VACCINES BETWEEN WAR AND MARKET

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Abstract: *This short paper presents a theoretical analysis which is intended to throw light on some issues related to supply of vaccines in a context where producer countries are involved in armed conflicts. We present a simple model which combines elements of Hirshleifer-style economic analysis of conflict and microeconomic modelling of oligopolistic markets. In particular, we apply a simple Cournot duopoly model to two producer countries. Findings show that world supply of vaccines is indirectly and negatively affected by the existence of armed conflicts in a producer country which is involved in an armed conflict. Yet such negative impact on supply also increases the world price. In brief, participation of producer countries into armed conflicts turns to be detrimental for global supply of vaccines. Such result is driven by: (i) the characteristics and the technology of conflict; (ii) the market structure.*

Keywords: COVID-19, Vaccines, Armed Conflict, Oligopoly.

Jel codes: I18; D43; D74

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Introduction

This short paper presents a theoretical analysis which aims to contribute to the understanding on the relationship between armed conflicts worldwide and global health emergency due to COVID-19 pandemic. In particular, we focus on the impact of armed conflicts on world supply of vaccines through the standard mechanism of an oligopolistic market. Albeit indirectly, we show that there could be a clear relationship between armed conflict and world supply of vaccines.

In fact, this paper contributes to the study on the relationship between armed conflicts and pandemic. The focus on such relationship is not a novelty in history. In fact, only few months after the outbreak of the COVID-19, several scholars warned about the risk of increasing violence worldwide. Caruso and Kibris (2020) in the introduction of the special issue 'Reflections on the post COVID-19 World' posed the question on whether the process of human betterment is to be halted or even reversed by such a shock. Recently, Chowdury and Karmakar (2022) have surveyed the literature in economics and related fields on the relationship between the COVID-19 pandemic and conflict behaviour. There the authors cover the impact of the pandemic on micro-level conflict (among individuals), macro-level conflict (interstate, intrastate, and extra-state), and the effect of existing conflict on the spread of the pandemic. In brief, there is an increase in intimate partner violence, a spillover between work-family conflict and domestic violence, and a spike in the anti-East-Asian crimes. At the macro-level there was an initial drop in the conflict count, but it eventually returned to the pre-pandemic level. Negative performance of the economy and food insecurity associated with the pandemic were major drivers of conflict in the developing countries, but in some cases state stimulus have reduced conflicts.

At global level, enhancing cooperation between states appeared as a crucial priority in order avoid emergence and recrudescence of further conflicts. In particular, focus on cooperation and diplomacy on health issues gained momentum. Before the COVID-19 diseases, however, health issues have already become a crucial aspect of political agenda. In fact, health cooperation has become pervasive in states' foreign policy as well as in patterns of multilateral cooperation since early 2000s. In fact, global health diplomacy has become a crucial aspect of foreign policy. Katz et al. (2011) have highlighted three features of global health diplomacy: (1) the core diplomacy, namely the standard interactions between nations leading to bilateral and multilateral treaties; (2) multistakeholder diplomacy, i.e., negotiations between or among nations and international agencies such as WHO, nongovernmental organizations (NGOs); and (3) informal diplomacy, which includes peer-to-peer scientific partnerships. Global health diplomacy has therefore now received a substantial attention in the literature [see among others Fazal (2020), Chattu and Knight (2019), Ruckert et al. (2016), Feldbaum and Michaud (2010)]. In particular, vaccine diplomacy also can be considered a relevant pillar of global health diplomacy. Vaccine diplomacy refers to all aspects for securing delivery of vaccines (Hotez, 2014). Needless to say, the outbreak of COVID-19 pandemic has made vaccine diplomacy more relevant than ever. In particular, different major states have designed different strategies. [see among others Suzuki and Yang (2022), Deters and Zardo (2022), Gruszczynski and Wu (2021), Cardenas (2021)].

This paper aims to contribute to this strand of studies and reflections taking as point of departure a different perspective. In fact, we start first considering both the market structure of the vaccine market and the existence of armed conflict in countries which may produce vaccines. We present a simple theoretical model which combine elements of Hirshleifer-style economic analysis of conflict and microeconomic modelling of oligopolistic markets. Then we show that world supply of vaccines is - indirectly and negatively - affected by the existence of armed conflicts in producer countries. Yet such negative impact on supply also increases the world price. Whether the maximization of a global supply of vaccines can be considered a reference point for a global health cooperation, then the existence of armed conflicts turns to be detrimental for global supply of vaccines. Such result is driven by: (i) the characteristics and the technology of conflict; (ii) the market structure.

