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Cournot vs. Bertrand competition in the international transport market with environmental standard

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Abstract

We revisit the classic comparison of Bertrand and Cournot competition by studying how the form of competition between shipping companies affects transport prices, international trade, consumer and producer surplus, and social welfare in two countries that coordinate their environmental policies. We show that the standard Bertrand-Cournot ranking only prevails when pollution abatement technologies are sufficiently efficient.

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1 Introduction

International trade accounts for a significant proportion of global greenhouse gas emissions, primarily through the transport of goods (Cristea et al., 2013; Shapiro, 2016). The favored approach to reducing emissions is to establish technical standards through international organizations such as the International Maritime Organization (IMO) or the International Civil Aviation Organization (ICAO). These member state organizations have shown an increasing inclination to take coordinated action on environmental regulations. For example, the latest measures proposed by the IMO and EU under the MARPOL 73/78 convention include the common regulation of ships' emissions.[1]

Our focus is on the effects of endogenous transport prices, resulting from price competition (Bertrand competition) or quantity competition (Cournot competition) between carriers, on the economic and environmental performance of two trading countries. In keeping with the conditions imposed by international shipping organizations, we assume that countries impose environmental standards on carriers in a coordinated manner.[2]

This article complements recent work on environmental regulations for international shipping (Abe et al., 2014; Takarada et al., 2021) and is part of a broader literature on the effects of international transport on trade (Behrens and Picard, 2011; Francois and Wooton, 2001; Ishikawa and Tarui, 2018, 2021; Mizuno and Takauchi, 2020) and innovation (Kanehara and Kamei, 2019; Takauchi, 2015; Takauchi and Mizuno, 2022). Most of these studies focus on the shipping sector by assuming a monopoly or competition in quantities on the interregional transport market, neglecting upstream price competition. Two recent articles (Takauchi and Mizuno, 2022; Mizuno and Takauchi, 2020) highlight the importance of accounting for price competition based on empirical evidence of the existence of this form of competition. In the present article, we will consider the two forms of competition in turn by concentrating on the "upstream" transport market, and compare their effects when this market is subject to environmental regulation.

Several recent studies have called into question the conventional result that competition on prices is always more efficient than Cournot competition when the goods produced are homogeneous. Bertrand competition leads to lower prices, but yields higher quantities, consumer surplus and total welfare than obtained under Cournot competition (Singh and Vives, 1984; Vives, 1985; Cheng, 1985; Dastidar, 1997). These standard conclusions do not hold however in vertically related markets (Maria Alipranti and Petrakis, 2014; Basak and Mukherjee, 2017), mixed markets (Ghosh and Mitra, 2010) or in the presence of convex cost functions (Delbono and Lambertini, 2016b,a).

We contribute to the debate by showing that price competition is not necessarily more efficient than quantity competition: the standard Bertrand-Cournot ranking only prevails when pollution abatement technologies are sufficiently efficient; the emission standards adopted at equilibrium under Bertrand competition are less stringent (implying more environmental damage) than under Cournot competition. On the other hand, when abatement technologies are moderately efficient, the opposite result holds: the stricter optimal environmental standards under Bertrand competition lead to higher transport

[1] https://www.imo.org/en/About/Conventions/Pages/Action-Dates.aspx

[2] The non-cooperative scenario, in which countries do not coordinate their environmental policies, has been studied by the author but is not presented in this short paper. The analysis is available on request. We show that cooperation always outperforms non-cooperation in terms of economic and environmental outcomes (higher social welfare and stricter environmental standards) regardless of the form of competition between carriers. The results of this article still hold in the non-cooperative scenario.

costs than under Cournot competition, calling into question the standard conclusions. Finally, when abatement technologies are inefficient, a different ranking prevails: despite transport prices being higher under Bertrand competition (implying reduced international trade and lower consumer surplus), the Bertrand-Nash equilibrium welfare is higher because environmental policies have a greater negative impact on producer surplus and thus on welfare under Cournot than under Bertrand competition.

