Mergers as an environmental ally
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 firms have stronger incentives to merge when goods are more differentiated, costs are more symmetric, and products generate similar environmental damages. However, socially excessive mergers can arise when firms shift output to the more cost-efficient firm after the merger, which may cause more pollution. In contrast, socially insufficient mergers can arise if output shifts after the merger would have reduced 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).

Allowing for firm-level heterogeneities can help us better understand firm’s behavior and predict the welfare effects associated with their mergers. As our paper shows, if antitrust authorities incorrectly assume that all firms are symmetric (e.g., polluting), then mergers may be blocked on the basis that they can lead to an output reduction, as observed in the waste disposal sector (US Department of Justice, 2017). 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 (brown) firm where we allow for cost asymmetries and product differentiation. In the first period, firms choose whether to file a merger to the antitrust authority for approval or not. In the second period, the antitrust approves or blocks the merger. In the third period, the environmental regulator (such as the Environmental Protection Agency, EPA) sets emission fees, considering 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. Under no environmental regulation, mergers induce an output shift from the less to the more cost-efficient firm irrespective of pollution differentials. Such mergers constitute a welfare loss if firms produce relatively homogeneous goods but are significantly different in their pollution intensities.\(^1\)

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\(^1\)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).

\(^2\)Monsanto, which manufacturers Roundup™ weedkiller, is faced with multiple litigations for allegations of causing
We then consider environmental regulation to 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 provide firms with incentives to shift their output after the merger from the brown firm to the green firm, that did not exist in the absence of environmental regulation. As a result, the reduction in the brown firm’s output and, hence, consumer surplus, is more than offset by the increase in green firm’s output, which reduces overall pollution. In other words, emission fees and their effect on output shifts after the merger help to generate a welfare gain. Nonetheless, when firms are relatively homogenous and pollution is less significant, mergers still entail output reductions and price increases, which decrease overall welfare, as in standard merger models (Salant et al., 1983).

We also measure how this output shift, and ultimately assess whether firms have stronger incentives to merge or not, when environmental regulation is in place. We find that when firms are relatively symmetric in costs, they have stronger (weaker) incentives to merge under regulation if firms produce relatively differentiated (homogeneous) goods, and the regulator sets stringent taxes (subsidies) on the brown (green) good. However, these mergers can be welfare-reducing if the brown firm is significantly more polluting than its green rival. Therefore, antitrust authorities that ignore environmental externalities can approve mergers which would be blocked by an antitrust that also includes pollution considerations in its welfare function. We refer to these mergers as “socially excessive mergers,” and they could be expected in our setting.

Nonetheless, we also identify situations where “socially insufficient mergers” occur because antitrust authorities that ignore environmental effects block a merger that could have helped reduce pollution, entailing that the antitrust decision produced an overall welfare loss. These mergers arise, specifically, when firms are relatively cost symmetric, sell differentiated goods, and the brown firm generates significantly more pollution than its green rival. Overall, we show that, while the presence of environmental policy ameliorates pollution, if it operates separately from antitrust authorities, we

non-Hodgkin lymphoma (NHL) and multiple myeloma by its active ingredient glyphosate (Bayer AG, 2019, p.250). Bayer, which acquired Monsanto in 2018, manufacturers 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 predicts that the merger would induce output shift from conventional to organic herbicides. 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.
may observe socially excessive or insufficient mergers arising in equilibrium. Our results then call for more concerted efforts between antitrust authorities and environmental agencies in evaluating mergers, especially in industries where firms have different pollution intensities.

Our results 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 only, 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.³ As our paper shows, if pollution is sufficiently severe, mergers that are blocked by traditional antitrust authorities should be approved by agencies considering all the welfare effects from mergers. The current Horizontal Merger Guidelines (US Department of Justice and Federal Trade Commission, 2010), however, do not explicitly consider the broader impact of mergers on the environment, while the EPA do not actively monitor mergers.⁴

To the best of our knowledge, this is the first paper that studies mergers between firms with (i) differentiated goods, (ii) asymmetric costs, and (iii) different pollution intensities under endogenous emission fees, analyzing the effect of firm heterogeneities on output shifts and welfare. Interestingly, we find that socially excessive or insufficient mergers are approved by antitrust authorities in equilibrium, and then evaluate how these regulatory inefficiencies are affected by the presence or absence of environmental regulation in that market.

³See, 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.

⁴Our paper demonstrates that the EPA could set emission fees to induce socially optimal output at the firm level. However, if the implementation of emission fees is administratively costly, or if it requires a close monitoring of firms’ production decisions, then an antitrust authority which considers environmental externalities may help the EPA set the appropriate emission fees by approving (blocking) mergers that (do not) contribute to an overall welfare improvement.
1.1 Related Literature

A large body of the literature analyzes horizontal mergers in oligopolistic markets with environmental externalities. 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 as in Salant et al. (1983) or if costs are relatively convex (Perry and Porter, 1985). 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. Our model, however, shows that mergers can be welfare-improving even if output shifts from the more to the less efficient firm if these shifts mitigate environmental damages. Gelves (2014) considers two-firm mergers in an oligopolistic

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5Our 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.

6Some recent examples are (1) in the pollution abatement industry, 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); and (2) in the waste management industry, the acquisition of Quantex Environmental Inc., an Ontario based company, by Covanta Environmental Solutions, a New Jersey based environmental services provider (Waste 360, 2018).
setting with \( N \) firms similar to that in Salant et al. (1983), but allowing for cost asymmetries and product differentiation, suggesting that cost asymmetry increases firms’ incentives to merge and the parameter space that supports profitable and welfare-enhancing mergers expands in product differentiation and the number of firms in the industry.\(^7\)

The closest articles to our paper are Fikru and Gautier (2016, 2017), who examine mergers in Cournot markets with product differentiation and emission fees under symmetric costs. They assume, however, an exogenous change in production technology that lowers pollution intensity upon merger.\(^8\) In contrast, we characterize output shifts from the brown firm, with a more severe pollution intensity, to the less polluting green firm. We show that mergers can be welfare-improving when goods are relatively homogeneous and costs are more asymmetric even in the absence of environmental externalities, since output shifts from the less efficient to the more cost-efficient firm help save production costs. When those externalities are present, however, we propose another channel of welfare gains different from exogenous technological change. Specifically, emission fees on the brown firm can induce output shifts from the brown to the green firm even when they do not merge. Interestingly, the brown firm has more incentives to merge with the green firm under environmental regulation to save emission fees, and such incentives are emphasized when the brown firm becomes more polluting relative to its green rival. Our research then complements Fikru and Gautier (2017), 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 asymmetric in production costs because the brown firm has more incentives to increase output when merging with a less efficient rival, so that a higher emission fee is required to counteract its output expansion effects and align its output to socially

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\(^7\)A related paper to ours is Espínola-Arredondo et al. (2019) that considers three dimensions of asymmetries, namely (i) product differentiation, (ii) cost asymmetry, and (iii) different demand intensities, in the context of organic versus non-organic food in which the former exhibits stronger demand intensity than the latter. This paper, in contrast, assumes for simplicity that goods have the same demand intensity but asymmetric environmental damages.

\(^8\)Fikru and Gautier (2016) report that, in a sample of food processors engaged in mergers and acquisitions during 2001-2012, there was a 17.6% increase in the number of process modifications aimed at reducing the release of toxic pollutants one year after the deal was announced. These can be implemented through output shifts that reduce (increase) the output of the more (less) polluting firm. In addition, Woodall and Shannon (2018) provide a survey on recent mergers in the food processing industry and acquisitions of natural food companies by conventional food companies.
optimal levels. In addition, we identify under which conditions socially excessive and insufficient mergers may be approved by antitrust authorities.