In brief, the theoretical analysis suggests that a large world supply of vaccines and the existence of armed conflicts are somehow incompatible. In broader terms, it also suggests that governments of producer countries cannot credibly commit to global health cooperation if they are participating into armed conflicts. Yet, this result to some extent poses doubts on the expected outcomes of vaccine diplomacy.

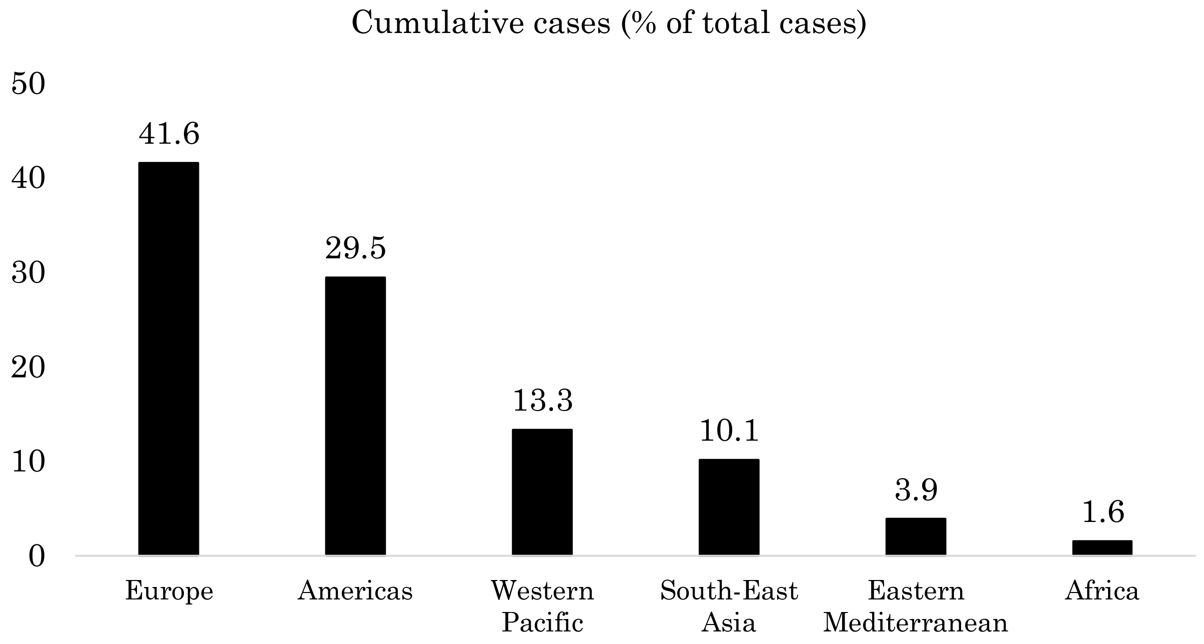
The paper is organised as follows: in the first section we present some descriptive facts and figures about the production of vaccines against COVID-19 disease. In the second section we present the theoretical model. In a third section we discuss the results and policy implications descending from them. Conclusions summarise the insights from the model.

1. Facts and figures about vaccines' supply

In what follows we present some facts and figures on COVID-19 and vaccines. Data are drawn from both the World Health Organization (WHO) and the COVID-19 Vaccine Tracker developed by World Trade Organization (WTO) and International Monetary Fund (IMF).

Figure 1 shows the confirmed cumulative cases reported by region. The most affected regions are Europe (41.6% of total cases) and the Americas (29.5% of total cases). Poorer regions, such as Africa, reported poorer figures (1.6% of total cases). However, with regard to poorer countries with less developed state capacity it is likely that there is some reporting bias which affected negatively the figures.