2 Model

Consider two symmetric countries, 1 and 2, and four firms: one producer and one carrier in each country. It is the carriers' behavior we are interested in. The two producers are identical and produce a homogeneous good in their respective country at constant marginal cost, c. They provide q_{ii} for the domestic market and aim to export q_{ij} to the foreign market. In the following, we take $(i, j) \in \{1, 2\}^2$, with $i \neq j$. The inverse demand in each country is given by:

$$p(D_i) = A - D_i$$

where $p(0) - c \equiv A > 0$ with A being a measure of market size, and $D_i = q_{ii} + q_{ji}$ is the total consumption of final goods in country i.

We assume that markets are segmented and that producers compete in quantities. They pay a per-unit transport price, p^T, and use a transportation service to export their product q_{ij}, which is transported from country i to country j. The final goods profit of firm i is given by:

$$\pi_i = (A - D_i)q_{ii} + (A - D_j)q_{ij} - p^T q_{ij} \tag{1}$$

From the profit maximization of producer i, we obtain the output for domestic consumption, q_{ii} and exports, q_{ij}. We deduce the demand D_i in each country.

$$q_{ii} = \frac{A + p^T}{3}, \quad q_{ij} = \frac{A - 2p^T}{3} \quad \text{and} \quad D_i = \frac{2A - p^T}{3} \tag{2}$$

Substituting (2) into producer i's profit (Eq.1), we obtain

$$\pi_i = q_{ii}^2 + q_{ij}^2 \tag{3}$$

The total quantity of goods exported by the producers, Q^T , depends on the price of transport, p^T, endogenously determined by price/quantity competition among carriers.

$$Q^T = q_{ij} + q_{ji} = 2\frac{A - 2p^T}{3} \tag{4}$$

In our model, international transportation is a homogeneous service. The two carriers (each one based in one country) compete either in prices (Bertrand competition) or in quantities (Cournot competition). Under Bertrand competition, the carriers set their transport price p^T. Under Cournot competition, the carriers set the volume of goods they will transport, q_T. At the equilibrium, the total demand for transportation should be satisfied, such that: $q_{ij} + q_{ji} = q_i^T + q_j^T$. The two shipping companies transport domestically produced goods to the foreign country and distribute goods imported from the foreign country. The implied assumption is that the shipping companies can cover all the export demand (no capacity constraints) and that the producers do not exclusively use either of the shipping firms.[3]

We assume that the only source of pollution is international shipping: each unit of transported goods creates one unit of emissions. The total amount emitted, $E \equiv q_{ij} + q_{ji}$, affects both countries equally. The damage function is assumed to be quadratic, with the severity of the damage captured by $d \geq 1$, the slope of the marginal environmental damage curve [4]: $D(E) = d/2E^2$. To limit environmental damage, the governments of the two countries can set environmental standards, $\bar{e}$, defined as a cap on the local transport company's emissions. The damage function can therefore be expressed as: $D(E) = d/2(\bar{e}_1 + \bar{e}_2)^2$.

The shipping companies have to keep their emissions below the cap and cover the associated cost of pollution abatement. If government i sets the emission standards $\bar{e}_i$ and carrier i transports a quantity of goods q_i^T, which depends on the price it sets for shipping, carrier i has to abate emissions by $(q_i^T - \bar{e}_i)$. Following Fanti and Buccella (2017), the total cost of pollution abatement (CA) for carrier i is assumed to be,

$$CA_i = \begin{cases} \frac{\gamma}{2}(q_i^T - \bar{e}_i)^2 & \text{if } q_i^T > \bar{e}_i \\ 0 & \text{if } q_i^T \leq \bar{e}_i \end{cases}$$

where the parameter $\gamma (> 0)$ can be interpreted as a measure of the efficiency of abatement technologies. The two shipping companies have constant marginal transportation costs, which are normalized to zero here for simplicity.

It follows that carrier i's profit is

$$\pi_i^T = p^T q_i^T - \frac{\gamma}{2}(q_i^T - \bar{e}_i)^2 \tag{5}$$

Country i's social welfare can be defined as the sum of consumer surplus (CS) and producer surplus (PS), minus the environmental damage:

$$SW_i = CS_i + PS_i - D(E) \tag{6}$$

where $CS_i = \frac{1}{2}D_i^2$ and $PS_i = \pi_i + \pi_i^T$.