The remainder of this article is organized as follows. Section 2 sets up the model. Sections 3 and 4 examine firms’ incentives to merge with and without environmental regulation, respectively, analyzing socially excessive/insufficient mergers, output shifts, emission fees, and welfare effects. Finally, Section 5 concludes with policy implications and directions for future research.

2. Model

Consider a market with two firms, $i$ and $j$, where $i, j = \{B, G\}$ stands for the brown and green firms, respectively. The brown (green) firm has lower (higher) marginal production cost $c_B$ ($c_G$), where $c_G \geq c_B \geq 0$, and 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 $\tilde{c}_G = c_G - c_B$, which can be interpreted as its cost differential relative to the brown firm. Analogously, we normalize the pollution parameter of the brown firm to $\tilde{d} = d_B - d_G$ which represents the pollution intensity differential relative to the green firm. Therefore, environmental damages can be expressed as $Env(q_B) = d_B q_B^2$, which are increasing and convex in the brown good (Espínola-Arredondo and Muñoz García, 2015, Lambertini and Tampieri, 2012).\footnote{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 case 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).}

As in Singh and Vives (1984), assume that firm $i$’s inverse demand function is

$$p_i(q_i, q_j) = 1 - q_i - \beta q_j$$

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).

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.

$$p_i(q_i, q_j) = 1 - q_i - \beta q_j$$
(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 $(q_M^B, q_M^G)$. If the merger does not ensue, every firm $i$ independently selects its output level $q_i^{NM}$ and engage in Cournot competition.

We first introduce a setting with no environmental regulation (as if stage 3 did not exist), and solving for the firms’ equilibrium output with and without the merger. Next, we allow the regulator to set emission fee $t_i^k$ and analyze its effects on firms’ output, mergers, profits, and welfare. We conclude our study with two extensions. In Appendix 1, we investigate if firms still have incentives to merge when side payments are not allowed by analyzing the profit differences, $\Delta \pi_i^R \equiv \pi_i^{M,R} - \pi_i^{NM,R}$ under regulation and $\Delta \pi_i^{NR} \equiv \pi_i^{M,NR} - \pi_i^{NM,NR}$ under no regulation. This forms the basis to compare the profit gains from mergers under regulation, $\Delta \pi_i^R$, against that in a setting without regulation, $\Delta \pi_i^{NR}$, to determine whether environmental regulation makes mergers more attractive or not for firms. For simplicity, we assume $\beta < \bar{\beta} \equiv 2(1 - c)$ throughout this paper.

3. Equilibrium analysis without regulation

In this section, we assume that firms operate in the absence of the environmental regulator, making the firms’ output decisions the third stage of the game, after the firms contemplate and the antitrust authority evaluate mergers in the first and second stage of the game, respectively.

3.1 Third stage - output decisions

Operating by backwards induction, we begin our analysis with the third stage of the game by characterizing the firms’ equilibrium output with and without the merger, respectively.

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10 In this context, we allow for every firm $i$ to earn its profits and receive part of its rival’s profits in the form of side payments.

11 When $\beta \geq \bar{\beta}$, the brown firm dominates the market without the merger, rendering the merger problem uninteresting.
Lemma 1. Under no merger, the green and brown firm’s equilibrium output is $q_{NM}^G = \frac{2-\beta - 2c}{4-\beta^2}$ and $q_{NM}^B = \frac{2-\beta + \beta c}{4-\beta^2}$, respectively. Under a merger, the green firm’s output becomes $q_{M}^G = \frac{1-\beta - c}{2(1-\beta^2)}$ which is positive if and only if $\beta < \frac{\sqrt{3}}{2}$, and the brown firm’s output becomes $q_{M}^B = \frac{1-\beta + \beta c}{2(1-\beta^2)}$ which is positive for all parameter values. Otherwise, firms set $q_{M}^G = 0$ and $q_{M}^B = \frac{1}{2}$ if $\beta \geq \frac{\sqrt{3}}{2}$ after the merger.

Figure 1: Output under no regulation

Figure 1 illustrates the results from Lemma 1 when firms do not merge (left panel) and when they merge (right panel). The shaded areas in both panels indicate $(\beta, c)$-pairs sustaining a positive output level for both green and brown firms. Intuitively, when firms produce relatively differentiated goods (low $\beta$) and/or firms’ costs are relatively symmetric (low $c$), firms have incentives to produce a positive output with and without the merger. The region of $(\beta, c)$-pairs sustaining positive output from both firms, however, shrinks when firms merge, that is, $\frac{\sqrt{3}}{2} \leq \beta < \bar{\beta}$. As the following corollary shows, this result is due to output reduction that comes with the merger.

Corollary 1. Under a merger, the green firm reduces output when $\beta < \frac{\sqrt{3}}{2}$ and stops production otherwise. The brown firm reduces output when $\beta < \beta_{NR}^B$, increases output when $\beta_{NR}^B \leq \beta < \frac{\sqrt{3}}{2}$, and monopolizes the market otherwise, where $\beta_{NR}^B \equiv \frac{3 - \sqrt{9 - 2\beta^2}}{\beta}$. 

Figure 2 shows that when firms are relatively differentiated (low $\beta$) or cost symmetric (low $c$), the green (brown) firm reduces output after the merger below cutoff $\frac{\beta}{2}$ (cutoff $\beta < \beta_B^{NR}$) in the left (right) panel; otherwise, this firm stops (expands) the production of green (brown) good.

In this context, let us define the output change for firm $i$ as $\Delta q_i^{NR} = q_i^{NM} - q_i^{M}$, where $i \in \{B, G\}$. Corollary 2 identifies this output change across green and brown firms.

**Corollary 2.** The green firm reduces output more than the brown firm, that is, $\Delta q_G^{NR} > \Delta q_B^{NR}$.

The green firm’s cost inefficiency relative to the brown firm causes it to reduce output more significantly than its brown rival; a result that holds for all values of $\beta$ and $c$. Specifically, when output becomes more homogeneous (differentiated), the merged firm reduces output to a larger (smaller) extent because of facing a more (less) intense output competition. In contrast, when goods are completely differentiated ($\beta = 0$), output does not change with and without the merger.

### 3.2 Second stage - merger approval

In the second stage, the antitrust authority approves the merger if and only if it increases social welfare, defined as the sum of consumer surplus ($CS$) and producer surplus ($PS$) less

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**Figure 2: Output change under no regulation**

(a) Green firm

(b) Brown firm

Green firm becomes inactive after merger $q_G^M = 0$

Green firm reduces output after merger $q_G^M < q_G^{NM}$

Brown firm expands output after merger $q_B^M \geq q_B^{NM}$

Brown firm reduces output after merger $q_B^M < q_B^{NM}$

environmental damages, $Env(q_B) = dq_B^2$, where

$$SW(q_G, q_B) = CS + PS - Env(q_B)$$

In the following lemma, we characterize the antitrust authority’s decisions on merger approval.

**Lemma 2.** The antitrust authority approves the merger if and only if $\beta < \beta_A(d)$ when $d > 1$ or $\beta > \beta_B(d)$ when $d < 0.5$, where cutoffs $\beta_A(d)$ and $\beta_B(d)$ solve $SW(q_M^G, q_M^B) = SW(q_{NM}^G, q_{NM}^B)$.

