Global Access to Covid-19 Vaccine: A Game Theoretic Approach

Arindam Laha[1], **Sumit Kumar Maji**[2] **and Subir Kumar Sen**[3]

Abstract

The socio-economic challenge emanating from the Covid-19 pandemic can be effectively arrested by inoculating the people around the globe. Tiding over the pandemic warrants vaccine solidarity by ensuring equity in the vaccine distribution amongst the countries around the globe. However, the 'Vaccine Nationalism' attitude of many countries especially the countries from global north is threatening the global fight against the pandemic. In this backdrop, this paper considers the global access of COVID-19 vaccine in the perspective of the idealism vis-à-vis realism debate in the international relations. Specifically, this article employs game theoretic approach to determine the optimal strategy under different technology assumptions. Considering vaccine as a global public goods, private contributions of the vaccine producing countries are analysed in financing public goods. A game theory perspective of this paper can explain the real-life outcomes (vaccine nationalism, vaccine solidarity, tepid form of nationalism) under different technology assumptions. On policy implication ground, scaling up vaccine production and promoting vaccine solidarity will remain at the centre of the vaccine policy decision in near future.

Introduction

Vaccination is widely believed as a feasible solution to tide over the humanitarian crisis in the wake of Covid-19. Public health issues related to vaccination can be considered as a constituent of global public goods. In addition to non-rivalry and non-excludability characteristics of any public goods, it can be commonly used as a commodity generating benefits more than one group of countries. Non-rivalry and

[1] Professor, Department of Commerce, The University of Burdwan, Burdwan, West Bengal, India-713104. Email: alaha@com.buruniv.ac.in

[2] Assistant Professor, Department of Commerce, The University of Burdwan, Burdwan, West Bengal, India-713104. Email: 2009sumitbu@gmail.com

[3] Associate Professor, Department of Commerce, Tripura University, Agartala, Tripura, India-799022. Email: subirkumarsen@gmail.com

non-excludable benefits of global public goods outreached to the world at large, while regional public goods yield benefits to a more limited geographical area (Sandler, 1998; Sandmo, 2007). Stiglitz (1995; 1999) identified five global public goods: international economic stability, international security (political stability), the international environment, international humanitarian assistance, and knowledge. In addition, eight broad themes related to global public goods are environment, global public health, research, trade policy and transport policy, conflict peace and security, communications, humanitarian international Non-Governmental organisations and other (Development Initiatives, 2016).

On public health, the first institutional intervention can be traced back to 1347-1352, when organized efforts were made in controlling plague epidemic across international borders. Formation of global funds in mitigating challenges related to AIDS, Polio, Tuberculosis and Malaria is also known as a global initiative to control health related communicable diseases. A global partnership in research and development in vaccine can be an effective way to prevent communicable diseases. Participation of private sector in financing global public goods is noticeable in the formation of Global Alliance for Vaccines and Immunizations (GAVI) (Development Initiatives, 2016). Private provision of global public goods (like vaccines) in such contributory funds creates a positive externality beyond citizen of a country as benefits (i.e., a safe world having no more mutants of the virus) cuts across borders of the country. Public goods with positive externality are generally under supplied by the market due to the presence of the free rider problem. Therefore, it can be noted that contributions add to the collective benefit by accelerating the pace of ending pandemic, however, it requires strategic cooperation of the contributing countries.

In this context, this paper conceptualises the case of provisioning of vaccines as a global public good in a game theoretic framework. Idealistic and realistic attitudes are considered as the strategies chosen by the donor countries, while vaccine solidarity and vaccine nationalism are the outcome of the game. Payoffs of the game are derived by considering collective benefit and private cost implications of the country.

Conceptual Framework: Formulation of a Game

Consider a formulation of a game played by two symmetric donor countries aimed at accelerating the pace of vaccination to lower-middle-income countries. Contribution adds to the global public goods (McAdams et al, 2020) by means of unilateral gifts, sale, or COVAX initiative. However, contribution depends on their choice of idealist or realist strategy.