The countries are assumed to coordinate their environmental policies. To do this, the governments maximize the aggregate social welfare:

$$SW_c = \sum_{k=1}^{2} SW_k = SW_1 + SW_2 \tag{7}$$

The two models of competition between carriers are considered separately in the following three-stage game. In the first stage, the governments cooperatively set optimal emission standards. In the second, the carriers compete on price (in the first competition model) or in quantities (in the second competition model). In the last stage, the final-goods firms simultaneously set their levels of local supply and exports. We use the subgame perfect Nash equilibrium as the equilibrium concept and solve the game by backward induction.

[3] The demand for shipping is only distributed equally between the two firms, by symmetry, at the equilibrium of the game, in which case $q_{ij} = q_i^T$.

[4] To ensure the emissions abatement term is positive at equilibrium, we assume that $d \geq 1$.

3 Analysis

We investigate the two canonical competition models, Bertrand price competition and Cournot output competition. The last stage of the game (the choices of the final-goods firms) is the same in both models.

3.1 Bertrand Competition

Second stage - pricing decisions. In the second stage, since the two carriers provide a homogeneous service, the demand for each carrier's services i, q_i^T, is a discontinuous function of its price

$$q_i^T(p_i^T;p_j^T) = \begin{cases} 0 & \text{if } p_i^T > p_j^T \\ \frac{1}{2}Q(p_i^T) & \text{if } p_i^T = p_j^T \\ Q(p_i^T) & \text{if } p_i^T < p_j^T \end{cases}$$

We denote $Q(p_i^T)$ the total quantity of goods transported when carrier i sets price p_i^T. Each carrier's profit, π_i^T, can now be expressed as

$$\pi_i^T(p_i^T;p_j^T) = \begin{cases} 0 & \text{if } p_i^T > p_j^T \\ p^T\frac{1}{2}Q(p^T) - \frac{\gamma}{2}(\frac{1}{2}Q(p^T) - \bar{e}_i)^2 & \text{if } p_i^T = p_j^T = p^T \\ p^TQ(p^T) - \frac{\gamma}{2}(Q(p^T) - \bar{e}_i)^2 & \text{if } p_j^T > p_i^T = p^T \end{cases}$$

We follow Dastidar's (1995) approach, whereby if firms face convex costs and are committed to satisfying the full demand of a homogeneous good, Bertrand competition yields a continuum of prices above the competitive price as Nash equilibria in pure strategies. By lowering its price, a carrier increases its revenue by transporting more goods. But since the costs of pollution abatement are convex, their increase will outweigh the increase in revenue, making this deviation nonprofitable. More precisely, the Nash equilibrium in pure strategies involves all firms setting the same price $p^{T^N} \in [p_{min}^T, \bar{p}^T]$ (see also Gori et al. (2014); Delbono and Lambertini (2016a,b); Takauchi and Mizuno (2019, 2022)). Dastidar (2001) has shown that the collusive price p^{T^*} can be included in this set of Nash equilibria.

More precisely, we define the upper bound $\bar{p}^T$ of the interval as the critical price at which a carrier is indifferent to operating in the market alone or with its rival. After a few algebraic manipulations, we obtain

$$\bar{p}^T(\bar{e}_i) = \frac{\gamma(A - 2\bar{e}_i)}{2(1+\gamma)} \tag{8}$$

We also define the minimum upper bound p_{min}^T as the minimum price compatible with transporting goods in the second stage. In our model, the minimum price is equal to the average variable cost:

$$p_{min}^T(\bar{e}_i) = \gamma\frac{(1/2Q(p_{min}^T) - \bar{e}_i)^2}{Q(p_{min}^T)} = \frac{((3+2\gamma)A - 6\gamma\bar{e}_i) - 3\sqrt{A^2 + 4(A - 3\bar{e}_i)\bar{e}_i\gamma}}{4(3+\gamma)} > 0 \tag{9}$$

Finally, we define $p^{T^*}(\bar{e}_i)$, the price that maximizes carrier i's profit when both carriers operate in the market. This can be interpreted as the collusive price and is given by

$$p^{T^*}(\bar{e}_i) \stackrel{\text{def}}{=} \arg\max_{p^T}\{\pi_i(p^T, Q(p^T)/2)\} = \frac{(3+2\gamma)A - 6\gamma\bar{e}_i}{4(3+\gamma)} \tag{10}$$

It is important to understand how these prices depend on one another.