Figure 3a depicts the case where environmental damages are absent ($d = 0$), in which antitrust approves the merger if $\beta \geq \beta_B(0)$ referring to the shaded region. If firms are completely cost asymmetric ($c = 1$), the merger is welfare-reducing regardless of the degree of product differentiation (for all values of $\beta$). Graphically, this is represented by the shaded region in Figure 3a, which is nil at $c = 1$ in the right-hand corner of the figure. However, when the green firm experiences a smaller cost disadvantage (that is, $c$ decreases as we move leftward in Figure 3a), this shaded area expands, indicating that the merger is welfare-improving for a larger range of $\beta$. Intuitively, when the green firm suffers more significant cost disadvantage, the merger shifts output from the green to the brown firm. This output shift improves efficiency and does not pollute (since $d = 0$ in this context), ultimately increasing social welfare. However, when the green firm is relatively cost symmetric to the brown firm (low $c$), mergers reduce output of both firms or induce small output shifts from the green to the brown firm, hindering welfare as in the unshaded regions.

Figure 3b depicts the case where environmental damages slightly increase to $d = 0.25$. Relative to Figure 3a, mergers enhance welfare under more restrictive conditions; in particular, the green firm must suffer a more significant cost disadvantage relative to the brown firm and goods must be more homogeneous. In that setting, output shifts to the brown firm yield a larger increase in consumer surplus and firms’ total profits, which offset the relatively mild environmental damages. Further increases in environmental damages, however, rotates cutoff $\beta_B(d)$ clockwise at $(c, \beta) = (1, 0)$, shrinking the shaded region depicting welfare-enhancing mergers. In particular, when $0.5 \leq d \leq 1$, this cutoff is to the right of $\beta$ so that mergers reduce welfare under all parameter conditions.

Figure 3c depicts the case of relatively substantial environmental damages at $d = 1.5$. When goods are completely homogeneous ($\beta = 1$), mergers hinder welfare for all parameter conditions.

\(^{12}\)For all $d \geq 0$, $\beta_B(d) > \beta_B^{NR}$ indicates that the brown firm expands output in the shaded region above cutoff $\beta_B(d)$.  

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However, when goods become more differentiated (lower $\beta$), the range of parameters supporting welfare-enhancing mergers expands, which increases welfare even if the green firm is less efficient (high $c$). In that setting, both firms reduce output, but profit gains, along with pollution reduction, offset the reduction in consumer surplus, ultimately constituting a welfare improvement. Otherwise, when firms are relatively asymmetric and homogeneous (high $\beta$ and high $c$) above cutoff $\beta_A (d)$, mergers hinder welfare since the brown firm reduces output to a small extent (or may even increase output), so pollution decreases by a small amount (increases, respectively) and welfare decreases.
3.2.1 Antitrust who overlooks environmental effects

Suppose the antitrust authority ignores environmental damages, welfare function then becomes

$$\tilde{SW}(q_G, q_B) = CS + PS$$
This antitrust authority considers consumer and producer surplus alone, leaving all environmental considerations to other government agencies, which we will explicitly consider in the next section. Figure 4a provides the same results as Figure 3a, namely, when environmental damages are absent \( (d = 0) \), the antitrust authority approves a merger under the same \((\beta, c)\)-pairs. However, when environmental damages are present \( (d > 0) \), Figure 4b indicates that socially excessive mergers (SEM) arise because the regulator approves mergers when considering output shifts but ignoring the associated environmental damages. SEM are welfare-reducing when pollution is present, and should be blocked. Figure 4c shows that both SEM and socially insufficient mergers (SIM) are present when environmental damages become more significant \( (d = 1.5) \) since the regulator on the one hand, approves mergers between relatively homogeneous and cost-asymmetric firms that fail to enhance welfare (SEM), while on the other hand, blocks mergers between relatively differentiated and less asymmetric firms that are possible to enhance welfare (SIM), as they help to significantly reduce pollution.

Table 1 illustrates how the areas of SEM and SIM vary with changes in environmental damages. When the brown firm is less polluting \((d < 1)\), cutoff \( \beta_{A} (d) \) does not exist because output reduction of both firms reduce welfare. In contrast, cutoff \( \beta_{B} (d) \) rises above cutoff \( \bar{\beta} \) which yields SEM occurring between cutoffs \( \beta_{SW} \) and \( \beta_{B} (d) \). In that case, output shifts from the green to the brown firm make mergers welfare-enhancing under more restrictive parameter conditions. When \( d > 0.5 \), SEM levels off because further output increase of the brown firm hinders welfare under all parameter values as \( \beta_{B} (d) \) shifts to the right of cutoff \( \bar{\beta} \). Whereas, when \( d > 1 \), SIM emerges when output reduction of both firms reduces environmental damages sufficiently to cause welfare improvement.
Figure 4: Socially excessive and inefficient mergers
3.2.2 Antitrust who only considers consumer surplus

Suppose the antitrust authority only considers consumer surplus in its welfare evaluation, that is, $\overline{SW} = CS$, ignoring producer surplus and environmental damages altogether. Figure 5 shows that social welfare is higher when the merger is blocked, which holds under all parameter conditions.

Figures 5a to 5c depict that, in settings where the antitrust focuses on consumer surplus, there may be socially insufficient mergers ($\overline{SIM}$). Graphically, this occurs in the area between cutoffs $\beta_B(d)$ and $\beta_{CS}$ when $\beta < 0.5$ and below cutoff $\beta_A(d)$ when $\beta > 1$, since mergers in those regions would have been approved under $SW$. In comparison, $\overline{SIM}$ does not exist when $0.5 \leq \beta \leq 1$ since mergers that would have been blocked under $SW$ continue to be blocked under $\overline{SW}$, yielding no SEMs.\(^{13}\)

\(^{13}\)Our results are connected with and further generalize the findings in Espínola-Arredondo et al. (2019), Gelves (2014), Kao and Menezes (2010), who suggest that the antitrust authority should consider environmental effects, apart from product heterogeneity and cost asymmetries, in the evaluation of mergers between differentiated firms.

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Table 1: Socially excessive and inefficient mergers
3.3 First stage - merger vote

Let us conclude our analysis in this section by analyzing merger incentives in the first stage by defining $\pi^k = \pi_i^k + \pi_j^k$, where $i, j = \{B, G\}$ and $k = \{M, NM\}$, to be the firms’ joint profits.
Lemma 3. Firms have incentives to merge under all parameter conditions.

When firms merge and coordinate output, the merged firm obtains larger profits than competing à la Cournot, that is, $\pi^M > \pi^{NM}$, such that every firm $i$ has incentives to merge if the merged firm can use the profit gain of one firm to offset the profit loss of the other firm. This follows the standard result in the mergers literature which suggests that the merger of duopolistic firms into a monopoly is always profitable if side payment is allowed (Kesavayuth et al., 2018). Our results further extend the traditional mergers model by identifying that even when firms differ in (i) product differentiation (ii) cost asymmetry, and (iii) pollution intensity, every firm $i$ finds it profitable to merge.

Mergers between differentiated firms are subject to scrutiny by the antitrust authority, who can only approve mergers deemed as welfare-enhancing when considering environmental effects. However, there is no guarantee that mergers can correct the environmental externalities from the brown good, and as such, output decisions of the merged firm may still fall short of socially optimal levels. In the coming section, we introduce environmental regulation in the above setting, studying how the regulator can work in tandem with the antitrust authority and use emission fees to affect firms’ merger incentives and output decisions.