Learning from the experience of World War I, idealist view dominated in the literature on international relations in the 1920s and the early 1930s. However, in the wake of great depression in 1930s and the 1940s, the idealist doctrine was replaced by realist (Lekon, 2003). Drawing lesson from the past, realist perspective (in contrast to normative

idealist perspective) stresses the need to protect national interest (i.e., 'ultimately for its own survival') over international morals. By criticizing the universal moralism of idealist stand, realists, on the other hand, believes in moral relativism[4](Lekon, 2003). The policy of vaccine solidarity is rooted to the idealist perspective, which believes in internationalist morality over nationalist interest. Vaccine nationalism, on the other hand, believes in realist perspective, which upholds the spirit of national interest and therefore prioritized the statesman's duty to their own nations.

Depending on their choice of strategy, the conventional form representation of the payoff matrix is presented. Adoption of idealist strategy by both the countries results in vaccine solidarity through cooperation (C). On the other hand, non-cooperation (NC) of both the players through choice of realist strategy can be guided by their vaccine nationalist attitude. These are two extreme situations. A conflict in the choice of strategy arises in other two situations. Sub-optimal allocation in the provision of global public goods is the most likely situation performed by a few well-to-do nations (Olson, 1965).

Table 1: Formulation of the Game

		Country 2	
		Idealist	**Realist**
Country 1	**Idealist**	C, C (Vaccine solidarity)	C, NC (Vaccine conflict)
	Realist	NC, C (Vaccine conflict)	NC, NC (Vaccine nationalism)

Note: C stands for cooperation, NC stands for non-cooperation

Development of a Model

Notations

Si: Contributions of public goods by country i

Ci: Cost incurred by country i in the provisioning of public goods

B: Collective benefits derived from such provisioning

V: Payoff derived from the collective benefit received and cost incurred

Model Framework

In the framework of two countries, countries must decide on their level of voluntary contribution. In reality, public goods (specifically, distribution of vaccine) are provided by voluntary contribution, rather than by actual contribution (Palfrey & Rosenthal, 1984). Depending on their idealistic or realistic strategies, they determine their level of contributions: Si>0 (for country i=1,2). The private cost to provide the public goods are: C(Si)=kiSi, where $C' > 0, C'' > 0$. The collective benefit depends on the

[4] Moral relativism sets boundary through its own particular code of morals within its borders. In the realist 'un-normative' objective analysis, international arena is divorced from domestic arena(Lekon, 2003).

contribution of both the countries in a social composition function, i.e., B=b(Si), where B^'>0,B^''≤0. Social composition function takes into account different possible ways of amalgamating individuals' contributions into social availabilities of a public good[5]. Three simple cases of social composition function include summation, weak link and best shot(Sandler, 1998; Arce, 2001; Arriagada & Perrings, 2011).

- *Summation technology:*each nations contribution to the public goods adds to the overall provisioning of the goods, i.e. B=b()
- *Weakest link technology:*the overall benefit to all countries is limited to the benefit offered by the least effective provider (or least effort level), i.e. B=b(min[Si])
- *Best shot technology:*the overall benefit to all countries is determined by the most effective provider (or largest effort level), i.e. B=b(max[Si])

The payoff for each country (say country i=1) depends on the collective benefit and cost:

$V_1(S_1,S_2)=b(S_1,S_2)-k_1S_1$

Any strategy S_1 is the best response for country 1 to strategy S_2 of country 2 if it yields higher payoff in comparison to any other strategy , i.e.

$V_1(S_1,S_2)\geq V_1(,S_2)$ for all S_1.

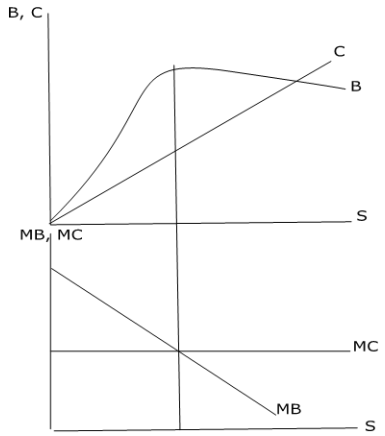
The pair (S_1,S_2) constitutes Nash equilibrium as these strategies are mutually best replies to each other.