Lemma 1. *For a given $\bar{e}_i > 0$,*

$$\begin{cases} p^T_{min}(\bar{e}_i) < \bar{p}^T(\bar{e}_i) < p^{T^*}(\bar{e}_i) & \text{if } \gamma < 3 \\ p^T_{min}(\bar{e}_i) < \bar{p}^T(\bar{e}_i) = p^{T^*}(\bar{e}_i) & \text{if } \gamma = 3 \\ p^T_{min}(\bar{e}_i) < p^{T^*}(\bar{e}_i) < \bar{p}^T(\bar{e}_i) & \text{if } \gamma > 3 \end{cases}$$

Proof: Lemma 1 follows obviously from equations (8), (9), (10). □

In Proposition 1 below, we look for the Nash equilibrium in transportation prices under Bertrand competition (BN).

Proposition 1. *[Takauchi and Mizuno (2022)-like result] In the second stage, for a given $\bar{e}_i = \bar{e}_j$,*

$$\begin{cases} \text{if } \gamma \leq 3, \quad p^{T^{BN}}(\bar{e}_i) = \bar{p}^T(\bar{e}_i) & \text{is a payoff-dominant Nash equilibrium,} \\ \text{if } \gamma \geq 3, \quad p^{T^{BN}}(\bar{e}_i) = p^{T^*}(\bar{e}_i) & \text{is a payoff-dominant Nash equilibrium.} \end{cases}$$

Proof: We use a payoff-dominance criterion to select equilibrium prices. If the collusive price p^{T^*} is included in the set of equilibria, both carriers will chose it because it generates the highest profits for all values of $\bar{e}_i = \bar{e}_j$. Lemma 1 shows that this is the case for $\gamma \geq 3$. For low γ (< 3), the price $\bar{p}^T$ will be adopted because it yields higher profits than other prices for both carriers. For details, see Cabon-Dhersin and Drouhin (2014, 2020). □

At the end of this stage of the game, by symmetry, the total supply $Q(p^T)$ is divided equally between the two carriers and $q_i^T = q_{ij}$. Producer i ships its goods according to transporter i's equilibrium price, $p^{T^{BN}}(\bar{e}_i)$, which depends on local emissions standards, $\bar{e}_i$. Substituting $p^T = p^{T^{BN}}(\bar{e}_i)$ into equation (1), equation (2) becomes:

$$q_{ii}^{BN} = \frac{A + p^{T^{BN}}(\bar{e}_j)}{3}, \quad q_{ij}^{BN} = \frac{A - 2p^{T^{BN}}(\bar{e}_i)}{3} \quad \text{and} \quad D_i^{BN} = \frac{2A - p^{T^{BN}}(\bar{e}_j)}{3} \tag{11}$$

First stage - environmental decisions

If we suppose that governments set their emission standards cooperatively in the first stage, we can deduce the Bertrand-Nash (BN) equilibrium by maximizing the sum of each country's social welfare (equation 7), with respect to $\bar{e}_i$. Using Equations (8), (10) and (11), we obtain

$$\begin{cases} \frac{\partial SW_c(\bar{p}^T(\bar{e}_i),\bar{p}^T(\bar{e}_j),\bar{e}_i,\bar{e}_j)}{\partial \bar{e}_i} = \frac{A\gamma(8+5\gamma)+8\gamma^3\bar{e}j-36d(1+\gamma)^2(\bar{ei}+\bar{ej})-2\gamma(9+\gamma(7+5\gamma))\bar{e}_i}{18(1+\gamma)^2} = 0 \quad \text{for} \quad 0<\gamma\leq 3 \\ \frac{\partial SW_c(p^{T*}(\bar{e}_i),p^{T*}(\bar{e}_j),\bar{e}_i,\bar{e}_j)}{\partial \bar{e}_i} = \frac{A\gamma(17+2\gamma)+4\gamma^2(3+\gamma)\bar{e}_j-16d(3+\gamma)^2(\bar{e}_i+\bar{e}_j)-2\gamma(36+\gamma(7+2\gamma))\bar{e}_i}{8(3+\gamma)^2} = 0 \quad \text{for} \quad \gamma\geq 3 \end{cases}$$