4. Equilibrium analysis with regulation

In this section, we introduce the regulator, who, after learning the antitrust’s decision on merger approvals, can observe the industry structure, that is, whether firms merge or not. This allows the regulator to set emission fees (which can be negative in the case of production subsidies) inducing firms to produce socially optimal levels of output, as the next lemma shows.

4.1 Fourth stage - output decisions

In the fourth stage, firm $i$, where $i \in \{B, G\}$, having learned the emission fees that the regulator sets on this firm and on its counterpart (rival), makes output decisions under (no) merger.

Lemma 4. Under regulation, the green firm’s equilibrium output is $q^{NM,R}_G = \frac{2(1-c-i^M_G)-\beta(1-i^M_B)}{4-\beta^2}$ without and $q^{M,R}_G = \frac{(1-c-i^M_G)-\beta(1-i^M_B)}{2(1-\beta^2)}$ with the merger. Similarly, the brown firm’s equilibrium output is $q^{NM,R}_B = \frac{2(1-c-i^M_B)-\beta(1-c-i^M_G)}{4-\beta^2}$ without and $q^{M,R}_B = \frac{(1-c-i^M_B)-\beta(1-c-i^M_G)}{2(1-\beta^2)}$ with the merger.
In words, firm $i$ responds negatively (positively) to emission fees charged to this (the other) firm, and firms’ output is more sensitive to emission fees under merger than no merger.

Next, we move on to the regulator, who is responsible for regulating firms’ production activities.

4.2 Third stage - emission fees

Operating by backwards induction, the regulator, in the third stage of the game, solves the following welfare maximization problem and identifies socially optimal levels of output that fully account for the environmental effects of firms’ production activities.

$$SW(q_G, q_B) = CS + PS + Tax(q_B)$$

where $Tax$ represents the regulator’s tax revenue from the emission fees. The following lemma identifies socially optimal output levels, which are independent of whether firms choose to merge or not.

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

$$q_G^{SO} = \frac{(1 + 2d)(1 - c) - \beta}{1 + 2d - \beta^2} \quad \text{and} \quad q_B^{SO} = \frac{1 - \beta (1 - c)}{1 + 2d - \beta^2} \quad \text{if} \quad \beta < \beta^R$$

$$q_G^{SO} = 0 \quad \text{and} \quad q_B^{SO} = \frac{1}{1 + 2d} \quad \text{if} \quad \beta \geq \beta^R$$

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

Figure 6a depicts socially optimal output when environmental damages are absent ($d = 0$), in which the green firm stops production above cutoff $\beta^R = 1 - c \equiv \frac{\beta}{2}$. In this case, the green firm exhibits relative cost disadvantage in producing a less differentiated good so that the regulator only assigns output to the brown firm (see the unshaded area). Figure 6b depicts the case of low environmental damages ($d = 0.5$), where both firms produce output below cutoff $\beta^R = 2(1 - c) \equiv \bar{\beta}$. Relative to Figure 6a, the regulator assigns a positive output to the brown firm alone under more restrictive conditions (unshaded area) since its production generates a more intense pollution.
The following corollary illustrates how socially optimal output changes in parameter values.

**Corollary 3.** When both firms are active, $q_G^{SO}$ ($q_B^{SO}$) decreases in $\beta$ and $c$ ($\beta$ and $d$) but increases in $d$ ($c$). When only the brown firm is active, $q_B^{SO}$ decreases $d$ but does not change with $\beta$ and $c$.

When goods become more differentiated (low $\beta$), the regulator seeks more units from both firms to satisfy consumers’ preferences for variety. However, when the green (brown) good becomes more costly (polluting), the regulator assigns fewer (more) units of green good, and similarly, more (fewer) units of brown good, to reduce social costs. When environmental damages increase, cutoff $\beta^R$ rotates counterclockwise at the point $(c, \beta) = (1, 0)$, so that the shaded area in which the regulator only assigns brown good shrinks when this firm becomes more polluting, and the green firm remains active for all parameter values when $d \geq 0.5$. Intuitively, the higher pollution intensity of the brown firm leads the regulator to only assign the brown good under more restrictive conditions, that is, only if costs become more asymmetric (high $c$) and goods become more homogeneous (high $\beta$).

In this setting, we allow the regulator to set specific emission fees: a pair of fees having observed the merger, $t^M = (t_G^M, t_B^M)$, and another pair of fees observing a merger did not occur,
\( t^{NM} \equiv (t_G^{NM}, t_B^{NM}) \). As Proposition 1 shows, these fees induce firms to produce socially optimal levels of output we identified in Lemma 5. For generality, we allow positive and negative fees.

**Proposition 1.** When \( q^SO_G > 0 \) and \( q^SO_B > 0 \), the regulator can set emission fees of

\[
\begin{align*}
t_G^{NM} &= -\frac{(1 + 2d)(1 - c) - \beta}{1 + 2d - \beta^2} \\
t_B^{NM} &= \frac{(2d - 1)(1 - \beta(1 - c))}{1 + 2d - \beta^2}
\end{align*}
\]

Otherwise, when \( q^SO_G = 0 \) and \( q^SO_B = \frac{1}{1 + 2d} \), the regulator can set emission fees of

\[
\begin{align*}
t_G^{NM} &= \frac{(1 + 2d)(1 - c) - \beta}{1 + 2d} \\
t_B^{NM} &= \frac{2d - 1}{1 + 2d}
\end{align*}
\]

When \( \beta < \beta^R \), the green firm is subsidized to produce the green good, and more substantially after the merger, that is, \( t_G^M < t_G^{NM} < 0 \). Intuitively, subsidies in this setting are more generous to offset the output-reduction effect of market monopolization (Collie, 2003, Huck and Konrad, 2004).

In contrast, the brown firm is taxed and its emission fees are more stringent before than after the merger \( (t_B^{NM} > t_B^M > 0) \) to internalize both market competition and environmental externalities.

When \( \beta \geq \beta^R \), the unmerged green firm is taxed to stop production \( (t_G^{NM} < 0) \), while the merged green firm has already been shut down.\(^{14}\) In comparison, the merged brown firm is subsidized, that is, \( t_B^M < 0 \) when \( 0 \leq d < 0.5 \), to expand beyond monopoly level of output, while the unmerged brown firm is taxed to reduce its production when relatively polluting, that is, \( t_B^{NM} > 0 \) for \( d \geq 0.5 \).

### 4.3 Second stage - merger approval

In the second stage, we investigate the antitrust authority’s decisions on merger approvals.

**Lemma 6.** The antitrust authority does not block mergers under all parameter conditions.

Since antitrust does not collect emission fees, its objective function of \( SW(q_G, q_B) = CS + PS - Env(q_B) \) coincides with that under no regulation. Interestingly, antitrust anticipates that the regulator in the third stage will respond by setting emission fees that align firms’ output to socially optimal levels, both when firms merge and when they do not. Thus, social welfare with and without the merger coincides, leading the antitrust not to block mergers under all parameter conditions.

\(^{14}\)When \( \beta^R \leq \beta < \beta^R \) and \( 0 \leq d < \frac{1}{2} \), \( q_G^M = q_G^{SO} = 0 \) so that \( t_G^M = 0 \).
4.4 First stage - merger vote

In the first stage, we analyze firms’ incentives to merge under environmental regulation.