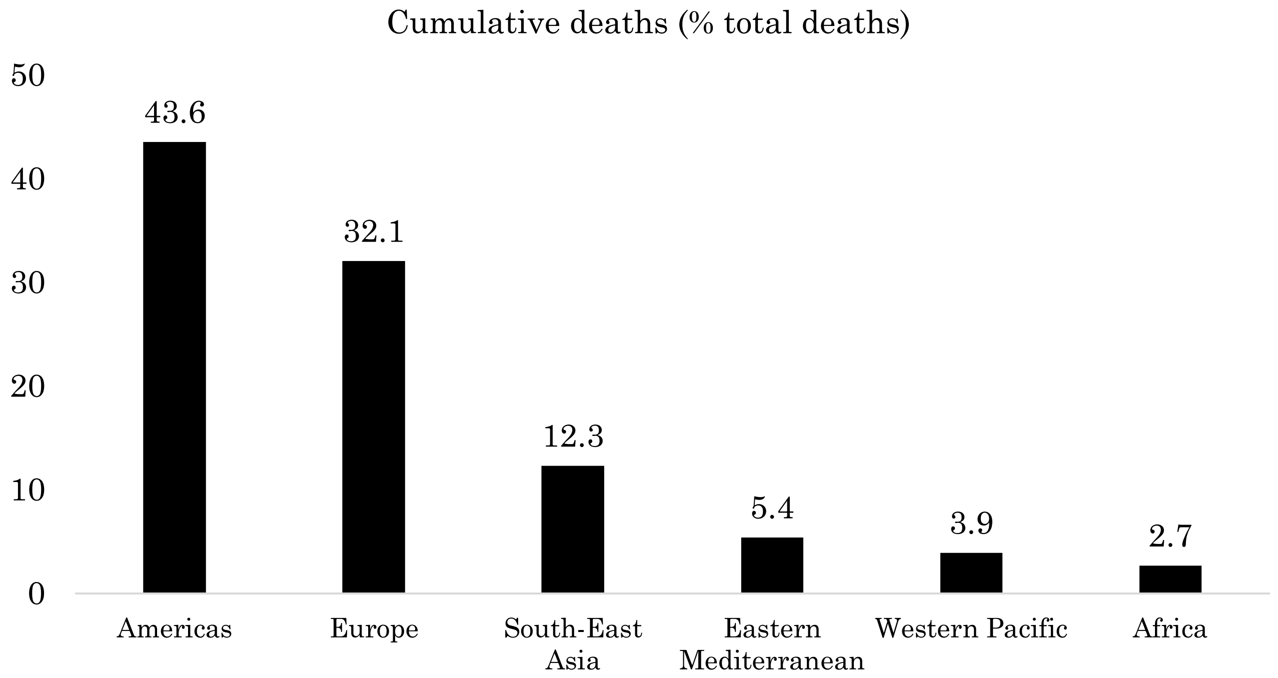
Figure 1



Source: World Health Organization - Retrieved on 13/08/2022

The negative impact of COVID-19 pandemic on the population is highlighted in Figure 2 which shows the reported cumulative deaths by region. At the time this paper is written, the total count of deaths is 6,433,794. In fact, 43.6% of the total deaths are reported by Americas and 32.1% are reported by Europe. As above, it is likely that figures embedded a reporting bias. However, we can notice that more peaceful regions proved to be most effective in managing the pandemic compared to poorer regions. For instance, 41.6% of total cases have been reported in Europe but only 32.1% of total deaths. On the contrary Africa reported 1.6% of total cases of COVID-19 but 2.7% of total deaths.