The symmetric solution $\bar{e}_1 = \bar{e}_2 = \bar{e}^{BN}$ yields the following unique solution for a cooperative equilibrium in the two countries' environmental standards:

$$\begin{cases} \bar{e}^{BN} = \gamma\frac{8+5\gamma}{D_1}A & \text{for} \quad 0<\gamma\leq 3 \\ \bar{e}^{BN} = \gamma\frac{17+2\gamma}{D_2}A & \text{for} \quad \gamma\geq 3 \end{cases} \tag{12}$$

where $D_1 = 72d(1+\gamma)^2 + 2\gamma(9+\gamma(7+\gamma))$ and $D_2 = 32d(3+\gamma)^2 + 2\gamma(36+\gamma)$.

The Bertrand-Nash equilibrium social welfare is therefore,

$$\begin{cases} SW^{BN} = \frac{4d(32+\gamma(56+27\gamma))+\gamma(32+3\gamma(8+\gamma))}{4D_1}A^2 \quad \text{for} \quad 0<\gamma\leq 3 \\ SW^{BN} = \frac{4d(119+12\gamma(6+\gamma))+\gamma(119+4\gamma)}{4D_2}A^2 \quad \text{for} \quad \gamma\geq 3 \end{cases} \tag{13}$$

3.2 Cournot competition

Second stage - quantity decisions At the equilibrium, the total demand for transportation should be satisfied, such that $q_{ij} + q_{ji} = q_i^T + q_j^T = Q^T$. The market-clearing condition for transportation services yields the inverse demand function for transportation services:

$$p^T = \frac{2A - 3(q_i^T + q_j^T)}{4} \tag{14}$$

In the second stage, each carrier i chooses to transport the quantity of goods that maximizes its profit

$$\max_{q_i^T} \pi_i^T = p^T q_i^T - \frac{\gamma(q_i^T - \bar{e}_i)^2}{2}$$

The Cournot-Nash (CN) equilibrium is then

$$q_i^{TCN} = \frac{2A(4\gamma+3) - 12\gamma\bar{e}_j + 8\gamma\bar{e}_i(2\gamma+3)}{(4\gamma+9)(4\gamma+3)}$$

and

$$Q^{TCN} = \frac{4}{4\gamma+9}(A + \gamma(\bar{e}_i + \bar{e}_j)) \tag{15}$$

Then, inserting equation (15) into equation (14) yields

$$p^{TCN} = \frac{(4\gamma+3)A - 6\gamma(\bar{e}_i + \bar{e}_j)}{2(4\gamma+9)} \tag{16}$$

First stage - environmental decisions

Let us now consider how the governments determine their cooperative environmental policies, $\bar{e}^{CN}$. The two governments maximize Equation (7). The symmetric solution $\bar{e}_1 = \bar{e}_2 = \bar{e}^{CN}$ yields the following unique solution for the equilibrium with cooperation on emission standards:

$$\bar{e}^{CN} = \gamma \frac{(4\gamma + 25)}{D_3} A \tag{17}$$

where $D_3 = 4d(4\gamma + 9)^2 + \gamma(4\gamma + 81)$.

The associated equilibrium social welfare is

$$SW^{CN} = \frac{4d(275 + 24\gamma(9 + 2\gamma)) + \gamma(275 + 16\gamma)}{8D3} A^2 \tag{18}$$

4 Comparison of Bertrand and Cournot competition

In this section, we compare the outcomes of the two competition models.