**Lemma 7.** Firms under regulation have incentives to merge when they are active in the market.

When environmental damages are low, the green firm earns low profits, so the brown firm has little incentives to merge with its green rival. Specifically, when goods become more homogeneous \((\beta \geq \beta^R)\), the above argument is emphasized since now the green firm would be shut down following the merger, entailing that the brown firm has no incentives to merge. However, when environmental damages become more severe, the brown firm has stronger incentives to merge with its green rival and implement output shifts to save emission fees. Similarly, the green firm has incentives to merge with its brown rival to benefit from the output shift that comes with the merger, where the more efficient brown firm produces a larger output share, yielding an increase in both firms’ profits.

4.5 Comparison across regulatory regimes

We are interested in the firms’ behavior, whether merged or not, when operating under different 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 firms merge, where \(i \in \{B, G\}\).

**Corollary 4.** When firms do not merge, the green (brown) firm produces more (less) output with than without environmental regulation if \(\beta < \bar{\beta}_G^{NM} (d) \left( \bar{\beta}_B^{NM} (d) < \beta < \bar{\beta}_B^M (d) \right)\), with cutoffs

\[
\bar{\beta}_G^{NM} (d) \equiv \frac{5 + 2d - \sqrt{(5 + 2d)^2 - 8 (1 - c)^2 (1 + 2d)(3 + 2d)}}{2(1 - c)(3 + 2d)} \\
\bar{\beta}_B^{NM} (d) \equiv \frac{(3 - 2d)(1 - c) - \sqrt{(3 - 2d)^2 (1 - c)^2 - 8(1 - 2d)}}{2} \\
\bar{\beta}_B^M (d) \equiv \frac{(3 - 2d)(1 - c) + \sqrt{(3 - 2d)^2 (1 - c)^2 - 8(1 - 2d)}}{2}.
\]

In contrast, when firms merge, the green (brown) firm produces more output with than without environmental regulation under all parameter values (when \(\beta < \bar{\beta}_B^M (d) \equiv \sqrt{1 - 2d}\), respectively).
Figure 7a depicts the effect of regulation on the unmerged green firm. When $\beta$ lies below cutoff $\widehat{\beta}_G^{NM}(d)$, the unmerged green firm produces more units of the green good when regulated than not regulated that satisfies $q_G^{NM,R} > q_G^{NM}$. Specifically, when firms are relatively symmetric in costs (low $c$), the regulator increases the output of the unmerged green firm only if it is sufficiently differentiated from the brown firm (low $\beta$).  

Figure 7b depicts the effect of regulation on the unmerged brown firm. When $\beta$ lies below cutoff $\widehat{\beta}_B^{NM}(d)$ or above cutoff $\widehat{\beta}_B^{NM}(d)$, the unmerged brown firm produces more units of the brown good under regulation than not ($q_B^{NM,R} > q_B^{NM}$). Thus, regulation induces the unmerged brown firm to increase production only when its cost advantage and/or product heterogeneity relative to the unmerged green firm widens. This advantage/heterogeneity must be more pronounced when the brown firm becomes more polluting. However, when environmental damages exceed a certain threshold, in particular, $d \geq 0.5$, the regulator seeks less output from the relatively polluting brown firm through the imposition of emission fees.

When firms merge, Corollary 1 states that the unregulated green firm always reduces output upon merger, so that the regulator offers production subsidies (i.e., negative emission fees) to increase this firm’s output to the socially optimal level. The unregulated brown firm, however, increases output when $\beta > \beta_B^{NR}$ upon merger, which exceeds socially optimal levels above cutoff $\widehat{\beta}_B^{NM}(d)$ indicating its relative severe environmental damages. This induces the regulator to make use of emission fees to bring the brown firm’s output closer to the socially optimal levels.

$^{15}$If the brown firm becomes more polluting ($d$ increases), cutoff $\widehat{\beta}_G^{NM}(d)$ shifts upward, indicating that the regulator seeks to induce an output increase from the unmerged green firm under less restrictive parameter conditions. For this to occur, firms can be more asymmetric in costs (higher $c$) or produce more homogeneous goods (higher $\beta$).

$^{16}$Specifically, the regulator seeks an output increase from the brown firm when its output is non-polluting, that is, $d = 0$, under all parameter values. If this firm becomes more polluting ($d$ increases), this cutoff bends away from the point $(c, \beta) = (0, 1)$, so that the regulator reduces the brown firm’s output when firms produce more homogeneous goods (high $\beta$) and are relatively symmetric in costs (low $c$) satisfying $\widehat{\beta}_B^{NM}(d) < \beta < \widehat{\beta}_B^{NM}(d)$. When $d = 0.5$, cutoff $\widehat{\beta}_B^{NM}(d)$ coincides with cutoff $\beta$ so that the regulator seeks less output from this firm under all parameter conditions.

$^{17}$Note that cutoff $\widehat{\beta}_B^{NM}(d)$ decreases in $d$, indicating that it is more likely that the unregulated brown firm’s merger production level exceeds socially optimal level of output designated for this firm when it becomes more polluting.
In this context, let us inspect whether environmental regulation improves social welfare or not, as well as the change in social welfare levels in the parameters, as the following corollary shows.

**Corollary 5.** When both goods are produced, social welfare decreases in $\beta$, $c$, and $d$; when only the brown good is produced, social welfare decreases in $d$ but does not vary with $\beta$ or $c$.

Taking $\beta = c = d = 0.5$ as an illustration and varying one parameter at a time, Figures 8a to 8c depict that environmental regulation, which induces firms to produce socially optimal levels of output that holds across industry structures, unambiguously increases social welfare over that under no regulation. Notice that social welfare level decreases if (i) goods become more homogenous ($\beta$ increases), (ii) the green firm becomes less efficient ($c$ increases), or the brown firm becomes more polluting ($d$ increases) when $\beta < \beta^R$. To the contrary, when $\beta \geq \beta^R$, only the brown firm is active so that social welfare decreases in $d$ but levels off in $\beta$ and $c$ as shown in the respective figures.\(^\text{18}\)

\(^{18}\)When $d = \frac{1}{2}$, check that $SW^{SO} = \frac{1}{2(1+2d)} = \frac{1}{4} = \frac{3-2d}{8} = SW^{NR}$ when $\beta > \beta^R = \overline{\beta}$, or equivalently, $c > \overline{c} = 1 - \frac{\beta}{2}$.
Figure 8: Social welfare

4.6 Antitrust who overlooks environmental effects

Suppose the antitrust authority, because of its directives, must focus on consumer and producer surplus. Then we consider two cases: (1) antitrust anticipating emission fees that the regulator sets
in the third stage; and (2) a naïve antitrust who does not anticipate those fees in the third stage.

In case (1), antitrust anticipates that firms, because of emission fees, will produce the same output that coincides with socially optimal levels whether they are merged or not. In this setting, antitrust does not block the merger under all parameter conditions since approving or blocking it yields the same welfare. Interestingly, this happens because antitrust anticipates that the regulator will, in the third stage, design emission fees to induce socially optimal output regardless of the market structure. This outcome is independent of the specific social welfare function that antitrust considers, and whether it differs from the regulator (e.g., EPA) who sets emission fees in the subsequent stage or not. In case (2), antitrust naively assumes that firms are not subject to emission fees in the third stage, so that antitrust approves (blocks) the merger if \( \beta \geq \beta_{\tilde{SW}} \) (\( \beta < \beta_{\tilde{SW}} \)) following the same decision rule as the one considered in Section 3.2.1. A similar argument applies to antitrust who only considers consumer surplus in welfare evaluation as examined in Section 3.2.2.