The first order conditions can be derived from the payoff functions: $\delta b/\delta Si - ki = 0$ (for country i). Intuitively, it suggests that public goods should be provided as long as the overall benefit to consumers from that good are at least as great as the cost of providing it (Samuelson, 1954). This condition is popularly known as Samuelson condition for efficient provision of public goods. It can be considered as the generalized supply and demand concepts from private to public goods. In figure 1, MB presents demand for public goods (or willingness to pay or contribute), while MC is the supply of public goods under competitive markets. By the interactions of MB and MC schedules, the optimal level of contribution can be determined.

Assume that country 1 can produce the vaccine at lower marginal cost than country 2, i.e., $k_1<k_2$. In order to satisfy the first order condition, it requires $\delta b/\delta S_1>\delta b/\delta S_2$. Higher marginal benefit of country 1 provides an incentive for the country to contribute more vaccines: $S_1>S_2$.

[5] The role of technology of public supply aggregation in social composition function was first mentioned by Hirshleifer (1983).

Figure 1: Derivation of MB and MC curves from Benefit and Cost Schedules



Let us now incorporate these payoffs in the normal form presentation of the game[6].

Constellation 1 (Summation):Summation is the mostly used assumption relating to the provision of public goods. Contributions made by countries are assumed as perfectly substitutable and anonymous in the sense that contributions add the same at the margin regardless of the country. The Nash equilibrium corresponds to cooperation in the provision of public goods in each country (table 2a).

Constellation 2 (Weak Link): Let us now consider a case of inadequate provisioning of public goods (Sa<Sn), where Sa denotes actual number of contributions, and Sn denotes number of contributions necessary to produce the public good. The problem can be solved by the matching behaviour of the other country exercising lowest effort. This weak link technology is extensively applied in controlling epidemic (where least effort of the nation sets the safety level of all nations)or immunisation programme (where the nation with the smallest efforts at immunisation determines the chances of eradicating a disease) (Sandler, 1998).However, it may provide a disincentive to the countries who are adopting idealist strategy unless a favourable response from the other country. Otherwise, it can unduly incur a cost of financing without any gain in terms of collective benefit. However, the game is similar to Stag hunt game, which is extensively used in international relations (especially international treaty, environmental regulations) (Gibbon, 2013). There is a possibility of cooperation through active participation of the countries in provisioning of public goods (table 2b). For this reason, this stag hunt game is alternatively known as assurance game, whereby the interest of the countries does not conflict, but there is need of assurance that the other country shall abide by the game plan (Rose, 2010).

[6] In general, all technologies relating to public supply aggregations exhibits diminishing returns in some form (Daniel & Arce, 2001). However, in this paper we have considered only discrete numerical figures associated with benefits and costs (excluded fractional figures) to make the payoffs comparable. In some situations, therefore, diminishing returns property may be violated.

In this game, Nash equilibrium are located along the diagonal of the payoff matrix, and therefore suggest a matching behaviour of the countries. The focal equilibrium is where each country follows idealist strategies in making contributions, since these payoffs Pareto-dominate the no-contribution cell's pay-offs. Such focal equilibrium provides us a Nash equilibrium solution, which can be chosen by default. In deriving such equilibrium, we assume that the collective benefit of the contributor is sufficiently large in meeting the private cost of provisioning public goods (i.e., B>C).

Constellation 3 (Best shot):In practice, the world can be safe (i.e., no more mutants of the virus) if sufficient number of contributions is made. Assume that there is an adequate private provisioning of public goods, i.e.,Sa≥Sn. From the payoff matrix, the solution of this game invites a conflict like situation, which provides an incentive to one country to free-rides (table 2c). Cost implications in this game generate fear motivation for free-rides of one country in the hope that other country shall follow idealist strategy and thereby meets the minimum requirement of public goods. In practice, some countries control over the final vaccine producers and vaccine ingredient producers (Evenett et al. 2021). Members of such 'vaccine production club' can adopt idealist strategy in immunizing the rest of the world. Adequate provisioning of vaccines by such countries results in an opportunity of other countries to free-rides. This game is similar to the chicken game, or anti-coordination game, where it is mutually beneficial for the countries to play different strategies. If the game is played repeatedly, then it may lead to cooperative response as nations can retaliate by adopting tit-for-tat strategy to punish non-cooperators.