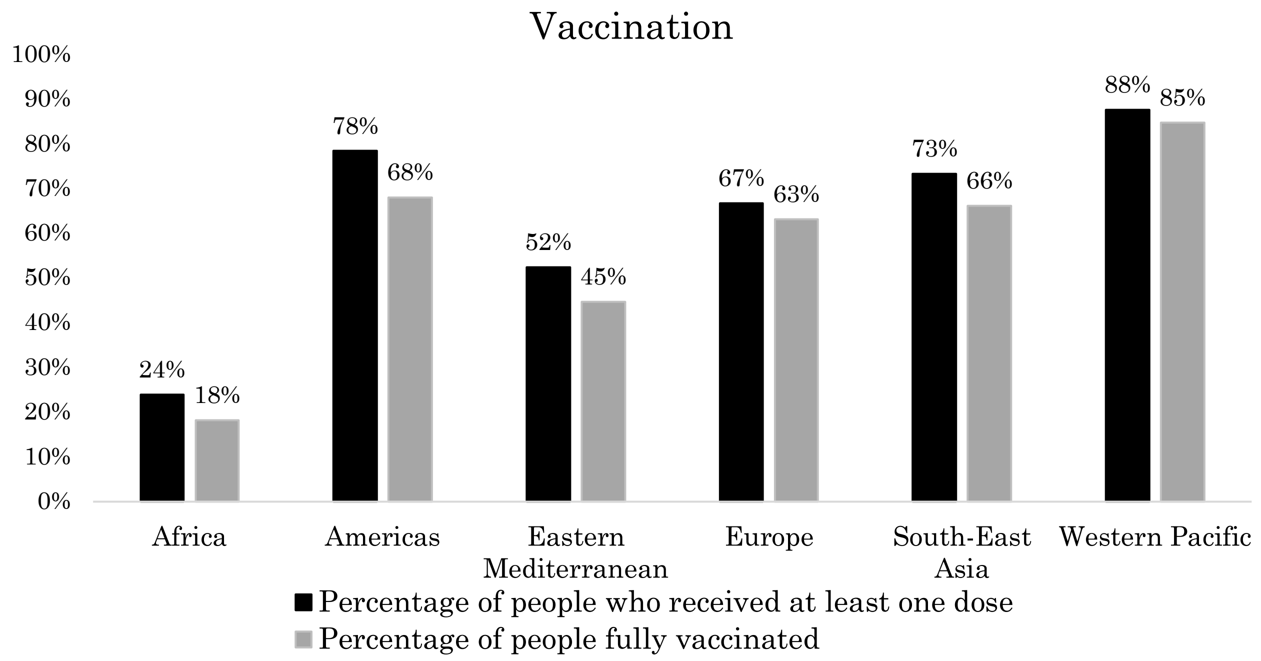
Figure 2



Source: World Health Organization - Retrieved on 13/08/2022

Differences in deaths might be partially explained, among other factors, by differences in vaccination campaigns as reported in Figure 3. Regions such as Africa and Eastern Mediterranean show the lowest level of vaccinated people.

Figure 3



Source: World health Organization - Retrieved on 13/08/2022

To face the pandemic, under the aegis of World Health Organization, countries settled the ACT Accelerator (Access to Covid-19 Tool), a global initiative that aimed to accelerate the access to COVID-19 diagnostics, therapeutics, and vaccines. COVAX is the pillar of ACT Accelerator tasked with vaccines deployment. It works through a mechanism of pooling resources of financing countries to negotiate prices and volumes with vaccine manufacturers to secure a global allocation of vaccines. Alongside the global mechanism, countries seek to finance and secure vaccines by themselves via bilateral deals and direct contact with manufacturers.

The scramble for vaccines results in a framework of an oligopolistic market. In simpler words, few countries have been able to develop a deploy a COVID-19 vaccine. Table 1 shows the breakdown of the total supply of vaccines by producing economy.

Table 1 – Total vaccine supply by producing economies

Producing economy	Number of doses (million)	Cumulative Share	Population (million)
China	6,077.30	40.1%	1,444.20
European Union	3,721.00	64.7%	447
India	2,465.60	80.9%	1,393.40
USA	1,609.80	91.6%	332.9
Russian Federation	286.2	93.4%	145.9
Korea, Republic of	263.5	95.2%	51.3
Brazil	172.3	96.3%	214
Mexico	138.2	97.2%	130.3
South Africa	125.2	98.1%	60
Thailand	95.1	98.7%	70
Other	198.9	100%	

Source: WTO-IMF COVID-19 Vaccine Tracker
Note: as of 31 May 2022

As we can observe China ranks first among producing economies. In fact, China has produced 40% of the total available doses. European Union stands second in this ranking producing 24.6% of total produced doses. Then there are India (16.3%) and United States of America (10.6%). Taken together the first four countries account approximately for 92% of the total supply. Nonetheless we can also observe that productive capacity differs widely.