In both cases, since the antitrust’s imperfect merger evaluation only affects industry structure but not output levels, the environmental 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 antitrust 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 antitrust’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, or at such a high administrative cost that may possibly outweigh the benefits of implementation (see Claassen et al. (2008) for a review of conservation compliance in practice). In these contexts, it becomes more necessary for antitrust authorities to also consider the impact of mergers on the environment.

5. 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 if firms sell relatively differentiated products and are more asymmetric in their costs and pollution intensity. In these settings, mergers should be promoted. Furthermore, if the regulator can charge
emission fees depending on the industry structure, then first-best outcome can be achieved whether firms are allowed to merge. Our paper then sheds light on the Horizontal Merger Guidelines (US Department of Justice and Federal Trade Commission, 2010) which suggest that antitrust authorities can approve mergers of differentiated duopolists if mergers lead to cost savings, and on top of that, 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, for example, 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 antitrust authorities fail to consider the environmental effects associated with mergers, socially excessive mergers can arise when relatively polluting firms expand their output after a merger significantly, which offsets the cost efficiencies that arise from the merger. These occur, in particular, when firms are relatively homogeneous, cost asymmetric, and dissimilar in pollution intensities. In contrast, socially insufficient mergers that were originally blocked may be reconsidered in the light of reduction of environmental externalities. These occur, specifically, when firms are relatively differentiated, cost symmetric, and inflicting different degrees of environmental damages onto the society.

In summary, while this paper examines emission fees/subsidies on one brown firm and one green firm, our model can be generalized into settings with an endogenous number of firms to study the effect of environmental regulation on the collusive behavior, market dynamics, and welfare implications of an antitrust authority which only considers consumer and producer surplus when deciding whether to approve new mergers or not (Espínola-Arredondo and Muñoz García, 2015, Qiu and Zhou, 2002). In addition, building upon Wan and Boyce (2014) and Benchekroun et al. (2019), we can model the strategic behavior of differentiated firms endowed with different levels of natural resources, analyzing the optimal extraction paths, merger incentives, and welfare effects.
6. Appendices

6.1 Appendix 1 - No side payments between firms

In Corollaries A1 to A3, let us assume away side payments and investigate whether firms still have individual incentives to merge with its rival when environmental regulation is in place or not.

**Corollary A1.** When firms merge under no regulation, the green firm generates larger profits, that is, \( \Delta \pi_G^{NR} > 0 \) when \( \beta < \beta_G^{NR} \), where \( \beta_G^{NR} \) solves \( \beta^2 ((1 - c) (1 - \beta - c) (8 + \beta^2) - 4 (1 - \beta^2)) = 0 \). Similarly, the brown firm generates larger profits, that is, \( \Delta \pi_B^{NR} > 0 \), under all parameter values.

Consider that firms are symmetric in costs (\( c = 0 \)); both firms have individual incentives to merge whether they produce completely differentiated (\( \beta = 0 \)) or homogeneous (\( \beta = 1 \)) products. However, when the green firm becomes less efficient (\( c \) increases), this firm still have individual incentives to merge only if its output is relatively more differentiated from its brown rival (\( \beta < \beta_G^{NR} \)). Otherwise, the green firm does not have individual incentives to merge in the absence of environmental regulation. In contrast, the brown firm still have individual incentives to merge under all parameter values because this firm can produce brown good more efficiently than its green rival.

**Corollary A2.** When firms merge under regulation, every firm \( i \) obtains larger profits when both firms are active in the market, that is, \( \Delta \pi_i^R > 0 \) when \( q_i^{SO} > 0 \). However, when only the brown firm is active, this firm generates the same profit whether merged with the inactive green firm or not.

Consider the case of no environmental damages (\( d = 0 \)). Every firm \( i \) has individual incentives to merge and capture the production subsidies offered by the regulator that induce firm \( i \) to increase its output to socially optimal levels, and those subsidies are larger when firms merge because of output reduction effected from the mergers. In the case when \( \beta > \beta^R \), the green firm is taxed to remain dormant so that the brown firm finds no profit gains from merging with the non-producing green firm. Otherwise, when the brown firm becomes more polluting at \( d > 0.5 \), both firms remain active under all parameter conditions, so that the green (brown) firm has individual incentives to merge and capture the larger subsidies offered (the lower emission fees charged) by the regulator.

**Corollary A3.** The green (brown) firm generates larger profit gains from mergers when regulated than not under all parameter values (when \( \beta < \beta_B^R \), where \( \beta_B^R \) solves \( \Delta \pi_B^{NR} = \Delta \pi_B^R \), respectively).
The shaded areas in Figure A1a shows that the green firm generates larger profit gains from merger under regulation for all parameter values. First, the green firm has individual incentives to merge absent regulation when \( \beta < \beta_{G}^{NR} \), but those incentives are emphasized under production subsidies. Second, when \( \beta \geq \beta_{G}^{NR} \), the unregulated green firm does not have individual incentives to merge, but merger incentives exist under regulation when \( \beta < \beta^{R} \). Third, when \( \beta^{R} < \beta \leq \beta^{B} \), the green firm is inactive whether it is under regulation or not, thus making the merger problem trivial.

Figure A1b depicts that the brown firm obtains larger profit gains from mergers under regulation below cutoff \( \beta_{B}^{R} \), as in the shaded areas. First consider that firms are symmetric in costs (\( c = 0 \)); regulation benefits the brown firm only if it produces brown goods sufficiently differentiated from the green firm (\( \beta < \beta_{B}^{R} \)), but the range of parameters supporting larger profit gains shrinks as its green rival becomes less efficient (\( c \) increases). This happens because the regulator charges emission fees to offset output increase of the brown firm that causes it to receive lower profits from mergers under environmental regulation. Second, when the brown good becomes more polluting (\( d \) increases), cutoff \( \beta_{B}^{R} \) shifts towards the origin shrinking the shaded areas, and the more polluting brown firm obtains larger profit gains only under more restrictive parameter conditions.

![Figure A1: Difference in differences in profits](image-url)
Appendix 2 - Technical Proofs

6.2.1 Proof of Lemma 1

No merger. For \( i = \{B, G\} \), each firm \( i \) chooses \( q_i \) to solve

\[
\max_{q_i \geq 0} \pi(q_i) = (1 - q_i - \beta q_j) q_i - (c_i) q_i
\]

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

\[
q_i = \frac{1 - \beta q_j - c_i}{2}
\]

such that the best response function of firm \( i \), in response to firm \( j \)’s output, becomes

\[
q_i(q_j) = \frac{1 - \beta q_j - c_i}{2}
\]

At the Cournot Nash equilibrium, firms’ output are mutual best response to each other, yielding

\[
q_i^{NM} = \frac{2(1 - c_i) - \beta(1 - c_j)}{4 - \beta^2}
\]

(A1)

Substituting \( q_i^{NM} \) into the profit function, equilibrium profits become

\[
\pi_i^{NM} = \left(\frac{2(1 - c_i) - \beta(1 - c_j)}{4 - \beta^2}\right)^2
\]

Merger. The profit maximization problem of the merged firm becomes

\[
\max_{q_i, q_j \geq 0} \pi(q_i, q_j) = (1 - q_i - \beta q_j - c_i) q_i + (1 - q_j - \beta q_i - c_j) q_j
\]

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

\[
q_i = \frac{1 - 2\beta q_j - c_i}{2}
\]

Solving \( q_i \) and \( q_j \) simultaneously, we obtain

\[
q_i^M = \frac{(1 - c_i) - \beta(1 - c_j)}{2(1 - \beta^2)}
\]

