

Export Restrictions and COVID-19

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Abstract As a result of COVID-19, the export of medical goods has been subject to various global restrictions. Consequently, several countries have increased the supply of medical goods to alleviate the effects of this health crisis. This study entails a theoretical and empirical analysis of the effects of such remedial measures. To this end, we have utilized a consistent conjectural variation in a three-country model entailing firms competing in two reciprocal markets in Cournot. When the restrictions are unilateral, the number of medical goods available in the exporting country tends to increase, culminating in better management of the pandemic. In contrast, bilateral restrictions typically reduce the total output of medical goods; therefore, they are inappropriate in a pandemic situation.

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I. Introduction

Several countries have imposed export restrictions (ERs) as remedial measures to assuage the economic repercussions of COVID-19. Within six months, 108 countries-including the world's largest exporters such as the USA, China, and Great Britain-had imposed ERs. Asian countries particularly China's neighboring countries such as India, Kazakhstan, and Russia (Figure 1) have imposed strict measures to overcome the adverse effects of the pandemic on the economy. The world has suddenly moved from free trade to a form of consensual protectionism. Thus, from January 2020 to June 2020, nearly 43% of the 205 ERs imposed in response to COVID-19 had been enforced by Asian countries. 21% of the total COVID-19 patients worldwide hail from

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ERs as “voluntary” in the sense that, compared to free trade, these restrictions have further increased the profits earned by Japanese firms. Meanwhile, considering the conjectural variations in a Cournot duopoly wherein firms typically produce substitutable goods, Mai and Hwang (1988) conclude that ERs may also be “involuntary”; they demonstrate that when free trade equilibrium is more collusive than Cournot equilibrium, imposing ERs causes a decrease in the prices and profit of the foreign firm. Karikari (1991) opines that such a free trade equilibrium is incompatible with the hypothesis of strategic substitutes,¹⁾ which has been highlighted by Mai and Hwang (1988). He considered the cases of Cournot and Bertrand to depict that ERs primarily increase the profit earned by the foreign firm. Leaving aside the duopoly hypothesis, Dinopoulos and Kreinin (1989) observed that the positive effect of ERs benefits the other unconstrained partners in the domestic country even more. More precisely, they found that the ERs imposed by the US on the Japanese automobile sector have been more profitable to unconstrained European firms than to American firms. Most recently, Walker (2015) obtained a similar result for Great Britain: the ERs imposed in Japan have generated more profits to unconstrained American firms than to the British industry. However, for these authors, the quantity imported into ERs is set at the same level as in free trade. In this sense, for Yoshida (1999), no real restrictions exist: the quantities exported in the ERs must be less than the quantities exported in free trade. Then, he introduced this possibility and showed that the ERs can only lower the profit of the foreign firm. Additionally, for some authors, the value of the coefficient of conjectural variation is arbitrary (Mai & Hwang, 1988; Karikari, 1991) or varies in the interval $[-1, 1]$ (Hwang, 1984; Dohni, 1998), which may result in incorrect conjectures. However, by assuming that oligopolistic firms behave strategically, firms must be able to correctly predict the reaction of their competitors to a variation in their own strategic variable (price or quantity); hence, the concept of consistent conjectures has emerged (Bresnahan, 1981; Perry, 1982; Boyer & Moreaux, 1983; Kamien & Schwartz, 1983). For firms producing differentiated goods, Chao and Eden (1996) calculated the value of the coefficient of conjectural variation and deduced that the consistent conjectural equilibrium is more competitive than a Cournot equilibrium and more collusive than a Bertrand equilibrium. From this, they deduced that the ERs are always voluntary, regardless of the competition mode.²⁾

Therefore, the general tendency is to consider ERs as a protection instrument that does not assist the importing countries’ firms. So, can ERs contribute to better manage the pandemic?

We note two changes, namely, how ERs are negotiated and a reorientation of the objectives related to their use, as compared to the 1980s. In the 1980s, they were negotiated between importing

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- 1) In a Cournot duopoly, this hypothesis admits that the reaction function of a given firm is a decreasing function of the quantity of its rival. In other words, the quantities (prices) of the two firms vary in the opposite direction (Bulow et al., 1985). However, in a collusive equilibrium, the quantities (prices) vary in the same direction.
 - 2) However, in Cournot, the more substitutable the goods are, the greater the profit of the foreign firms over the domestic firms. However, in Bertrand, when the degree of substitution increases, the difference between the two profits decreases (Chao & Eden, 1996, p. 106 and 108).

and exporting countries. With the current pandemic context, they are decided unilaterally by the exporting country, thus integrating the domestic market of the foreign country in our model. Furthermore, facing the pandemic, the authorities' objective was directed more to the number of medical goods consumed (e.g., masks, respirators, gloves, and gowns)³) than the profit of the firms (even if these two objectives can converge). In particular, confronted with the ERs of trading partners and the increase in demand for medical goods, importing countries were more interested in increasing their own output. This leads us to reconsider ERs in terms of their ability to influence the production of medical goods in importing and exporting countries, not in terms of their effects on profits.

The remainder of this paper is then structured as follows. Section 2 describes our theoretical model. Section 3 discusses the effect of ERs on the production of medical goods. Section 4 uses the databases of the International Trade Commission (ITC) that improves the transparency in international trade and market access, European Centre for Disease Prevention and Control (ECDC), the International Monetary Fund (IMF), and the World Bank to test the theoretical results in Section 3.

II. Benchmark

We assume that three oligopolistic firms (i.e., firms i , j and k) are located in three symmetrical countries (one domestic and two foreign firms). Firms i and j produce differentiated goods for their own market and for exports reciprocally, whereas firm k produces only for the export markets (market of countries i and j). We index each variable with the firm's country and the destination market. For example, firm i (from country i) supplies x_{ij} units of goods to the country j at unit price p_{ij} , and x_{ii} is the good supplied to country i at unit price p_{ii} . Firm k produces only from export; hence, we retain indexes ki and kj : for example, x_{ki} (x_{kj}) is the quantity supplied by firm k to country i (j) at unit price p_{ki} (p_{kj}). Following Singh and Vives (1984), we define the representative consumer program based in i by a quadratic linear utility function:

$$U_i = \alpha(x_{ii} + x_{ji} + x_{ki}) - \frac{1}{2}\beta(x_{ii}^2 + x_{ji}^2 + x_{ki}^2) - \gamma[x_{ii}x_{ji} + x_{ki}(x_{ii} + x_{ji})] \quad (1)$$

with $\alpha, \beta > 0$.

The function U_i is continuous and strictly concave.⁴) α and β represent the quality of medical

3) Vaccines that have just been developed are not included in our definition of medical goods. Hence, for the moment, they have not been subject to sufficient export restrictions. Only Italy, France, and Great Britain have taken measures against AstraZeneca's exports.

goods and the market size, respectively. We assume that the goods are substitutable; therefore, $\gamma \in]0, 1[$. $I = p_{ii}x_{ii} + p_{ji}x_{ji} + p_{ki}x_{ki}$ represents the income of the country i 's consumer. The first-order condition for maximization of (1) gives the following inverse demand functions:⁵⁾

$$p_{li} = a - \beta x_{li} - \gamma \sum_{l \neq i} x_{li} \quad \forall l = \{i, j, k\}. \quad (2)$$

Additionally, we assume that the production and export of goods require a constant marginal cost c . Therefore, the profit of the three firms is given by the following:

$$\begin{aligned} \Pi_l &= \Pi_{li} + \Pi_{lj} \\ &= (p_{li} - c)x_{li} + (p_{lj} - c)x_{lj} \quad \forall l = \{i, j, k\}, \end{aligned} \quad (3)$$

where the first term (Π_{li}) is the profit obtained in country i and the second (Π_{lj}), the profit obtained in the country j . We can focus on a single market because countries are symmetrical. Thus, for firms competing in quantity in country i , the first-order conditions of profit maximization yield the following reaction functions:

$$\frac{\partial \Pi_{li}}{\partial x_{li}} = a - 2\beta x_{li} - \gamma \left(\sum_{l \neq i} x_{li} + x_{li} \sum_{l \neq m} \mu_{lm} \right) - c = 0 \quad \forall \{l, m\} = \{i, j, k\}. \quad (4)$$