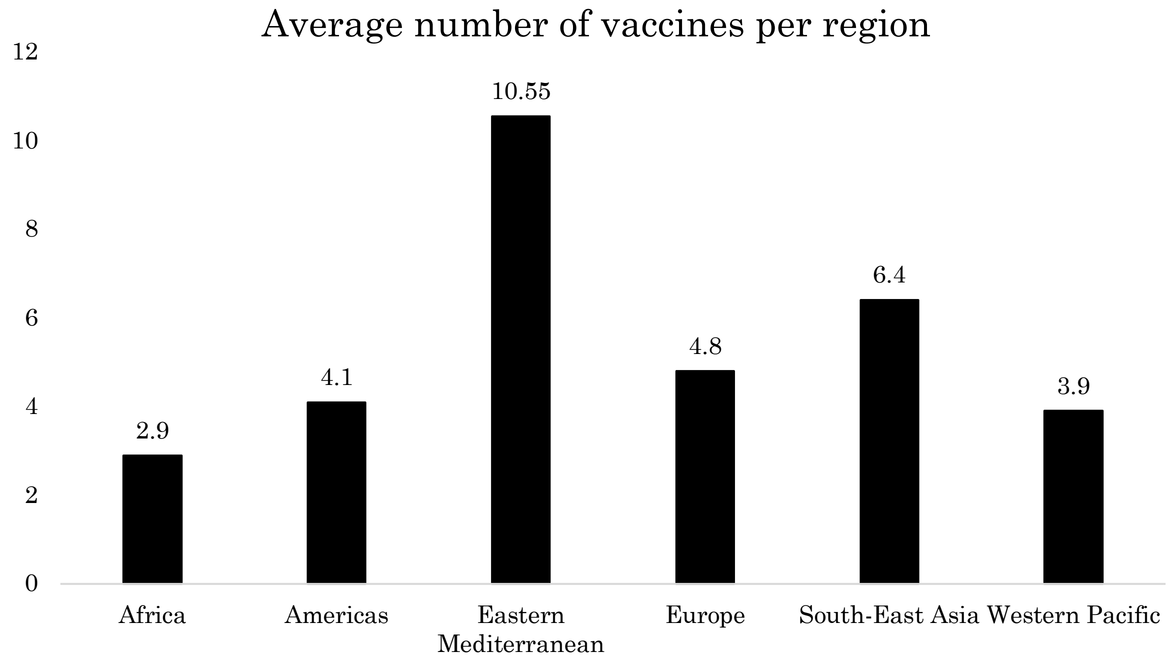
Figures in Table 1 includes both exported and domestically delivered doses. If we look at the production per capita, namely the number of doses produced for each person, European Union is the most productive region with 8.3 doses produced for each person, and the United States comes third with 4.8 doses per person. China and India are ranked respectively fourth with 4.2 doses per person and seventh with 1.8 doses per person. We observe the same framework if we consider total supply by vaccine type (Table 2).

Table 2 – Total vaccine supply by vaccine type

Vaccine	Country	Number of doses (million)	Share	Cumulative Share
AstraZeneca	UK	3,465.60	22.90%	22.90%
Sinovac	China	3,165.30	20.90%	43.80%
Pfizer	USA	3,097.70	20.40%	64.20%
Sinopharm	China	2,851.80	18.80%	83.00%
Moderna	USA	1,045.20	6.90%	89.90%
J&J	USA	878.2	5.80%	95.70%
Sputnik V	Russian Federation	310.1	2.00%	97.80%
Other		339.1	2.20%	100.00%
Source: WTO-IMF Covid-19 Vaccine Tracker Note: as of 31 May 2022				

The three most produced vaccines are AstraZeneca (UK), Sinovac (China) and Pfizer (USA). Taken together they account for more than half of the total supply of vaccines (64.2%).

Figure 4



Source: World health Organization - Retrieved on 13/08/2022

Needless to say, in producing regions, countries also have higher availability in terms of types of vaccines compared to non-producing regions as shown in Figure 4.

Table 3 – Exports

Producing economy	Number of doses (million)	Share of world exports	Cumulativ e share	Exports as share of total supply
European Union	2,440.40	39.60%	39.60%	65.60%
China	1,986.40	32.20%	71.80%	32.70%

United States of America	968	15.70%	87.50%	60.10%
Korea, Republic of	240.4	3.90%	91.40%	91.20%
India	140.2	2.30%	93.60%	5.70%
South Africa	110.4	1.80%	95.40%	88.20%
Russian Federation	102.4	1.70%	97.10%	35.80%
Japan	67	1.10%	98.20%	79.00%
Other	113.4	1.80%	100%	

Source: WTO-IMF Covid-19 Vaccine Tracker
Note: as of 31 May 2022

Table 3 shows the export of vaccines by producing economies. European Union is the largest exporter (39.6% of world exports) followed by China (32.2% of world exports) and United States (15.7%). These countries account for 87.5% of world exports.
Notably, the ranking of producing economies does not overlap with the ranking of exporting economies. In fact, China is standing first in the ranking of producing economies as it has produced 40.1% of total available doses, but it exports only 32.7% of its total supply. India accounts for 16.3% of total production, but it exports only 5.7% of the total amount of doses produced. On the contrary, European Union and United States that account respectively for 24.6% and 10.6% of total supply have exported respectively 65.6% and 60.1% of their total supply.

Producing economies differ also in the type of arrangements used to exchange doses, whether they be contracts or donations. In particular western producing regions, such as European Union and North America use both bilateral and multilateral mechanisms, while China and India only rely on bilateral deals.