(A2)

Substituting \( q_i^M \) and \( q_j^M \) into the profit function, the merging firm \( i \) generates profits of

\[
\pi_i^M = \frac{1 - c_i}{2} \cdot \frac{(1 - c_i) - \beta(1 - c_j)}{2(1 - \beta^2)}
\]

Since output must be non-negative, \( q_i^{NM} > 0 \) if \( \beta < \bar{\beta} \equiv 2(1 - c) \) and \( q_i^M > 0 \) if \( \beta < \frac{\bar{\beta}}{2} \equiv 1 - c \). Otherwise, \( q_i^{NM} = 0 \) if \( \beta \geq \bar{\beta} \) and \( q_i^M = 0 \) if \( \beta \geq \frac{\bar{\beta}}{2} \), yielding \( q_B^k = \frac{1}{2} \) and \( \pi_B^{kNR} = \frac{1}{4} \) where \( k \in \{M, NM\} \).
6.2.2 Proof of Corollary 1

For the green firm to reduce output upon merger, \( q^M_G < q^{NM}_G \) entails \( \frac{1-\beta-c}{2(1-\beta^2)} < \frac{2-\beta-2c}{4-\beta^2} \), which simplifies to \((2-\beta)(1-\beta)+3\beta c > 0\) that holds for all values of \(0 < \beta < \bar{\beta}\). Whereas, for the brown firm to reduce output upon merger, \( q^M_B < q^{NM}_B \) implies \( \frac{1-\beta+\beta c}{2(1-\beta^2)} < \frac{2-\beta+\beta c}{4-\beta^2} \), which holds for all values of \(c < \frac{(1-\beta)(2-\beta)}{2+\beta^2}, \) or rearranging to yield \( \beta < \beta^{NR}_B = \frac{3-V}{2(1-c)} = \frac{3-\sqrt{9-2\beta^2}}{\beta} \).

6.2.3 Proof of Corollary 2

We have \( q^{NM}_G - q^M_G > q^{NM}_B - q^M_B \) simplifying to \( \frac{(1+\beta)(2+\beta)c}{2(1-\beta^2)(4-\beta^2)} > 0 \) for all values of \(\beta\) and \(c\). Note that \( \frac{\partial q^M_G}{\partial \beta} = -(\frac{1-\beta^2+2c}{2(1-\beta^2)^2}) < 0 \) for all values of \(c\), and \( \frac{\partial q^M_B}{\partial \beta} = -(\frac{1-\beta^2-(1+\beta^2)c}{2(1-\beta^2)^2}) < 0 \) if \(c < \frac{(1-\beta)^2}{1+\beta^2}\).

6.2.4 Proof of Lemma 2

Consumer surplus is the utility that the representative consumer derives from both goods.

\[
CS(q_B, q_G) = q_B + q_G - \frac{1}{2} \left( q_B^2 + 2\beta q_B q_G + q_G^2 \right) - (1 - q_B - \beta q_G) q_B - (1 - q_G - \beta q_B) q_G
\]

\[
= \frac{1}{2} \left( q_B^2 + 2\beta q_B q_G + q_G^2 \right) + \frac{1}{2} (q_B + q_G - c) q_B - \beta q_B q_G
\]

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

\[
SW(q_B, q_G) = \frac{1}{2} \left( q_B^2 + 2\beta q_B q_G + q_G^2 \right) + \frac{p_B(q_B, q_G) q_B}{PS} + \frac{[p_G(q_B, q_G) - c] q_G}{Env} - \frac{d q_B^2}{2q_B q_G}
\]

\[
= \left( q_B + q_G - c \right) q_B + \left( 1 - \frac{1+2d}{2q_B} \right) q_B - \beta q_B q_G
\]

When \(\beta \geq \frac{\bar{\beta}}{2}\), the green firm is inactive after the merger, yielding social welfare of

\[
SW\left(q^M_B, q^M_G\right) = \frac{1}{2} \left( \frac{1}{2} \right)^2 + \left( \frac{1}{2} \right)^2 - \frac{d}{\left( \frac{1}{2} \right)^2} = \frac{3-2d}{8}
\]

When \(\beta = \beta^{NR}_B, c = \frac{(1-\beta)(2-\beta)}{2+\beta^2}, q^M_B = q^{NM}_B = \frac{1}{2+\beta^2}, q^M_G = \frac{\beta}{2+\beta^2}, \) and \(q^{NM}_G = \frac{\beta}{2(2+\beta^2)}, \) yielding

\[
SW^{NM}_{\beta^{NR}_B} = \frac{3+5\beta^2-2d}{2(2+\beta^2)^2}
\]

\[
SW^M_{\beta^{NR}_B} = \frac{3(4+5\beta^2)-8d}{8(2+\beta^2)^2}
\]

and it is straightforward to verify that \(SW^{NM}_{\beta^{NR}_B} > SW^M_{\beta^{NR}_B}\) for all values of \(0 \leq d < \infty\).
6.2.5 Proof of Lemma 3

Simplifying $\pi_i^M \geq \pi_i^{NM}$ to $(8 + \beta^2)(1 - c_i)^2 - \beta(8 + \beta^2)(1 - c_i)(1 - c_j) - 4(1 - \beta^2)(1 - c_j)^2 \geq 0$, its sufficient condition is $c_j \geq c_i$ yielding $(4 - 8\beta + 5\beta^2 - \beta^3)(1 - c_i)^2 \geq 0$ for all $\beta \in [0, 1]$. Simplifying $\pi_i^M \geq \pi_i^{NM}$ to $(4 + 5\beta^2)(1 - c_i)^2 - 2\beta(8 + \beta^2)(1 - c_i)(1 - c_j) + (4 + 5\beta^2)(1 - c_j)^2$, this expression is bounded below by $(4 + 5\beta^2)(c_j - c_i)^2$ that is always positive for all $c_i, c_j \geq 0$.

6.2.6 Proof of Lemma 4

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

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

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

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

Defining $x_i = 1 - c_i - t_i$, firms’ output are mutual best response to each other, yielding

$$q_i^{NM} = \frac{2(1 - c_i - t_i) - \beta(1 - c_j - t_j)}{4 - \beta^2} = \frac{2x_i - \beta x_j}{4 - \beta^2} \quad (A3)$$

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

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

Merger. The profit maximization problem of the merged firm becomes

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

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

\[
q_i^M = \frac{(1 - c_i - t_i) - \beta (1 - c_j - t_j)}{2 (1 - \beta^2)} = \frac{x_i - \beta x_j}{2 (1 - \beta^2)} \tag{A4}
\]

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

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

Further check that \( \frac{\partial q_i^k}{\partial t_j} > 0 > \frac{\partial q_i^k}{\partial t_i} \) and \( |\frac{\partial q_i^M}{\partial t_i}| > |\frac{\partial q_i^N M}{\partial t_i}| \) for \( i, j = \{B, G\} \) and \( k = \{M, NM\} \).