The term μ_{lm} designates the conjecture of firm l on firm m . For example, $\mu_{ij} = \frac{\partial x_{ji}}{\partial x_{ii}}$ is the firm's i conjecture on j . In other words, it is the firm's j reaction (according to the firm i) to a change in the quantity produced by i . Similarly, the conjectures of the firms j and k on i are given respectively by $\mu_{ji} = \frac{\partial x_{ii}}{\partial x_{jj}}$ and $\mu_{ki} = \frac{\partial x_{ii}}{\partial x_{ki}}$. Now, either $\mu_i = \mu_{ij} + \mu_{ik}$ is firm's i conjecture on foreign firms. Similarly, either $\mu_j = \mu_{ji} + \mu_{jk}$ and $\mu_k = \mu_{ki} + \mu_{kj}$ are the conjectures of firms j and k , respectively. Equation (4) can then be rewritten as:

$$\frac{\partial \Pi_{li}}{\partial x_{li}} = a - 2\beta x_{li} - \gamma \left(\mu_l x_{li} + \sum_{l \neq i} x_{li} \right) - c = 0 \quad \forall l = \{i, j, k\}. \quad (5)$$

When the coefficient of conjectural variation (μ_l) is zero, the equilibrium defined by (5) is

4) $\beta^2 > 2\gamma^2$ is a necessary condition.

5) Inverse demand functions in the foreign country are obtained by changing the index i to j in (2).

a Cournot equilibrium. If $\mu_l < 0$ ($\mu_l > 0$), this equilibrium is more competitive (collusive) than a Cournot equilibrium. As indicated by Chao and Eden (1996), the conjecture of a firm may not correspond to the reaction of its rival if the coefficient μ_l is set arbitrarily.⁶⁾ Therefore, we admit that each firm is capable of making a correct conjecture on the behavior of its rivals. Thus, the coefficient of conjectural variation is consistent, and we can deduce it from (5) as follows:⁷⁾

$$\mu_l = \mu = -\frac{\beta}{\gamma}(1 - \delta), \quad (6)$$

with $\delta = \sqrt{1 - \frac{2\gamma^2}{\beta^2}} < 1$. Then, it becomes clear from (6) that when the goods are substitutable, this coefficient is negative. The consistent conjectural equilibrium is more competitive than a Cournot equilibrium. This is consistent with the principle of compatibility described by Karikari (1991). Indeed, in our framework, the strategic effect of the domestic firm is given by:

$\frac{\partial^2 \Pi_{ii}}{\partial x_{ii} \partial x_{ji}} + \frac{\partial^2 \Pi_{ii}}{\partial x_{ii} \partial x_{ki}} = -2\gamma$. It measures the variation in firm's i profit with respect to a variation in the quantities supplied by foreign firms. If the variation is negative, goods are strategic substitutes: the quantities supplied by domestic and foreign firms vary in the opposite direction.

By contrast, if the variation is positive, goods are strategic complements, and the quantities supplied by the firms vary in the same direction. For $\gamma > 0$, we find that $\mu < 0$ (see 6), which is compatible with the hypothesis of strategic substitutes.⁸⁾ By substituting (6) into (5), we find that in free trade, the equilibrium quantity produced by each firm is given by the following:⁹⁾

$$X_{li}^* = \frac{\alpha - c}{\beta(1 + \delta) + 2\gamma} \quad \forall l = \{i, j, k\}. \quad (7)$$

By substituting (7) into (2), we obtain the equilibrium prices as follows:

$$P_{li}^* = \beta \delta X_{li}^* + c \quad \forall l = \{i, j, k\}. \quad (8)$$

Finally, substituting (7) and (8) into (3) gives a payoff of each firm:

6) Kamien and Schwartz (1983) indicated that the constant conjectural variations are rarely consistent. See Pery (1982) for more discussion.

7) The demonstration is provided in Appendix 5.1.

8) Similarly, we find that $\mu > 0$ when $\gamma < 0$, which is also consistent with the hypothesis of strategic complements.

9) Substituting (6) into (5) and simultaneously solving for outputs yield (7). The second-order maximization conditions, $-\beta(1 + \delta) < 0$, are satisfied.

$$\begin{aligned}\Pi_l^* &= \Pi_{li}^* + \Pi_{lj}^* \\ &= \beta\delta \left[(X_{li}^*)^2 + (X_{lj}^*)^2 \right] \forall l = \{i, j, k\}.\end{aligned}\quad (9)$$

The coefficient of conjectural variation is negative; therefore, none of the firm obtains deviation from this equilibrium. In fact, any increase (decrease) in the output of a given firm leads to a decrease (increase) in the output of its rivals. Thus, in free trade, the firms produce the same output, charge the same price, and earn the same payoff in the two countries where the total output of medical goods is:

$$X_i^* = X_j^* = 3X_{li}^* \quad \forall l = \{i, j, k\}.\quad (10)$$

However, facing a pandemic, a given country may have an increase in the demand for medical goods, prompting the authorities to set the maximum output of goods that can be exported. This was notably the case with COVID-19. Such a measure changes the interactions between competing firms.

III. The Effects of Export Restriction

A. Unilateral export restrictions

Let us assume that facing a pandemic, the authority of country j decides unilaterally to limit the exports of firm j to increase the total supply of medical goods locally. For Yoshida (1999), restrictions only occur when the new output exported (X_{ji}^u) is less than the free trade output. However, the common practice is to set this new output at the level of free trade. Hence, regardless of the output level, the simple presence of restrictions is enough to modify the conjectures of the producers and thus their profit functions (Dixit, 1988; Krishna, 1989). Here we take both points of view into account. Let X_{ji}^u be the new output exported, such that $X_{ji}^u < X_{ji}^*$. The difference between the output exported in free trade and that exported in ERs is the output retained. The non-reciprocal models cannot take this output into account. The retained output can either be exported to other markets or added to domestic output because the marginal cost is constant and invariant between free trade and ERs. The latter possibility is more likely in a pandemic context than in a non-pandemic one. Then, we assume that the output produced by j for its domestic market changes from X_{jj}^* in free trade to X_{jj}^u in ERs, with $X_{jj}^u = (1 + \lambda)X_{jj}^*$. Similarly, the output for export becomes $X_{ji}^u = (1 - \lambda)X_{ji}^*$, with $\lambda \in [0, 1]$.¹⁰⁾ The reaction functions defined

10) Implicitly, we admit that in free trade the firms produce at their maximum capacity, hence $X_{jj}^u + X_{ji}^u = X_{jj}^* + X_{ji}^*$. This assumption is consistent with the principle of restrictions. Indeed, if capacity is extensible and the foreign

by (4) are then rewritten as follows in country i :

$$\frac{\partial \Pi_{li}}{\partial x_{li}} = \alpha - 2\beta x_{li} - \gamma(\mu'_l x_{li} + \sum_{l \neq i} x_{li}) - c = 0 \quad \forall l = \{i, k\}. \tag{11}$$

Moreover, in country j , we have:

$$\frac{\partial \Pi_{lj}}{\partial x_{lj}} = \alpha - 2\beta x_{lj} - \gamma(\mu'_l x_{lj} + \sum_{l \neq j} x_{lj}) - c = 0 \quad \forall l = \{i, k\}, \tag{12}$$

with $\mu'_l = \mu_l|_{\mu_{ij}=0}$, the new conjecture of the firms i and k . The first effect of the restrictions is that they remove any reaction to the firm j (see, e.g., Eq. 11).