Table 4 – Supply to arrangement type

	Africa	**Asia**	**Europe**	**North America**	**Oceania**	**South America**
Arrangement type	Share	Share	Share	Share	Share	Share
Contracted supply via COVAX	21.5%	3.0%	0.5%	2.8%	1.8%	6.0%
Direct donations	6.9%	2.6%	0.7%	2.6%	2.8%	3.6%
Domestic supply	1.5%	66.6%	83.8%	56.7%	17.8%	15.0%
Donations via COVAX	46.1%	3.4%	0.2%	1.4%	3.3%	1.6%
Supply via AVAT	11.4%	-	-	0.1%	-	-
Supply via bilateral deals	12.5%	24.4%	14.8%	36.5%	74.4%	73.8%
Total number of doses received (million)	970.8	9,811.3	1,794.2	1,294.6	82.7	1,199.5

Source: WTO-IMF Covid-19 Vaccine Tracker
Note: as of 31 May 2022

Unsurprisingly in producing regions most vaccines depend on domestic supply (Asia 66.6%, Europe 83.8% and North America 56.7%). The COVAX mechanism has mainly exploited for providing vaccines to African countries. In brief, Africa relies more than others on donations via COVAX. Slightly less than half of doses received come from donation via COVAX (46.1%), mainly from United States (80%) and European Union (15.6%).

Anyway, highlighting a more general pattern, it is clear-cut that most vaccines are delivered through bilateral deals. For instance, in South America bilateral deals account for 73.8% of received doses. Main partners are European Union and China, who accounted respectively for 52% and 32% of doses received by means of bilateral deals.

More interestingly China and India did not share any doses via COVAX mechanism. They only used direct donations to recipient countries. In fact, COVAX donations, the multilateral tool, have been mainly used by European Union and United States. With the only exception of exchanges within their own region, both European Union and the United States shared more doses via COVAX than direct donations.

In sum, facts and figures presented here point to the following aspects: (i) the vaccine market is an oligopoly; (ii) supply of vaccines have been secured mostly through bilateral deals; (iii) there are clear-cut asymmetries between producer countries. In particular, it seems that less democratic countries like Russia and China are less prone to exports.

2. The theoretical model

In what follows we present a simple theoretical model in order the analyse the current scenario characterized by emerging armed conflicts worldwide and global health emergency due to COVID-19 pandemic. The model is built upon a standard economic model of conflict and a microeconomic model of oligopoly.

As mentioned above, the point of departure is that the vaccine market is an oligopoly. In particular, we present a very simple model of a Cournot duopoly. Assume that there are two countries 1,2 where vaccines are to be produced. They compete à la Cournot in the world vaccine market. In addition, both countries cannot be considered as unitary actors. In one country (say Country #1) there is an armed conflict whereas the same does not hold in the other country (say Country #2). In other words, there is an asymmetry between the two countries which depends on the existence of conflict only. In fact, we are also assuming that in both countries a similar productive capacity is available. So we employ a two-stage model. In the first stage we model the armed conflict within Country #1 and eventually in the stage 2 we model the competition between Country #1 and Country #2 in the vaccine market.

The conflict interaction is modelled following the theoretical literature of conflict based upon Hirshleifer (1988) and eventually surveyed in Garfinkel and Skaperdas (2007)[2]. In general, a conflict implies that a fraction of resources is allocated to "unproductive activities" of fighting and therefore productive capacity shrinks. That is, in simpler words whenever an armed conflict takes place productive capacity is undermined and supply of civil goods decreases.

2.1 Stage 1 – Conflict in Country #1

2 See among others: Anderton, Anderton & Carter (1999); Baker (2003); Bös & Kolmar (2003); Caruso (2006/2007); Grossman (1991); Grossman & Kim (1995); Hausken (2004/2006); Maxwell & Reuveny (2005); Münster (2007).; Skaperdas (1992); Skaperdas & Syropoulos (1996).