### 6.2.7 Proof of Lemma 5

Social welfare is given by

\[
SW(q_i, q_j) = \frac{q_i^2}{2} + 2 \beta q_i q_j + \frac{q_j^2}{2} + \frac{\left[ p_i(q_i, q_j) - c_i \right] q_i + \left[ p_j(q_i, q_j) - c_j \right] q_j + t_i q_i + t_j q_j - (d_i q_i^2 + d_j q_j^2)}{PS \cdot T_{ax} \cdot Env} \]

\[
= \left( 1 - \frac{1 + 2d_i}{2} q_i - c_i \right) q_i + \left( 1 - \frac{1 + 2d_j}{2} q_j - c_j \right) q_j - \beta q_i q_j \tag{A5}
\]

Total differentiation of expression (A5) yields

\[
dSW(q_i, q_j) = \left( 1 - q_i - \beta q_j - 2d_i q_i - c_i \right) dq_i + \left( 1 - q_j - \beta q_i - 2d_j q_j - c_j \right) dq_j
\]

The regulator, who takes the firms’ responses to the emission fees into account, solves

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

Differentiating expression (A3) 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 \( \frac{\partial q_i^{NM}}{\partial t_i} = -\frac{1}{2(1-\beta^2)} \) and \( \frac{\partial q_i^{NM}}{\partial t_j} = \frac{\beta}{2(1-\beta^2)} \), respectively. Similarly, differentiating expression (A4) with respect to \( t_i \) and \( t_j \), the merged firm \( i \)’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, who chooses to approve the merger, solves

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

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

\[(1 - \beta^2 + 2d_i) q_i - 2\beta d_j q_j = (1 - c_i) - \beta (1 - c_j) \quad (A6)\]

The regulator, who chooses to block the merger, solves

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

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

\[(2 - \beta^2 + 4d_i) q_i + \beta (1 - 2d_j) q_j = 2 (1 - c_i) - \beta (1 - c_j) \quad (A7)\]

Socially optimal output, which solves $dSW(q_i, q_j) = 0$ in (A6) and (A7) simultaneously, is

\[q_i^{SO} = \frac{(1 + 2d_j)(1 - c_i) - \beta (1 - c_j)}{(1 + 2d_j)(1 + 2d_j) - \beta^2} \]

Further setting the numerator of $q_i^{SO}$ equal to zero, we obtain cutoff $\beta^R = (1 + 2d) (1 - c)$.

We further check the Hessian matrix of social welfare function in expression (A5), given by

\[\frac{\partial^2 SW}{\partial q^2} = \begin{bmatrix} \frac{\partial^2 SW}{\partial q_G^2} & \frac{\partial^2 SW}{\partial q_G^2 \partial q_B^-} \\ \frac{\partial^2 SW}{\partial q_G^2 \partial q_B^-} & \frac{\partial^2 SW}{\partial q_B^-} \end{bmatrix} = -\begin{bmatrix} 1 & \beta \\ \beta & 1 + 2d \end{bmatrix} = -(1 + 2d - \beta^2) \]

Since $\frac{\partial^2 SW}{\partial q^2} < 0$, the interior solution of $(q_B^{SO}, q_G^{SO})$ is unique in maximizing social welfare.

### 6.2.8 Proof of Corollary 3

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

\[\frac{\partial q_B^{SO}}{\partial \beta} = -\frac{2\beta(1 - \beta(1 - c))}{(1 + 2d - \beta^2)^2} > 0; \text{ and similarly, } \frac{\partial q_B^{SO}}{\partial d} = -\frac{(1 - c)(1 + 2d + \beta^2) - 2\beta}{(1 + 2d - \beta^2)^2} < \]

\[-\left(\frac{1 - \beta}{(1 + 2d - \beta^2)}\right)^2 < 0, \frac{\partial q_B^{SO}}{\partial c} = -\frac{\beta}{1 + 2d - \beta^2} > 0, \text{ and } \frac{\partial q_B^{SO}}{\partial d} = -\frac{1 - \beta(1 - c)}{(1 + 2d - \beta^2)^2} < 0. \]

### 6.2.9 Proof of Proposition 1

Setting $q_i^{NM} = q_i^{SO}$ in expression (A3), the emission fees that align the competition output with socially optimal levels must satisfy $t_i^{NM} = 1 - 2q_i - \beta q_j - c_i$, which, after rearranging, yields

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

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Setting \( q_i^M = q_i^{SO} \) in expression (A4), the emission fees that align the coordinated output with socially optimal levels must satisfy \( t_i^M = 1 - 2q_i - 2\beta q_j - c_i \), which, after rearranging, yields

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

### 6.2.10 Proof of Lemma 7

Substituting \( t_i^{NM} = 1 - 2q_i^{SO} - \beta q_j^{SO} - c_i \) into the non-merger profit of regulated firm \( i \),

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

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

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

It is obvious that \( \pi_i^{M,R} > \pi_i^{NM,R} \) for \( i = \{B, G\} \). Also, when environmental damages increase,

\[
\frac{\partial \pi_i^{M,R}}{\partial d} = (q_i^{SO} + \beta q_j^{SO}) \frac{\partial q_i^{SO}}{\partial d} + q_i^{SO} \frac{\partial (1 - \beta (1 - c))}{(1 + 2d - \beta^2)^2} > 0
\]

\[
\frac{\partial \pi_i^{B,M,R}}{\partial d} = (q_i^{SO} + \beta q_j^{SO}) \frac{\partial q_j^{SO}}{\partial d} + q_j^{SO} \frac{2\beta^2 - 1}{(1 + 2d - \beta^2)^2} (1 - \beta (1 - c)) < 0 \quad \text{if} \quad \beta < \frac{1}{\sqrt{2}}
\]

### 6.2.11 Proof of Corollary 5

When \( \beta < \beta^R \) (\( \beta < \frac{7}{2} \)) under (no) regulation, totally differentiating expression (A5), we obtain

\[
dSW = \frac{\partial SW}{\partial \beta} = \frac{\partial SW}{\partial q} \frac{\partial q}{\partial \beta} \quad \text{and} \quad \frac{\partial SW}{\partial \beta} = -q_b^k q_g^k \leq 0,
\]

\( = 0 \) by Envelope Theorem

\[
\frac{\partial SW}{\partial c} = -q_g^k \leq 0, \quad \text{and} \quad \frac{\partial SW}{\partial d} = -\left(q_b^k \right)^2 \leq 0, \quad \text{where} \quad k \in \{M, NM, \{M, R\}, \{NM, R\}\}. \quad \text{Similarly, when} \quad \beta \geq \beta^R \left( \beta \geq \frac{7}{2} \right), \quad SW^{SO} = \frac{1}{2(1 + 2d)} (SW^{NR} = \frac{3 - 2d}{8}) \quad \text{that decreases in} \ d \quad \text{but does not vary with} \ \beta \text{ or } c.
\]

### 6.2.12 Proof of Corollary A1

Check that \( \Delta \pi_B^{NR} = \frac{\beta^R ((1 - \beta (1 - c)) (8 + \beta^2) - 4 (1 - \beta^2) (1 - c)^2)}{4 (1 - \beta^2) (4 - \beta^2) c} \) which attains a minimum when \( c = 0 \), under which \( \Delta \pi_B^{NR} (c = 0) = 4 - 8\beta + 5\beta^2 + \beta^3 > 0 \) that is sufficient for \( \Delta \pi_B^{NR} > 0 \) for all \( \beta \in [0, 1] \).
6.2.13 Proof of Corollary A2

Check that when $q^S_B \cdot q^S_G > 0$, $\Delta \pi^R_B = \Delta \pi^R_G = \beta q^S_B \cdot q^S_G = \frac{\beta ((2d+1)(1-c) - \beta)(1-\beta(1-c))}{(1+2d-\beta^2)} > 0$ under all parameter values of $\beta, c \in [0, 1]$. In contrast, when $q^S_B > q^S_G = 0$, $\Delta \pi^R_i = 0$ for $i \in \{B, G\}$.

References