Similarly, firms i and k are no longer conjectured about firm j , whose output is now fixed in both markets. Then, the new conjecture of these two firms is:

$$\mu'_l = \mu' = -\frac{\beta}{\gamma}(1 - \delta'), \tag{13}$$

with $\delta' = \sqrt{1 - \frac{\gamma^2}{\beta^2}} < 1$. The ER equilibrium is thus more competitive than a Cournot equilibrium ($\mu' < 0$), but it is less competitive than the free trade equilibrium ($\mu < \mu'$). Indeed, in contrast to the duopoly where the ER equilibrium is Cournot, the presence of the unconstrained firm k leads to an equilibrium different from Cournot, allowing the continuous existence of competition. The substitution of (13) into (11) gives the outputs in country i :

$$X_{li}^u = \frac{\beta(1 + \delta) + \gamma(1 + \lambda)}{\beta(1 + \delta') + \gamma} X_{li}^* \quad \forall l = \{i, k\}. \tag{14}$$

In country j , the substitution of (13) into (12) yields:

$$X_{lj}^u = \frac{\beta(1 + \delta) + \gamma(1 - \lambda)}{\beta(1 + \delta') + \gamma} X_{lj}^* \quad \forall l = \{i, k\}. \tag{15}$$

Meanwhile, substituting (14) and (15) into (3), we obtain the following payoffs:

firm could produce more to respond to the increase in local demand due to the pandemic, there would be no restrictions.

$$\frac{\Pi_l^u}{\Pi_l^*} = \frac{\beta(1+\delta)[\beta(1+\delta)+2\gamma]+\gamma^2(1+\lambda^2)}{(\beta+\gamma+\beta\delta')^2} \frac{\delta'}{\delta} \quad \forall l = \{i, k\}, \quad (16)$$

and

$$\frac{\Pi_j^u}{\Pi_j^*} = \frac{(\beta-\gamma)[\beta\delta-\lambda^2(\beta+2\gamma)]+\beta\delta'[\beta(\delta-\lambda^2)+2\gamma]}{\beta\delta(\beta+\gamma+\beta\delta')}. \quad (17)$$

The payoff ratio of firms i or k , on the one hand, and the firm j , on the other hand, is obtained using (16) and (17):

$$\frac{\Pi_l^u}{\Pi_j^u} = \frac{[\beta(1+\delta)[\beta(1+\delta)+2\gamma]+\gamma^2(1+\lambda^2)]\beta\delta'}{(\beta+\gamma+\beta\delta')[(\beta-\gamma)[\beta\delta-\lambda^2(\beta+2\gamma)]+\beta\delta'[\beta(\delta-\lambda^2)+2\gamma]]}. \quad (18)$$

First, consider the extreme case. When the authorities of country j set the output of ERs at the level of free trade ($\lambda = 0$) firms i and k decrease their output in the same proportions in both markets (see 14 and 15). In this case, ERs reduce the total output of medical goods in country i and in country j . This contributes to increasing the effects of the pandemic. However, since the firm j can no longer react to the actions of its rivals, their lower output leads to higher prices (see 2). Therefore, for the same output, the price charged by j to the ERs becomes higher than the price it was charging in free trade: payoff can only increase, and the ERs become voluntary (Harris, 1985; Karikari, 1991; Chao & Eden, 1996).

More precisely, for $\lambda = 0$, we can deduce from (17) that the payoff in ERs is higher than the payoff in free trade ($\frac{\Pi_j^u}{\Pi_j^*} > 1$). In addition, the payoff of j increases more than the payoff of

firms i and k ($\frac{\Pi_l^u}{\Pi_j^u} < 1$). Outside this extreme case, other values of λ lead to different results.

In particular, another possibility for the authorities of the country j is to reduce sufficiently the exports of medical goods. Thus, the following proposition is posited:

Proposition 1

In a reciprocal model where three firms producing differentiated goods compete in Cournot with a consistent conjectural variation, the total offer of medical goods increases in the country

that reduces exports sufficiently ($\lambda > \lambda_f = \frac{2\beta(\delta' - \delta)}{\beta(1+\delta) - \gamma}$).

Proof 1

The total offer of medical goods in country j is given by the following:

$$X_j^u = \sum_{l=i}^k X_{lj}^u.$$

By using the definition of X_{jj}^u and (15), we obtain:

$$X_j^u = \frac{X_{lj}^* [\beta(3 + 2\delta + \lambda + (1 + \lambda)\delta') + \gamma(3 - \lambda)]}{\beta(1 + \delta') + \gamma}. \tag{19}$$

By comparing (19) and (10), we have:

$$X_j^u - X_j^* = \frac{X_{lj}^* [\lambda(\beta(1 + \delta') - \gamma) - 2\beta(\delta' - \delta)]}{\beta(1 + \delta') + \gamma}. \tag{20}$$

Thus, for $\lambda > \lambda_f = \frac{2\beta(\delta' - \delta)}{\beta(1 + \delta') - \gamma}$ the numerator of (20) is positive: the ERs leads to an increase in the total offer of medical goods in the country j , thus supporting Proposition 1.

This result is explained by the fact that for $\lambda > \lambda_f$, the local output of firm j increases with ERs compared to free trade. These rivals decrease their output without compensating for this increase in output of j .¹¹⁾ The total offer of medical goods then increases in the country j , which reduces the effects of the pandemic. Additionally, the price of medical goods supplied by firm j decreases. However, this price will always be positive for the following:

$$\lambda < \bar{\lambda}^u = \frac{\beta [(\beta - \gamma)\delta + (2\gamma + \beta\delta)\delta']}{\beta^2(1 + \delta') + \gamma(\beta - 2\gamma)}. \tag{21}$$

Furthermore, in country i , the reaction of firm j 's rivals depends primarily on the level of restrictions. Indeed, facing a decrease in exports, firms i and k increase their output if and only if:¹²⁾

11) Using (15) and the definition of X_{jj}^u , we obtain $\frac{\partial (X_{ij}^u + X_{kj}^u)}{\partial \lambda} < \frac{\partial X_{jj}^u}{\partial \lambda}$.

12) From (14), we can deduce that the ratio $\frac{X_{ii}^u}{X_{ii}^*} > 1$ if $\lambda > \lambda_{ii}$.

$$\lambda_i > \lambda_h = \frac{\beta(\delta' - \delta)}{\gamma}, \quad (22)$$

and again, they do not compensate for the decrease in firm j output. Thus, the total offer of medical goods always decreases in country i where the three firms increase their prices. The ER equilibrium is less competitive than free trade equilibrium ($\delta < \delta'$); therefore, the payoffs of firms i and k increase (see 16), whereas that of firm j decreases: the ERs are involuntary.

B. Bilateral ERs

Now, let's assume that both countries simultaneously decide to reduce their exports of medical goods. We admit that the output retained in the country i (X_{ii}^b) is equal to the output retained in the country j (X_{jj}^b): so either $X_{ii}^b = X_{jj}^b = (1 + \lambda)X_{ii}^*$. Thus, with the restriction, the two constrained firms export the same output of medical goods: $X_{ij}^b = X_{ji}^b = (1 - \lambda)X_{ij}^*$. Likewise, they can no longer react to the actions of the firm k . Therefore, equation (4) becomes:

$$\frac{\partial \Pi_k}{\partial x_{ki}} = \alpha - 2\beta x_{ki} - \gamma \sum x_{li} - c = 0 \quad \forall l = \{i, j\}. \quad (23)$$

Using the definitions of X_{ii}^b and X_{ji}^b , the output supplied by the firm k is given by:

$$X_{ki}^b = \frac{1 + \delta}{2} X_{ii}^*. \quad (24)$$

Then, we can deduce from (24) that compared to free trade, the total output supplied to both countries decreases at the ERs. In fact, since the constraint is bilateral, the restrictions are mutually compensating: in both countries the decrease in imports is compensated by an increase of local output. Thus, the firms i and j continue to supply the same output as in free trade. The variation of the total offer of medical goods depends only on the output supplied by k . The free trade equilibrium is more competitive ($\delta < 1$) than the bilateral ER equilibrium (which is a Cournot); therefore, the output of k decreases. This reduces the total output of medical goods in countries i and j . Thus, we can make the following proposition:

Proposition 2

In a reciprocal model where three firms producing differentiated goods, compete in Cournot with a consistent conjectural variation, a bilateral ER by the two reciprocal countries reduces the

total offer of medical goods.