In order to model the conflict in Country #1, we employ the basic model of conflict as presented by Hirshleifer (1988). As mentioned above, only one country is assumed to experience a conflict and therefore in this section we need to analyse only the implications of conflict in Country #1. Let us assume that in Country #1 there are two belligerent actors, A and B. They are both rational and are risk-neutral. Each actor has a positive resource endowment denoted by $m_i \epsilon (0, \infty)$, $i = A, B$. Each actor can allocate its resources between productive activities and unproductive activities according to the following relation:

$$m_i = x_i + z_i, \forall i$$

Conventionally we refer to productive activities (x) as 'butter' and unproductive activities as 'guns' (z). The Hirshleifer model in its simplest form assumes that $m_A = m_B$, namely parties are equally endowed. Aggregate production of (X) in Country #1, is an additive function of productive resources of each actor:

$$X = f(x_A, x_B) = x_A + x_B$$

The outcome of conflict is determined by means of an ordinary Contest Success Function[3] (henceforth CSF for brevity) in its ratio form:

$$p_i = \frac{z_i}{z_i + z_j} \quad i = A, B \quad j \neq i$$

The functional form adopted for CSF is a special case of the general ratio form of CSF. This functional form adopted implies that there is no preponderance of an actor over the other. This is of course a limiting assumption, even if in fact many armed conflicts fall in this category. The CSF is differentiable and follows the conditions below:

$$\begin{cases} p_1 + p_2 = 1 & p_1 = 1 - p_2 \\ \partial p_i / \partial z_i > 0 & \partial p_i / \partial z_j < 0 \\ \partial^2 p_i / \partial z_i^2 \leq 0 & \partial^2 p_i / \partial z_j^2 \leq 0 \end{cases}$$

Then, the payoff function of each actor is:

$$U_i = p_i X = \frac{z_i}{z_i + z_j}(x_A + x_B) \quad i = A, B\ ;\ j \neq i$$

Rationality assumption imposes that each group will maximize his own utility. We employ the Nash equilibrium as the solution concept. In equilibrium, the optimal level of resources devoted to conflict will be:

$$z^* = z_A = z_B = (m_A + m_B)/4$$

whereas the optimal level of resources devoted to productive activities will be:

$$x^* = x_A = x_B = (m_A + m_B)/4$$

That is, in equilibrium both parties devote the same amount of resources to butter and guns $x^* = z^*$. We can define a measure of conflict as the ratio between the aggregate level of butter in equilibrium X^* and the aggregate endowments, namely:

$$\xi = \frac{X^*}{m_a + m_b}, \xi \epsilon (0,1)$$

In fact, ξ captures the productive capacity which is available once the conflict has taken place. As ξ approaches zero the conflict is more destructive for Country #1.

2.2 Stage 2 – The Vaccine market

[3]Selective seminal contributions on CSF: Dixit (1987); Hirshleifer (1989); O'Keeffe, Viscusi & Zeckhauser (1984); Rosen (1986); Tullock (1980). See for a basic axiomatization: Clark & Riis (1998); Skaperdas (1996).

In the second stage we consider the oligopolistic market of vaccines. In particular, Country #1 and Country #2 produce a vaccine in an oligopolistic market à la Cournot. This means that each country rationally chooses its own level of vaccine production given the amount of vaccines produced by other country. In other words, they choose their quantities simultaneously. The inverse demand function is given by:

$$p = a - TV$$

Let $x \epsilon (0, a)$ be the potential level of production in Country #1 and $y \epsilon (0, b)$ the potential level of production in Country #2. The total vaccine production is denoted by TV and p denotes the price.

$$TV = x + y$$

For both countries payoff functions are:

$$\pi_1(x, y, c, \xi, a) = xa - (x + y)x - \left(\frac{c}{\xi}\right)x$$

$$\pi_2(y, x, c, a) = ya - (x + y)y - cy$$

As mentioned above, countries are almost equal since only cost functions differ. In particular, the cost function of Country #1 depends also on ξ . In particular, the cost function of the production of vaccines in Country #1 is:

$$c_1(x, \xi) = \left(\frac{c}{\xi}\right)x$$

Such formulation implies that as the conflict becomes more destructive (i.e. as ξ approaches zero) the cost for Country #1 rises. Instead, the Cost function of Country #2 depends only on standard marginal costs:

$$c_2(y) = c(y)$$

In equilibrium optimal quantities of vaccines are:

$$x^* = \frac{\xi(a + c) - 2c}{3\xi}$$

$$y^* = \frac{\xi(a - 2c) + c}{3\xi}$$

The equilibrium is asymmetric as $x^* < y^*$. That is, Country #1 produces a smaller quantity of vaccines because of the armed conflict. Overall, the market equilibrium is given by:

$$TV^* = \frac{\xi(2a - c) - c}{3\xi}$$

$$p^* = \frac{\xi(a + c) + c}{3\xi}$$

It is worth noting that $\partial TV^*/\partial\xi = c/3\xi^2 > 0$ and $\partial p^*/\partial\xi = -c/3\xi^2 < 0$. This implies that as long as ξ approaches to 1, namely as the conflict becomes less destructive, the total vaccine production (TV^*) increases while the price of vaccine (p^*) decreases.

