0$ and $i = \{B, G\}$.

In this context, when environmental damages increase, changes in merger profits become

$$\frac{\partial \pi_G^{M,R}}{\partial d} = \left(q_G^{SO} + \beta q_B^{SO}\right) \frac{\partial q_G^{SO}}{\partial d} + q_G^{SO} \frac{\partial (1-c)}{\partial d} > 0$$

$$\frac{\partial \pi_B^{M,R}}{\partial d} = \left(q_B^{SO} + \beta q_G^{SO}\right) \frac{\partial q_B^{SO}}{\partial d} - q_B^{SO} \frac{2(1-\beta^2)\left[1 - \beta(1-c)\right]}{\left(1 + 2d - \beta^2\right)^2} < 0$$

7.3.11 *Proof of Corollary A2*

Setting $q_i^{SO} > q_i^{NM}$, parameter β solves the following inequality,

$$\left(1 - 2d_j\right)(1 - c_i)\beta^2 - \left[4 - (1 + 2d_i)\left(1 + 2d_j\right)\right]\left(1 - c_j\right)\beta + 2(1 - 2d_i)\left(1 - 2d_j\right)(1 - c_i) > 0$$

In this context, we obtain that $q_G^{SO} > q_G^{NM}$ if and only if $\beta < \widehat{\beta}_G^{NM}(d)$, where

$$\widehat{\beta}_G^{NM}(d) = \frac{3 - 2d - \sqrt{(3-2d)^2 - 8(1-4d^2)(1-c)^2}}{2(1-2d)(1-c)}.$$

In contrast, we obtain that $q_B^{SO} < q_B^{NM}$ if and only if $\underline{\beta}_B^{NM}(d) < \beta < \overline{\beta}_B^{NM}(d)$, where

$$\underline{\beta}_B^{NM}(d) \equiv \frac{(3-2d)(1-c) - \sqrt{(3-2d)^2(1-c)^2 - 8(1-2d)}}{2}, \text{ and}$$

$$\overline{\beta}_B^{NM}(d) \equiv \frac{(3-2d)(1-c) + \sqrt{(3-2d)^2(1-c)^2 - 8(1-2d)}}{2}.$$

Since $\frac{\partial q_G^{SO}}{\partial d} > 0$, it suffices to evaluate $q_G^{SO} > q_G^M$ at $d = 0$, which simplifies to $\frac{1-\beta-c}{1-\beta^2} > \frac{1-\beta-c}{2(1-\beta^2)}$ that holds. In addition, $q_B^M > q_B^{SO}$ reduces to $d > \frac{1-\beta^2}{2}$, which is rearranged to yield $\beta > \widehat{\beta}_B^M \equiv \sqrt{1-2d}$.

7.3.12 *Proof of Corollary A3*

Consider $\beta < \beta^R(d)$ ($\beta < \frac{\overline{\beta}}{2}$) under (no) regulation. Totally differentiating the social welfare function in expression (A3) and applying the Envelope Theorem, we obtain $\frac{dSW}{d\beta} = \underbrace{\frac{\partial SW}{\partial q}\frac{\partial q}{\partial t}\frac{\partial t}{\partial \beta}}_{=0} + \frac{\partial SW}{\partial \beta} = -q_B^k q_G^k < 0$, and similarly, $\frac{dSW}{dc} = \frac{\partial SW}{\partial c} = -q_G^k < 0$ and $\frac{dSW}{dd} = \frac{\partial SW}{\partial d} = -\left(q_B^k\right)^2 < 0$, where $k \in \{M, NM, \{M, R\}, \{NM, R\}\}$. When $\beta \geq \beta^R(d)$, $SW^{SO} = \frac{1}{2(1+2d)}$ and similarly, $SW^M = \frac{3-2d}{8}$ when $\beta \geq \frac{\overline{\beta}}{2}$, both being monotonically decreasing in d but invariant with β and c.

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