Proof 2

The total output offered in the country i is given by the following:

$$X_i^b = \sum_{l=i}^k X_{li}^b = \frac{1}{2} (5 + \delta) X_{ii}^*.$$

Compared to (10), we obtain:

$$X_i^b - X_i^* = -\frac{1}{2} (1 - \delta) X_{ii}^*. \tag{25}$$

With $\delta < 1$, we have $X_i^b < X_i^*$. The same result is obtained in the country j by changing index i to j in (25). So, compared to free trade, to bilateral ERs, the total output of medical goods decreases in countries i and j , which prove Proposition 2.

Furthermore, for firm k , lower output leads to higher prices. As for the firms i and j , the increase in output on the domestic market implies a decrease in price. However, local prices will be positive for the following:

$$\lambda < \bar{\lambda}^b = \frac{(2\beta - \gamma)\delta - \gamma}{2(\beta - \gamma)}. \tag{26}$$

Finally, the substitution of the outputs in (3) gives the following payoffs:

$$\Pi_l^b = \Pi_l^* - [2(\beta - \gamma)\lambda^2 - \gamma(1 - \delta)] (X_{li}^*)^2 \forall l = \{i, j\}, \tag{27}$$

and

$$\Pi_k^b = \Pi_k^* + \frac{\beta(1 - \delta)^2}{2} (X_{li}^*)^2. \tag{28}$$

The payoff difference between firms i or j and firm k is obtained using (27) and (28):

$$\Pi_l^b - \Pi_k^b = \Pi_k^* - \frac{4\lambda^2(\beta - \gamma) + (1 - \delta)[\beta(1 - \delta) - 2\gamma]}{2} (X_{li}^*)^2. \tag{29}$$

The ERs increase the payoff of firm k and this, independently of λ (see 28). With the constraint, the firm k knows that its rivals can no longer react to a variation of its own output. Thus, even if firms i and j were to produce in ERs the same output as in free trade ($\lambda = 0$), the firm k would lower its output to increase its prices and have a higher payoff. The simple presence of the constraint was enough to modify the strategic interactions between the firms. Similarly, we can deduce from (27) that for $\lambda = 0$, the ERs are voluntary for firms i and j . However, as the restriction increases, it becomes less voluntary. More precisely, for $\lambda > \lambda_p = \sqrt{\frac{\gamma(1-\delta)}{2(\beta-\gamma)}}$, the term between brackets of (27) is positive and the ERs becomes involuntary.

Unlike unilateral ERs, bilateral ERs cannot increase the total offer of medical goods. However, we deduce from equations (21) and (22) that the effects of unilateral ERs on prices and quantities of each firm in countries i and j , depend on the proportion λ of quantity retained. Similarly, we deduce from (27) that the effects of bilateral ERs on each firm’s domestic price also depend on λ . A detailed discussion of the effects of ERs as a function of λ is therefore necessary.

C. Discussions

Table 2 summarizes the effect of ERs for different levels of λ . Since the goal of the restrictions is to respond to increased demand for medical goods, from (20) we can consider that when the ERs are unilateral, $\lambda \in [0, \lambda_f] \cup [\lambda_f, \overline{\lambda^u}]$. Similarly, from (14) the level of λ above which firms i and k start producing more than free trade is given by λ_h (see 22). Moreover, unlike in country i where ERs increase the price of all three firms, in country j the prices of firms i and k increase only if $\lambda < \lambda_{ij} = \frac{(\beta + \gamma)(\delta' - \delta)}{\gamma\delta'}$. Also, the price of j increases only if $\lambda < \lambda_{jj} = \frac{2\beta\gamma(\delta' - \delta)}{\beta^2(1 + \delta') + \gamma(\beta - 2\gamma)}$ ¹³.

These different levels of λ are classified as follows: $0 < \lambda_{jj} < \lambda_f < \lambda_h < \lambda_{ij} < \overline{\lambda^u} < 1$.

Table 2. Unilateral ERs Versus Free Trade

λ	Country i	Country j
$\lambda \leq \lambda_{jj} < \lambda_f$	$X_{ii}^u < X_{ii}^*$, $X_{ji}^u < X_{ji}^*$, $P_{ii}^u > P_{ii}^*$, $P_{ji}^u > P_{ji}^*$, $X_i^u < X_i^*$	$X_{ij}^u < X_{ij}^*$, $X_{jj}^u > X_{jj}^*$, $P_{ij}^u > P_{ij}^*$, $P_{jj}^u \geq P_{jj}^*$, $X_j^u < X_j^*$
$\lambda_{jj} < \lambda \leq \lambda_f$	$X_{ii}^u < X_{ii}^*$, $X_{ji}^u < X_{ji}^*$, $P_{ii}^u > P_{ii}^*$, $P_{ji}^u > P_{ji}^*$, $X_i^u < X_i^*$	$X_{ij}^u < X_{ij}^*$, $X_{jj}^u > X_{jj}^*$, $P_{ij}^u > P_{ij}^*$, $P_{jj}^u < P_{jj}^*$, $X_j^u \leq X_j^*$
$\lambda_f < \lambda \leq \lambda_h$	$X_{ii}^u \leq X_{ii}^*$, $X_{ji}^u < X_{ji}^*$, $P_{ii}^u > P_{ii}^*$, $P_{ji}^u > P_{ji}^*$, $X_i^u < X_i^*$	$X_{ij}^u < X_{ij}^*$, $X_{jj}^u > X_{jj}^*$, $P_{ij}^u > P_{ij}^*$, $P_{jj}^u < P_{jj}^*$, $X_j^u > X_j^*$
$\lambda_h < \lambda < \lambda_{ij}$	$X_{ii}^u > X_{ii}^*$, $X_{ji}^u < X_{ji}^*$, $P_{ii}^u > P_{ii}^*$, $P_{ji}^u > P_{ji}^*$, $X_i^u < X_i^*$	$X_{ij}^u < X_{ij}^*$, $X_{jj}^u > X_{jj}^*$, $P_{ij}^u > P_{ij}^*$, $P_{jj}^u < P_{jj}^*$, $X_j^u > X_j^*$
$\lambda_{ij} < \lambda < \overline{\lambda^u}$	$X_{ii}^u > X_{ii}^*$, $X_{ji}^u < X_{ji}^*$, $P_{ii}^u > P_{ii}^*$, $P_{ji}^u > P_{ji}^*$, $X_i^u < X_i^*$	$X_{ij}^u < X_{ij}^*$, $X_{jj}^u > X_{jj}^*$, $P_{ij}^u < P_{ij}^*$, $P_{jj}^u < P_{jj}^*$, $X_j^u > X_j^*$

13) Substituting (15) in (2) gives P_{ij}^u as follows: $P_{ij}^u - P_{ij}^* = -\frac{\beta[\gamma\lambda\delta' - (\beta + \gamma)(\delta' - \delta)]}{\beta(1 + \delta') + \gamma} X_{ij}^*$ which is positive for $\lambda < \lambda_{ij}$.