Proposition 2. *Comparing the optimal environmental standards under Bertrand and Cournot competition, we have*

$$(i) \quad \bar{e}^{BN} \geq \bar{e}^{CN} \quad \textit{iff} \quad \begin{cases} 0 < \gamma \leq 3/2, & \forall d \geq 1 \\ \gamma \geq 3, \quad \textit{and} & d \geq d_1(\gamma) \geq 1 \end{cases}$$

$$(ii) \quad \bar{e}^{BN} \leq \bar{e}^{CN} \quad \textit{iff} \quad \begin{cases} 3/2 \leq \gamma \leq 3, & \forall d \geq 1 \\ \gamma \geq 3, \quad \textit{and} & 1 \leq d \leq d_1(\gamma) \end{cases}$$

$$\textit{with} \quad d_1(\gamma) = \frac{3\gamma(47+12\gamma)}{4(-141-34\gamma+8\gamma^2)}$$

Proof: The difference between $\bar{e}^{BN}$ and $\bar{e}^{CN}$ can be calculated from equations (12) and (17) for $\gamma \leq 3$ and then for $\gamma \geq 3$. For $\gamma \leq 3$, $\bar{e}^{BN} - \bar{e}^{CN} = (3 - 2\gamma)\frac{\gamma A}{D_1 D_3}(4d(66 + (47 - 4\gamma)\gamma) + \gamma(66 + \gamma(49 + 4\gamma)))$. Thus, sign$\{\bar{e}^{BN} - \bar{e}^{CN}\}$=sign$\{3 - 2\gamma\}$. For $\gamma \geq 3$, $\bar{e}^{BN} - \bar{e}^{CN} = \frac{\gamma A}{D_2 D_3}(-9\gamma(47 + 12\gamma) + 12d(-141 - 34\gamma + 8\gamma^2))$. $f(\gamma, d)$ is plotted in Fig.(1a) at the threshold value d_1, $f(\gamma, d_1) = \bar{e}_c^{CN} - \bar{e}_c^{BN} = 0$. Points to the left (right) of $f = 0$ correspond to combinations of γ and d where $\bar{e}^{BN} < (>)\bar{e}^{CN}$. □

As illustrated in Fig.1a, the environmental policy is stricter under Bertrand competition (grey area in Fig.1a) when abatement technologies are somewhat inefficient (intermediate values of γ), or when abatement technologies are very inefficient and pollution damage is low (high γ and low d). By setting emission standards $\bar{e}$, governments have to strike the balance between reducing pollution by setting stricter standards (lower $\bar{e}$), and preserving consumer and producer surplus; stricter standards increase abatement costs for carriers all the more the more inefficient abatement technologies are, which drives up prices and reduces consumer surplus. The following proposition sheds light on the different effects.

Proposition 3. *Under the coordinated environmental policies, there are values of abatement technology efficiency (γ) and values of the damage parameter (d) for which:*

(A) $p^{T^{CN}} > p^{T^{BN}}, Q^{T^{CN}} < Q^{T^{BN}}, CS^{CN} < CS^{BN}, PS^{CN} > PS^{BN}, SW^{CN} < SW^{BN}$
(B) $p^{T^{BN}} > p^{T^{CN}}, Q^{T^{BN}} < Q^{T^{CN}}, CS^{BN} < CS^{CN}, PS^{BN} > PS^{CN}, SW^{BN} < SW^{CN}$
(C) $p^{T^{BN}} > p^{T^{CN}}, Q^{T^{BN}} < Q^{T^{CN}}, CS^{BN} < CS^{CN}, PS^{BN} > PS^{CN}, SW^{CN} < SW^{BN}$

These regions are drawn in Fig.1b in (γ, d) space.

Proof:
The price of transport under Cournot and Bertrand competition can be compared using equations (12), (17), (8), (10) and (16):
(i) when $0 < \gamma \leq 3$, $p^{T^{CN}} - p^{T^{BN}} = \frac{3A(3-2\gamma)(48d^2(1+\gamma)(9+4\gamma)+\gamma^2(27+2\gamma(11+\gamma))+4d\gamma(54+\gamma(61+6\gamma)))}{D_1.D_3}$,
whose sign is given by $\{3-2\gamma\}$.
(ii) when $\gamma \geq 3$, $p^{T^{BN}} - p^{T^{CN}} = 9A\frac{32d^2(3+\gamma)(9+4\gamma)+\gamma^2(54+19\gamma)+4d\gamma(108+61\gamma)}{D_2.D_3} > 0, \quad \forall d \geq 1$.
From Eq.(2) and (4), it is easy to verify that $Q^{T^{CN}} - Q^{T^{BN}}$ and $CS^{CN} - CS^{BN}$ are the same sign as $p^{T^{BN}} - p^{T^{CN}}$. The difference between PS^{BN} and PS^{CN} is:

$$
\begin{aligned}
PS^{BN} - PS^{CN} &= (\pi^{BN} + \pi^{T^{BN}}) - (\pi^{CN} + \pi^{T^{CN}}) \\
&= \frac{p^{T^{BN}} - p^{T^{CN}}}{9}(A - p^{T^{CN}} - p^{T^{BN}}) + \frac{\gamma}{2}(q^{T^{BN}} - \bar{e}^{BN} + q^{T^{CN}} - \bar{e}^{CN})(q^{T^{CN}} - \bar{e}^{CN} - q^{T^{BN}} + \bar{e}^{BN}) \\
&= \frac{p^{T^{BN}} - p^{T^{CN}}}{9}\underbrace{(A - p^{T^{CN}} - p^{T^{BN}})}_{>0} + \frac{\gamma}{2}\underbrace{(q^{T^{BN}} - \bar{e}^{BN} + q^{T^{CN}} - \bar{e}^{CN})}_{>0}\underbrace{(2/3p^{T^{BN}} + \bar{e}^{BN} - 2/3p^{T^{CN}} - \bar{e}^{CN})}_{TermA}
\end{aligned}
$$

(i) when $\gamma \leq 3$, since $sign\{TermA\} = sign\{\frac{A(2\gamma-3)}{D_2.D_6}(96d^2(1+\gamma)(9+4\gamma)+4d\gamma(42+75\gamma+16\gamma^2)-\gamma^2(12+15\gamma))\}$ and $sign\{p^{T^{BN}}-p^{T^{CN}}\} = sign\{2\gamma-3\}$, thus $PS^{BN}-PS^{CN} > (<)0$ for $\gamma > (<)3/2$.
(ii) when $\gamma \geq 3$, since $sign\{TermA\} = sign\{2A(3+\gamma)(9+4\gamma)(\gamma^2(-33+2\gamma)+64d^2(3+\gamma)(9+4\gamma)+4d\gamma(75+8\gamma(11+\gamma)))\}$ is positive $\forall d \geq 1$, $PS^{BN} - PS^{CN} > 0$.
Hence, $PS^{BN} > PS^{CN}$ when $\gamma > 3/2$, $\forall d \geq 1$.
It follows from Eq (13) and (18 that the sign of $SW^{BN} - SW^{CN}$ is given by:

$$(3-2\gamma) \quad \text{when} \quad 0 < \gamma \leq 3$$

and

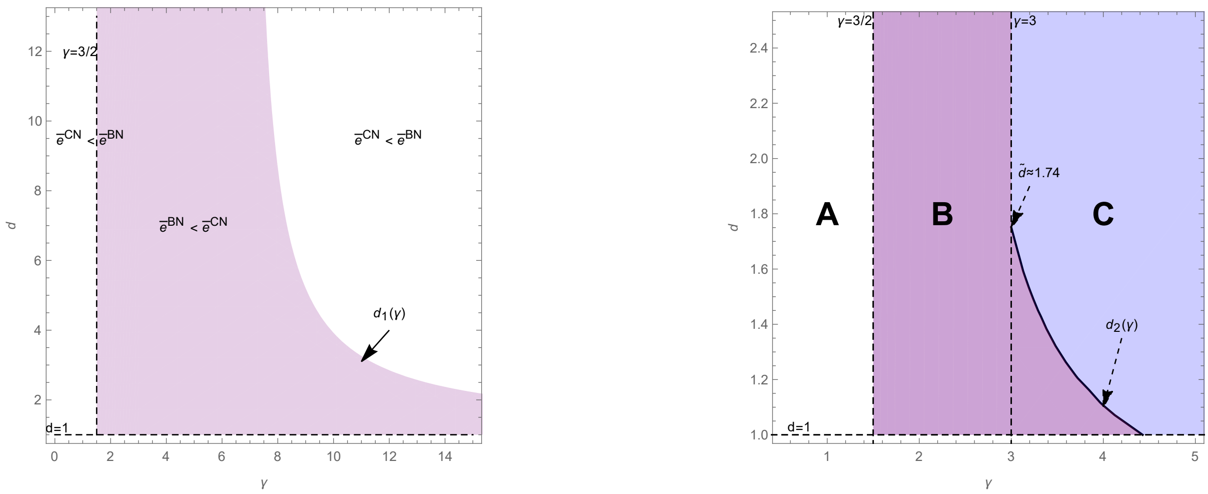
$$-3\gamma^2(87+17\gamma) + 48d^2(-87+8\gamma(1+2\gamma)) + 12d\gamma(-174+\gamma(-9+8\gamma)) \quad \text{when} \quad \gamma \geq 3$$