3. Discussion and policy implications

Insights from the model say that if producer countries are involved in armed conflicts, the productive capacity of vaccines shrinks so lowering the world supply. In other words, in the absence of peace the supply of vaccines in the world turns to be smaller. In this perspective, the results of the model are not in line with a prevailing idea, namely that cooperation and diplomacy on health issues may bring also to more peaceful relations between states. Our model suggests that a relationship between peace and health diplomacy in fact does exist but its direction is the opposite. In fact, results rather suggest that conflict resolution and mitigation may favour a larger supply of vaccines in the market. A larger supply would also generate lower prices for vaccines. In fact, this would determine a global benefit. In simpler words, the prevailing idea states that diffusion of vaccines would contribute to world peace, whereas our model suggests something different, namely if there is no peace there would not be an adequate supply. In simpler words, it is not vaccines diplomacy that would determine peace but rather 'classical' diplomacy and conflict resolution that would determine an adequate supply of vaccines.

However, limitations of the model are clear. Our results are driven by: (i) the characteristics and the technology of conflict; (ii) the market structure. First, needless to say, our results are driven by the functional form of CSF adopted. The literature on conflict has shown that different functional forms of CSF may lead to different results. As noted above, the functional form of CSF implies that there is no preponderance of one actor over the other. If such assumption is relaxed and some asymmetry in technology of conflict is introduced so to change the decisiveness, therefore in equilibrium the level of guns would change. Eventually this would have an impact on the cost function in stage 2. For example, in Caruso (2007) it was shown that if the possibility of a stalemate is added to the CSF, the equilibrium level of butter is lower compared to that attainable in the Hirshleifer's basic model presented here. If we consider that most armed conflicts end with no clear-cut outcome and eventually they become persistent over time, this also contributes to maintain that continuing conflicts are incompatible with an efficient cooperation in the production and diffusion of vaccines.

Secondly, our results are also driven by the model of Cournot oligopoly. The choice of an oligopoly model was clear-cut. The actual data presented in the first section highlight that the COVID-19 vaccine market is an oligopoly. This is not neutral to the results and the implications. On the one hand, it is likely that different market structures would lead to different results. On the other hand, according to many, the oligopolistic structure of the pharmaceutical market ought to be overcome to secure more efficiently an adequate supply in the long-run (Florio and Gamba, 2021).

Third, we presented a static analysis. There is a tendency to believe that in the long-run peaceful settlements are more likely to take shape because cooperation would be sustained more easily in repeated interactions. This is the standard outcome descending from the folk theorem. However, Skaperdas and Syropoulos (1996) and Garfinkel and Skaperdas (2000) show that conflict models, under some conditions, can lead to opposite outcomes. That is, in the long-run conflicts can worsen so distorting the allocation of resources persistently. Therefore, we cannot exclude from the start that future interactions in conflict-prone country worsen so lowering the capacity to provide an adequate supply of vaccines given the indirect impact on productive capacity.

Conclusions

In this short paper we have presented a theoretical analysis intended to contribute to the debate on the appropriate mechanism to secure an adequate world supply of vaccines taking into consideration that some producing countries are involved in armed conflicts. In order to do that, we have presented a simple model which combines elements of Hirshleifer-style economic analysis of conflict and microeconomic modelling of a Cournot duopoly. In particular, we applied a simple Cournot duopoly model to two producer countries. The model is simply built on two-stages. In first stage we have modelled a conflict in one country where vaccines may be produced. In a second stage the two countries which produce vaccines are in a Cournot-style duopoly. The only difference between the two countries is that the cost function of one country is affected by the existence of the armed conflicts. In brief, insights from the model, show that world supply of vaccines is indirectly and negatively affected by the existence of armed conflicts in which producer countries are involved. Yet such negative impact on supply also increases the world price. In brief, participation of producer countries into armed conflicts turns to be detrimental for global supply of vaccines. Such result is driven by: (i) the characteristics and the technology of conflict; (ii) the market structure.

In terms of policy implications, our simple analysis suggests that it is not vaccines diplomacy that would determine peace but rather 'classical' diplomacy and conflict resolution that would determine an adequate supply of vaccines.

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