Similarly, $P_{jj}^u - P_{jj}^* = -\frac{\lambda[\beta^2(1 + \delta') + \gamma(\beta - 2\gamma)] - 2\beta\gamma(\delta' - \delta)}{\beta(1 + \delta') + \gamma} X_{ij}^*$ is positive if $\lambda < \lambda_{jj}$.

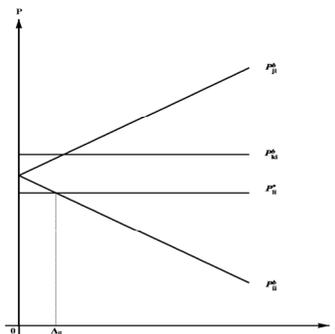
Furthermore, at the bilateral ERs, $\lambda \in [0, \lambda_{ii}] \cup [\lambda_{ii}, \bar{\lambda}^b]$, with $\lambda_{ii} = \lambda_p^2$ the level of λ for which the firm i practices the same price at ERs and free trade.

Now, when the output retained in the country j is negligible, $\lambda \in [0, \lambda_{jj}]$: the ERs cause decrease of the total output of medical goods, increases the prices and profits of the three firms in both countries. Similarly, the output is insufficient if $\lambda \in [\lambda_{jj}, \lambda_f]$. Here, the only positive effect of ERs in country j is a decrease in prices of medical goods supplied by firm j because the total output of goods is always below (or equal to) the level of free trade. The ERs become sufficient if $\lambda \in [\lambda_f, \lambda_h]$, because it increases the total offer of medical goods in the country j . In fact, the more restrictions increase, the more the firm j considers that the country i is protected. It then adopts a strategic behavior that consists of reducing its output in i and increasing it by the same level in j . However, in these two markets, firm j 's rivals do not compensate for a variation of its output. Thus, compared to free trade, the total output offered by the three firms always decreases in i and increases in j .

Also, in country i since the output exported by j is fixed, firms i and k have always been interested in producing less than in free trade as long as the restrictions remain below the threshold $\lambda < \lambda_h$. This allows them to sell less outputs and charge a high price. Particularly, for $\lambda = \lambda_h$, they will sell in ERs the same outputs as in free trade but at a higher price. Above the threshold λ_h , they will produce more than in free trade, but as they do not compensate for the decrease in the output of j , they will continue to charge a high price.

Similarly, the more the output retained increases in the country j , the more the three firms lower their prices. Particularly for $\lambda > \lambda_{jj}$, the firms i and k also lower their prices. Here, the unilateral ERs increase the total offer of medical goods and lower their prices in country j . However, bilateral ERs are less favorable to both countries (see Figure 2). It certainly induces each firm to produce more outputs that replace imports, but the total offer of medical goods is decreased. This is because the unconstrained firm k will prefer to lower its output to charge a high price. Because of the constraint, the price of imported goods also increases. However, the more the restrictions increase, the more the price of the local goods decreases: This is particularly the case when $\lambda > \lambda_{ii}$.

Figure 2. Prices with Bilateral ERs



IV. Empirical Analysis

A. Data

In the previous section, we have demonstrated theoretically that ERs, when unilateral and sufficient, increase the total quantity of medical goods in the country that imposes it. They then contribute to a better management of the pandemic. In this section, we prove this result empirically. To do so, we investigate the determinants of the COVID-19 incidence rate in 104 countries from January 2020 to June 2020. Our data come mainly from the World Bank, the IMF, the ECDC, and the ITC (see Table 3). We use the variable *Cov-Inc* to designate incidence rate of COVID-19. We obtain this rate in each country by reporting the number of COVID patients per 100,000 inhabitants. This rate is spatially illustrated in Figure 3. It varies from 0.04 (Madagascar) to more than 1900 cases (Chile) per 100,000 inhabitants. On average, the incidence rate of COVID-19 in our sample is 190 per 100,000 inhabitants (Table 4). Africa, Asia and Oceania are above this average, whereas the American and European countries are well below. Thus, a high spatial heterogeneity in the distribution of the COVID incidence rate among the countries. Furthermore, we admit that the ERs are likely to affect this incidence rate. So, we define by the variable ERs, the decision of country i , to take an ER measure against COVID-19. We consider this decision to be binary. Thus, the variable ERs take the value of 1 if the decision is taken and 0 otherwise.

Table 3. *Variables and Data Sources*

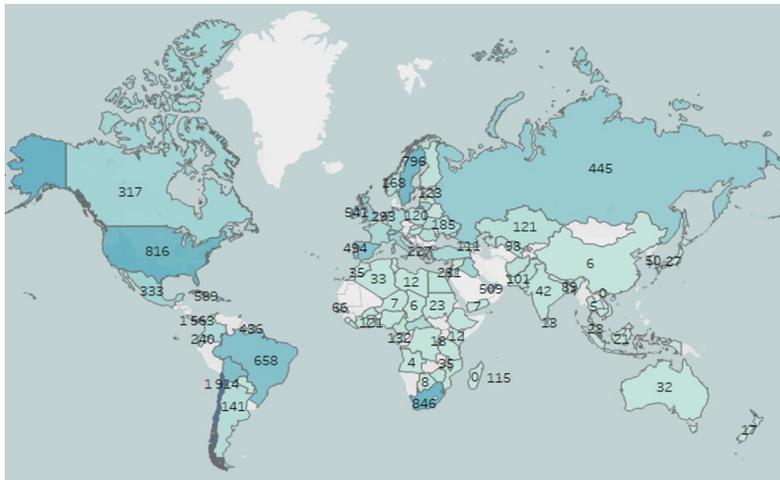
	Meaning	Data Sources
Cov-Inc	COVID Incidence Rate	Our own calculation based on ECDC's database
ERs	Export Restriction Dummy	ITC: International Trade Commission
Int-Tour	International Tourist	IMF
Gi	Gini Index	IMF
Emp	Unemployment Rate	World Bank
Carb-Em	Carbon Emission	United Nation Statistics Division
Mig	Migration Rate	World Bank

Additionally, several other determinants in the literature explain the transmission of pandemics. Thus, like Mamelund (2017), we use the Gini index (Gi) and the unemployment rate (Emp) to evaluate the effect of socio-economic determinants.¹⁴⁾ Another determinant that may increase the speed of pandemic spread is human mobility. Therefore, in response to COVID-19, various public health measures have been taken to encourage people to stay at home and thus reduce social contacts: for example, confinement measures, border closures, prohibition of mass gatherings, closure of schools, religious

14) Sà (2020) shows that social and economic variables affect the number of COVID-19 related cases and deaths. See also Brown and Ravallion (2020).

places, and places of entertainment (Bayham & Fenichel, 2020; Chen et al., 2020; Chinazzi et al., 2020). Thus, we use international tourism (Int-Tour) and migration (Mig) as two variables of mobility likely to explain the incidence rate of COVID-19. Finally, for Van Doremalen et al. (2020) and Zhu et al. (2020), pollution increases the risk of viral infections. Thus, we use carbon emissions (Carb-Em) to measure the effects of the environment on the diffusion of COVID-19.

Figure 3. Covid's Incidence Rate for 100,000 inhabitants



(Source) Authors' calculations based on European Centre for Disease Prevention and Control's database.