This last equation yields the critical threshold

$$d_2(\gamma) = \gamma\frac{174+(9+8\gamma)\gamma+\gamma\sqrt{3400+16\gamma(59+4\gamma)}}{8(-87+8\gamma(1+2\gamma))}$$

for which ${SW_c}^{BN} - SW^{CN} = 0$. For $d \gtreqless d_2(\gamma) \geq 1$, $SW^{BN} \gtreqless SW^{CN}$ when $\gamma \geq 3$. □

The ranking of the equilibrium outcomes of the two competition models depends mainly on the efficiency of pollution abatement technologies, and very little on the severity of the environmental damage. In region A (see Fig.1b), the standard Bertrand–Cournot ranking prevails when abatement technologies are efficient ($\gamma < 2/3$) for all values of d. Above a certain level of $\bar{d} \approx 1.74$, the equilibrium welfare under Cournot competition exceeds the value under Bertrand competition for intermediate values of $\gamma \in [3/2, 3]$ regardless of the level of environmental damage (region B). When pollution abatement is relatively inefficient ($\gamma > 3/2$), the Bertrand price at equilibrium is higher than the Cournot price: the increase in the convexity of the cost of pollution abatement under Bertrand competition pushes carriers toward the collusive price, with a corresponding decrease in international exchanges and a greater decrease in consumer surplus than under Cournot competition.



(a) (b)

Figure 1: Ranking equilibrium outputs in (γ, d) space

This surprising result comes from an "emission standard effect". From Equations (8), (10) and (16), it is easy to see that the price functions are decreasing in $\bar{e}$ and $\frac{\partial p^{TBN}}{\partial \bar{e}} \leq (>) \frac{\partial p^{TCN}}{\partial \bar{e}}$ for all $\gamma \geq (<) 3/2$. A marginal decrease in the emission cap (a stricter policy) increases prices more under Bertrand than under Cournot competition when $\gamma > 3/2$. The emission standards play a determining role in explaining the difference in price between Bertrand and Cournot.

However, the ranking obtained for inefficient abatement technologies (region C) goes against the conventional wisdom in the field; even though the Bertrand equilibrium price is collusive (and higher than under Cournot competition), equilibrium welfare is higher under Bertrand than under Cournot competition: the optimal emissions standards are stricter under Cournot competition ($\bar{e}$ is lower) at high values of γ (Proposition 1), increasing the cost of pollution abatement for the carriers and reducing their profits. The environmental benefits under Cournot competition are therefore greater, but at the cost of a lower producer surplus than under Bertrand competition.

5 Conclusion

This article shows that a policy of coordinated emission standards applied to the transport market leads to results that go against received wisdom: stricter standards increase prices more under Bertrand than under Cournot competition. Because of the convexity of carriers' abatement costs, aggravated by stricter environmental standards and inefficient abatement technologies (high γ), the carriers have no interest in lowering their prices under Bertrand competition. This is very much a Dastidarian property of price competition with homogeneous goods, a property that explains high prices (above the competitive price) under Bertrand competition, whereas this form of competition is traditionally considered more efficient than quantity. Two interesting extensions of this work would be (i) to endogenize the form of competition chosen by the firms at the start of the game in the manner of Singh and Vives (1984) (see also Xu et al. (2022) on this topic), and (ii) to include upstream Bertrand-type competition between producers.

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