Table 4. Summary Statistics

Variables	Observation	Mean	Std. Dev.	Min	Max
Cov-Inc	104	190	3,02	0,043	1914,06
Int-Tour	104	8,06	1,71	4,04	11,37
Gi	104	38,30	7,71	25,2	63
ERs	104	0,50	0,50	0	1
Carb-Em	104	3,99	4,28	0	20,5
Mig	104	-0,28	8,47	-54,7	41,5
Emp	104	6,89	5,05	0,3	27,3

B. Methodology

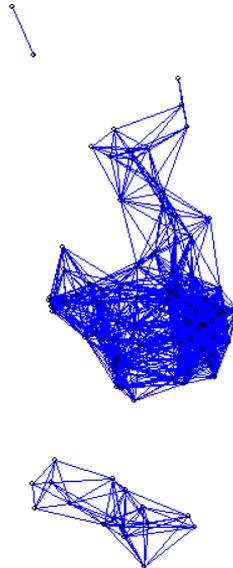
Our first specification is based on Ordinary Least Squares (OLS):

$$y = \beta x + \epsilon, \tag{30}$$

where y is the dependent variable so the incidence rate of COVID-19, x characterizes the vector of explanatory variables, β is the vector of regression coefficients and ϵ is the term of error.

OLS assumes that observations in each country are independent of each other and therefore ignore spatial dependence. However, a high degree of heterogeneity exists in the distribution of the COVID incidence rate among the countries in our sample. This can result in spatially autocorrelated residuals and therefore biased and non-convergent OLS estimators. To check this possibility, we apply a test of Moran (1950) using a spatial weighting matrix W based on distance. In other words, we consider two countries i and j as neighbors when country j is in the critical distance band of country i (Anselin & Bera, 1998; Florax & Nijkamp, 2004). So, beyond a certain threshold, the two countries are no longer considered neighbors.¹⁵⁾ Therefore, we have chosen this threshold in such a way that each country, defined by its geographical coordinates (latitudes, longitudes), has at least one neighbor.¹⁶⁾ Thus, the weight matrix provides a broader definition of the concept of neighbors that exceeds the simple principle of contiguity. Therefore, our specification allows us to easily consider islands or all countries with no common borders with other countries. The connectivity lines obtained by this configuration of the matrix W consist of two subgraphs and a pair of dots (see Figure 4). The absence of isolates and the density of these lines reflects the high intensity of the linkages between the countries in our sample. Also, the histogram of connectivity provided by W reveals a high level of country heterogeneity as function of the number of neighbors (see Figure 5).

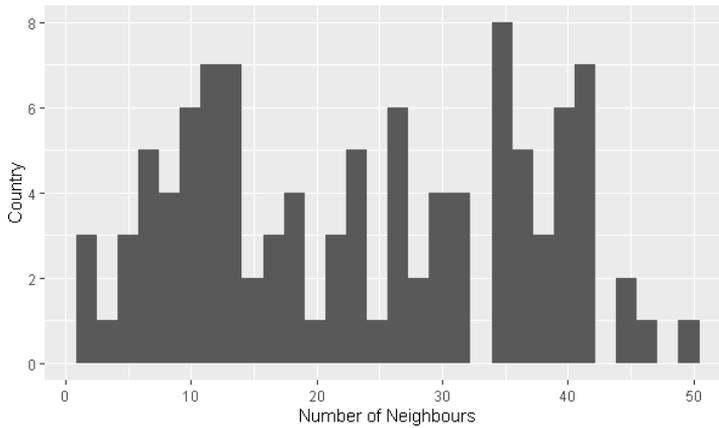
Figure 4. Connectivity of Countries based on W



15) $j \in N(i)$ if $d_{ij} < d_{\max}$ where d is the distance between i and j .

16) Geographic coordinates are available in the CEPII database.

Figure 5. Distribution of the number of neighbors



Indeed, 3 countries have only 5 neighbors, whereas 3 other countries have more than 40 neighbors. Similarly, the number of neighbors for a single country varies between 3 and 50. This heterogeneity may be at the origin of a spatial autocorrelation. Several models capture this autocorrelation, including the Spatial Autoregression Model (SAR) and the Spatial Error Model (SEM).

The SAR consists of integrating an endogenous variable lagged to the inverse of the weight matrix (ρWY_{SAR}), into the linear model defined by Equation (30); therefore,

$$Y_{SAR} = \rho WY_{SAR} + \beta x + \epsilon, \tag{31}$$

where ρ is a spatial auto-regressive parameter. It captures the intensity of interactions between observations of the dependent variable Y_{SAR} (Anselin & Bera, 1998; Ward & Gleditsch, 2018). Contrary to the linear model, the SAR model considers that the incidence rate of COVID-19 in a given country is partly explained by that in neighboring countries. Thus, this potential diffusion process is captured by the spatial lag WY_{SAR} (Kostov, 2010).

The SEM model consists of admitting that a spatial dependence in the error term of the linear model explains heterogeneity. By decomposing the latter, we write the SEM as follows:

$$Y_{SEM} = \beta x + u, \tag{32}$$

with $u = \lambda W_u + \epsilon$, the spatially uncorrelated error term. The parameter λ captures the intensity of the interdependence between the residuals of the linear regression.

Similar to Le Gallo (2002), we adopt a bottom-up approach that consists of first to estimate the linear model and to extract the residues from it.¹⁷⁾ Then, we use these residues to measure and test the spatial autocorrelation coefficient of Moran (1950). If this coefficient is significative, we perform

the Lagrange multiplier test (Anselin et al., 1996) to select the appropriate model: SAR, SEM or OLS.¹⁸⁾ This methodology leads us to the following results.

C. Result

1. OLS

To test the effect of ERs on the COVID incidence rate, we defined four different specifications that correspond to the four columns of Table 5. As shown, ERs significantly decrease the incidence rate of COVID-19. This result holds for each selected specification. Although migration is not significant, human mobility through international tourism tends to significantly increase the incidence rate of COVID-19. In fact, since the COVID is mainly transmitted by droplets, international tourism, which promotes direct human-to-human contact, is an important vector of dissemination. Similarly, we find that the unemployment rate is not significant. However, the positive and significant Gini index increases the COVID-19 incidence rate. In fact, because of inequalities and poverty, some populations are forced to work. Thus, they cannot respect the rules of social distancing and thus contribute to increasing the COVID-19 incidence rate. Finally, we find that emissions also significantly increase the incidence of COVID-19. This result can be explained by the fact that atmospheric pollutants, like carbon emissions, reduce the body's immunity and thus increase the risk of COVID-19 infections (Fattorini & Regoli, 2020).

Furthermore, we can deduce from the test of Moran (1950) that a positive and significant spatial autocorrelation exists in the data (Table 6). The coefficients of the linear model contained in Table 5 are then biased and non-convergent.

Table 5. Results of COVID-19 Incidence Rate Estimates (OLS)

Variables	(1)	(2)	(3)	(4)
Constant	-8.716***	-8.851***	-8.796***	-8.692***
ERs	-1.663**	-1.606**	-1.626**	-1.717**
Int-Tour	0.803***	0.681***	0.786***	0.790***
Gi	0.130***	0.145***	0.135***	0.124***
Carb-Em		0.129*		
Mig			0.031	
Emp				0.045

17) However, the spatial lag of W can cause an endogeneity problem. In appendix 5.2 we consider this problem via a generalized spatial two-stage least squares regression model (GS2SLS).

18) By comparing the significance levels of the Lagrange multiplier test LMError, LMLag, and its robust version RLMError and RLMLag, we can choose between the three models. If LMLag is as significant as LMError and only RLMLag is significant, a lagged endogenous variable should be included, and the preferred model will be SAR. Inversely, if LMError is as significant as LMLag, and only RLMError is significant, then the choice is made on the SEM model (Le Gallo, 2002; Florax et al., 2003). Finally, if the parameters ρ and λ are not significant, the OLS model becomes preferable.

Table 5. *Continued*

Variables	(1)	(2)	(3)	(4)
Statistics				
R^2	0.251	0.277	0.258	0.256
R^2 ajusté	0.228	0.248	0.228	0.226
F-statistic	11.17***	9.509***	8.637***	8.544***
Log likelihood	-247.227	-245.353	-246.694	-246.84
AIC	504.455	502.706	505.389	505.679
BIC	517.677	518.572	521.256	521.546
Breusch-Pagan test	7.035.	6.875	7.242	7.189
Jarque Bera Test	801.95***	906.11***	793.43***	862.37***

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 6. *Moran's test with W*

Specifications	Observed value	Expected value	Variance	$z - test$	$p - value$
(1)	0.128	-0.017	0.001	4.218	1.228e-05
(2)	0.120	-0.018	0.001	4.07	2.351e-05
(3)	0.127	-0.017	0.001	4.159	1.597e-05
(4)	0.131	-0.019	0.001	4.424	4.834e-06

2. Spatial Regression

The results of the SEM and SAR models that take spatial autocorrelation into account are, respectively, provided in Tables 7 and 8. We find that in both models, the spatial parameters λ and ρ are positive and significant. Also, given that the likelihood ratio test is significant, a diffusion effect of COVID-19 would exist among neighboring countries. However, this diffusion effect is significantly reduced by ERs measures. This is because the total supply of medical goods increases in countries, which adopt ERs. Nevertheless, the decrease in the COVID incidence rate due to the ERs is more drastic in the SEM model than the SAR model.

Table 7. *Results of COVID-19 Incidence Rate Estimates (SEM) with W*

Variables	(1)	(2)	(3)	(4)
Constant	-6.992***	-7.437***	-7.110***	-6.767***
ERs	-1.773**	-1.733**	-1.754**	-1.855**
Int-Tour	0.665***	0.594***	0.647***	0.645***
Gi	0.115***	0.129***	0.121***	0.104***
Carb-Em		0.110*		
Mig			0.029	
Emp				0.055
Statistics				

Table 7. *Continued*

Variables	(1)	(2)	(3)	(4)
λ	0.458***	0.430**	0.460***	0.464***
Asymptotic standard error	0.163	0.170	0.163	0.162
z - value	2.797***	2.524**	2.812***	2.859
Wald statistic	7.826***	6.375**	7.911***	8.174
Log likelihood	-243.822	-242.411	-243.310	-243.271
σ	2.497	2.467	2.485	2.483
AIC LM	504.46	502.71	505.39	505.68
AIC	499.64	498.82	500.62	500.54

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 8. *Results of COVID-19 Incidence Rate Estimates (SAR) with W*

Variables	(1)	(2)	(3)	(4)
Constant	-7.616***	-7.805***	-7.700***	-7.565***
ERs	-1.660**	-1.614**	-1.627**	-1.723**
Int-Tour	0.706***	0.616***	0.693***	0.689***
Gi	0.102***	0.116***	0.107***	0.095***
Carb-Em		0.103*		
Mig			0.028	
Emp				0.053
Statistics				
ρ	0.403***	0.372***	0.398***	0.411***
Asymptotic standard error	0.154	0.154	0.153	0.153
z - value	2.613***	2.405**	2.589***	2.674***
Wald statistic	6.827***	5.788**	6.706***	7.151***
Log likelihood	-243.195	-241.927	-242.744	-242.61
σ	2.489	2.461	2.478	2.474
AIC LM	504.46	502.71	505.39	505.68
AIC	498.39	497.86	499.49	499.22

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The coefficient of Gini index reveals that high inequalities reduce the global capacity of a given country to protect itself against COVID-19. This explains the positive and significant sign of this coefficient in each of the four specifications of the two models.

Moreover, it appears that the risk is increased for countries with a high tourism activity. Indeed, unlike migration, which takes on a certain form of a sedentary lifestyle, tourism is characterized by successive movements into a given country. Thus, it is more sensitive to space than migration. Therefore, we find that contrary to migration, which is not significant, tourism significantly increases the COVID incidence rate in both spatial models.

Finally, we make the choice of the optimal model by performing the Lagrange multiplier test. Hence, we find that the statistics of LMerr and LMLag are significant for all specifications (Table 9). Then, we compare the robust forms: it appears that the RLMerror statistics are insignificant while the RLMLag statistics are significant at the 5% threshold. The Lagrange multiplier test leads us to prefer the SAR model specifications to the SEM model.

Table 9. Statistics of the Lagrange Multiplier Test for Spatial Autocorrelation with w

Specifications	LMerror	RLMerror	LMLag	RLMLag
(1)	10.617***	0.191	15.97***	5.544**
(2)	9.346***	0.006	12.831***	3.490*
(3)	10.417***	0.108	15.495***	5.186**
(4)	11.14***	0.321	17.013***	6.193**

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

3. Robustness

The results of spatial models can be sensitive to the choice of the weight matrix (Harris et al., 2011; Gibson & Overman, 2012). Then, we test the robustness of our results by defining the second spatial weighting matrix based on the concept of the weight of the nearest neighbors. As the neighbors have different weights, the matrix W resulting from this approach is asymmetric. So, we make it symmetrical

by replacing it with $W_r = \frac{W + W'}{2}$.

Since the number of neighbors is fixed at 6, the histogram of connectivity is not useful. As shown in Figure 4, the connectivity lines, based on W_r are composed of two subgraphs. They show strong links between the countries in our sample (see Figure 6). From the residuals of the linear model, we deduce the statistics of Moran (1950). As in Table 6, Table 10 shows a positive and significant spatial autocorrelation in the data.

Figure 6. Connectivity of Countries with W_r

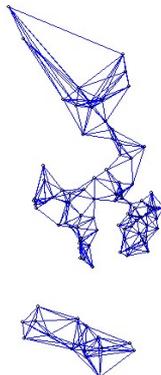


Table 10. Moran's Test with W_r

Specifications	Observed value	Expected value	Variance	z-test	p-value
(1)	0.134	-0.020	0.002	3.190	0.0007
(2)	0.121	0.121	0.002	2.937	0.001
(3)	0.002	-0.019	0.134	3.148	0.0008
(4)	0.140	-0.023	0.002	3.421	0.0003

The results of the SEM and SAR models, which consider this spatial dependence, are, respectively, provided in Tables 11 and 12. The spatial parameters λ and ρ are significant in both model.

Table 11. Results of COVID-19 Incidence Rate Estimates (SEM) with W_r

Specification	(1)	(2)	(3)	(4)
Constant	-6.701***	-7.285***	-6.838***	-6.639***
ERs	-1.795**	-1.741**	-1.770**	-1.860**
Int-Tour	0.642***	0.577***	0.626***	0.627***
Gi	0.114***	0.130***	0.121***	0.105**
Carb-Em		0.109*		
Mig			0.029	
Emp				0.061
Statistics				
λ	0.369**	0.340**	0.371**	0.380**
Asymptotic standard error	0.135	0.139	0.134	0.133
z - value	2.737***	2.443**	2.762***	2.856***
Wald statistic	7.491***	5.970**	7.630***	8.159***
Log likelihood	-244.413	-243.042	-243.872	-243.791
σ	2.511	2.483	2.498	2.495
AIC LM	504.46	502.71	505.39	505.68
AIC	500.83	500.08	501.75	501.58
BIC	516.69	518.59	520.25	520.09

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

For the choice of matrix W , we also find with the matrix W_r that ERs significantly reduce the incidence rate of COVID-19 in both the SEM and SAR models. Also, the coefficient of ERs is almost the same in the SEM models: -1.73 vs. -1.74 and -1.85 vs. -1.86 (see respectively on the one hand columns 2 and on the other hand columns 4 of Tables 7 and 11). Similarly, we find that the coefficient of ERs is almost invariant in the four specifications of the SAR models (see the columns of Tables 8 and 12). The coefficients and the significance of the other explanatory variables, including international tourism, the Gini index, and carbon emissions are not affected by a change in the weight matrix. Our results are therefore robust to the choices of the spatial weighting matrix.

Table 12. Results of COVID-19 Incidence Rate Estimates (SAR) with W_r

Variables	(1)	(2)	(3)	(4)
Constant	-7.416***	-7.640***	-7.503***	-7.367***
ERs	-1.656**	-1.610**	-1.622**	-1.716**
Int-Tour	0.693***	0.603***	0.680***	0.678***
Gi	0.103***	0.118***	0.108***	0.097***
Carb-Em		0.106*		
Mig			0.029	
Emp				0.050
Statistics				
ρ	0.322**	0.294**	0.319**	0.328**
Asymptotic standard error	0.127	0.129	0.127	0.126
z - value	2.533**	2.278**	2.502**	2.599***
Wald statistic	6.416**	5.193**	6.260**	6.756***
Log likelihood	-244.043	-242.726	-243.560	-243.523
σ	2.509	2.481	2.498	2.496
AIC LM	504.46	502.71	505.39	505.68
AIC	500.09	499.45	501.12	501.05
BIC	515.95	517.96	519.63	519.55

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The Adjusted Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC) and the Lagrange multiplier test (see Table 13) all three indicate that the SAR model is preferable to the SEM model. Also, considering the problem of endogeneity does not alter these results (see appendix 5.2)

Table 13. Statistics of the Lagrange Multiplier Test for Spatial Autocorrelation with W_r

Specifications	LMerror	RLMerror	LMlag	RLMlag
(1)	6.491**	0.044	9.014***	2.566
(2)	5.298**	0.005	7.247***	1.954
(3)	6.435**	0.035	8.902***	2.503
(4)	7.075***	0.007	9.393***	2.325

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

V. Conclusion

The current epidemic context has promoted the re-emergence and use of ERs as a means of protection. We have shown that when they are unilateral, their efficiency can be limited. In fact, if the output retained is negligible, they are particularly inefficient. Not only do they fail to increase

the total offer of medical goods, but also they increase the price of these goods in all markets. In contrast, they contribute to a better COVID-19 management if they are sufficient: this is the case when the retained output exceeds a certain threshold. The more this retained output increases, the more the ERs become efficient because they decrease each firm's price in the exporting country. Using several data sources, we have empirically demonstrated this result. The incidence rate of COVID-19 has significantly decreased in countries that have taken ER measures.

Finally, when they are bilateral, the ERs are mutually compensated. The unconstrained firm takes the opportunity to decrease its output because its rivals can no longer respond to its actions. This decreases the total supply of medical goods in both countries. Bilateral ERs are therefore not recommended in a pandemic situation.

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Appendix

A. Coefficient of consistent conjectural variation

The reactions of firms i and k conjectured by firm j are given by the following:

$$\mu_j = \frac{\partial x_{ii}}{\partial x_{ji}} + \frac{\partial x_{ki}}{\partial x_{ji}}. \quad (33)$$

With firm j conjecture, the reactions of firms i and k must, respectively, satisfy:¹⁹⁾

$$\begin{aligned} \mu_{ji} &= \frac{\partial^2 \pi_{ii}}{\partial x_{ii}^2} \partial x_{ii} + \frac{\partial \pi_{ii}}{\partial x_{ii} x_{ji}} \partial x_{ji} = 0, \\ \mu_{jk} &= \frac{\partial^2 \pi_{ki}}{\partial x_{ki}^2} \partial x_{ki} + \frac{\partial \pi_{ki}}{\partial x_{ki} x_{ji}} \partial x_{ji} = 0. \end{aligned}$$

That we can rewrite as follows:

$$\begin{aligned} \mu_{ji} &= \frac{\partial x_{ii}}{\partial x_{ji}} = - \frac{\frac{\partial \pi_{ii}}{\partial x_{ii} x_{ji}}}{\frac{\partial^2 \pi_{ii}}{\partial x_{ii}^2}}, \\ \mu_{jk} &= \frac{\partial x_{ki}}{\partial x_{ji}} = - \frac{\frac{\partial \pi_{ki}}{\partial x_{ki} x_{ji}}}{\frac{\partial^2 \pi_{ki}}{\partial x_{ki}^2}}. \end{aligned} \quad (34)$$

Substituting (34) into (33) and using (4) gives:

$$\mu_j = - \left[\frac{\gamma + \gamma x_{ii} \frac{\partial \mu_{ij}}{\partial x_{ji}}}{2\beta + \gamma(\mu_{ij} + \mu_{ik}) + \gamma x_{ii} \frac{\partial(\mu_{ij} + \mu_{ik})}{\partial x_{ii}}} + \frac{\gamma + \gamma x_{ki} \frac{\partial \mu_{kj}}{\partial x_{ji}}}{2\beta + \gamma(\mu_{ki} + \mu_{kj}) + \gamma x_{ki} \frac{\partial(\mu_{ki} + \mu_{kj})}{\partial x_{ki}}} \right]. \quad (35)$$

19) See Boyer and Moreaux (1983) for more discussion.

Following Bresnahan (1981), Chao and Eden (1996), μ_{ij} , μ_{kj} , μ_i and μ_k are four constants, then (35) becomes:

$$\mu_j = - \left[\frac{\gamma}{2\beta + \gamma\mu_i} + \frac{\gamma}{2\beta + \gamma\mu_k} \right]. \quad (36)$$

Solve (36) for $\mu_j = \mu_i = \mu_k = \mu$ to have (6).

B. Problem of endogeneity

Although the spatial analysis respects the prescriptions made by Le Gallo (2002) and Florax et al. (2003), an endogeneity problem could still occur due to the spatial lag of W . Neighbors influence each other, leading to simultaneity that biases the estimates (Kelejian & Prucha, 1998). To ensure unbiased estimates, the generalized spatial two-stage least squares regression model (GS2SLS) in which W is instrumented by spatial lags and explanatory variables (W^2X) can be used. The GS2SLS method is an extension of the 2SLS methodology combined with the GMM estimator to account for the spatial correlation structure in the perturbations. To start, consider the general spatial model equation of Anselin (1988) presented as follows:

$$Y = Z\beta + \lambda Wy + u, \quad (37)$$

with $Z = [x, Wx]$ denoting, respectively, the regressor matrix and the lagged spatial matrix of explanatory variables. Equation (37) shows that the GS2SLS procedure can be obtained by estimating the parameters β and λ via the 2SLS estimator. We then obtain $\tilde{\beta}$ and $\tilde{\lambda}$. We use these to re-estimate u , called \hat{u} , such as

$$\hat{u} = Y - Z\tilde{\beta} - \tilde{\lambda} Wy. \quad (38)$$

We use \hat{u} to estimate ρ consistently, via the GMM which we will call $\hat{\rho}$. Then, (37) takes the following form:

$$(I - \hat{\rho} W) Y = (I - \hat{\rho} W) Z\beta + \epsilon. \quad (39)$$

Estimating (39) using 2SLS with $H = [Z, WZ, W^2Z]$ as instruments provides parameters robust to the endogeneity problem. Table 14 contains the results obtained with this method. The findings of section 3.3 are confirmed. Particularly, the negative and significant influence of ERs on the

COVID incidence rate holds. Also, the sign of the parameter λ is confirmed. This estimation method addresses the shortcomings of the GS2SLS method due to an assumed correlation between the residuals. It considers both Wy 's endogeneity problem and the problem of spatial correlation between stochastic perturbations.

Table 14. Results of COVID-19 incidence rate estimates (GS2SLS) with H

Variables	(1)	(2)	(3)	(4)
Intercept	-7.264***	-7.689***	-7.381***	-7.084***
ERs	-1.749***	-1.704***	-1.726***	-1.826***
Int-Tour	0.692***	0.612***	0.676***	0.674***
Gi	0.116***	0.131***	0.122***	0.107***
Carb-Em		0.115**		
Mig			0.029**	
Emp				0.053
λ	0.393**	0.359**	0.393**	0.401**

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$