Table 2: Role of Technology Choice in Determination of Nash Equilibrium in a 2x2 Game

		Country j	
		Idealist	**Realist**
Country i	**Idealist**	0,0	b,b-c
	Realist	b-c,b	**2b-c, 2b-c**

Table 2(a): Summation Technology

		Country j	
		Idealist	**Realist**
Country i	**Idealist**	0,0	0,-c
	Realist	-c,0	b-c, b-c

Table 2(b): Weakest Link Technology

		Country j	
		Idealist	**Realist**
Country i	**Idealist**	0,0	b,b-c
	Realist	b-c,b	b-c, b-c

Table 2(c): Best Shot Technology

Extension of the Model

Through the lens of realist-cum-idealist strategy in the perspective of game theory approach, let us now examine the case of tepid form of nationalism as a solution to the problem of public goods provisioning. It calls for a proper balancing in such provisioning so as to meet the domestic as well as international demands. Therefore, solution lies in a synthesis of optimistic view of liberalism and the pessimistic view of realism. In this direction, tepid form of vaccine nationalism which propagates prioritizing domestic needs without compromising the needs of other countries may be argued for. This alternative policy can be realized by following limited national partiality in allocating vaccines as a component of justice rather than an obstacle in distributing vaccines to other nations(Ferguson & Caplan, 2020).A similar policy of 'convergence of idealism and realism in strategic decision making' is proposed by other researchers (Pant, 2021; Kliem, 2021; Prabhu, 2021).

Inclusion of synthesis strategy in the constellation form of game theory presentation under different technology assumptions is shown in the following table 3. As observed earlier, the presence of these alternative technologies of public goods aggregation has important implications in providing public goods. Inadequate provision of public goods calls for matching behaviour from other countries. An aggregative and weakest link technology opens up the possibility of matching behaviour as an equilibrium strategy. Specifically, a practice of matching behaviour along the diagonal of the matrix is an essential feature of weakest link technology (Sandler, 1998). The collective action in the form of adopting synthesis or idealist strategy is more pronounced in a weakest link scenario than summation-based technology. In contrary, either country 1 or 2 make largest effort in the provisioning of public goods adequately under best shot technology.

Table 3: Role of Technology Choice in Determination of Nash Equilibrium in a 3x3 Game

		Country j		
		Realist	**Synthesis**	**Idealist**
Country i	**Realist**	0,0	b,b-c	2b, 2(b-c)
	Synthesis	b-c,b	2b-c, 2b-c	3b-c, 3b-2c
	Idealist	2(b-c), 2b	3b-2c, 3b-c	4b-2c, 4b-2c

Table 3(a): Summation Technology

		Country j		
		Realist	**Synthesis**	**Idealist**
Country i	**Realist**	0,0	0,-c	0, -2c
	Synthesis	-c,0	b-c, b-c	b-c, b-2c
	Idealist	-2c, 0	b-2c, b-c	2(b-c), 2(b-c)

Table 3(b): Weakest Link Technology

		Country j		
		Realist	**Synthesis**	**Idealist**
Country i	**Realist**	0,0	b,b-c	2b, 2(b-c)
	Synthesis	b-c,b	b-c, b-c	2b-c, 2(b-c)
	Idealist	2(b-c),2b	2(b-c), 2b-c	2(b-c),2(b-c)

Table 3(c): Best Shot Technology

Implications to Practice and Policy

In practice, it is also imperative for a country to safeguard its own population by trying to save the world. However, this can only be possible by ramping up the production of the vaccines by making heavy investment in no time, speeding up the domestic inoculation process and allowing a greater number of pharmaceutical companies to go for clinical trials so that other vaccines can be approved and manufactured for domestic use.

In practice, global solidarity, cooperation and collective actions are the only alternatives to address any health crisis as severe as Covid-19 pandemic. In fact,global solidarity is extremely important in making the vaccines available to all parts of the globe. In this vaccine race, 'we can either win together or loose together' . In practice, there is a stark north-south divide in dealing with the Covid-19 crisis. While developed countries of the global north has adequate financial resources to combat the crisis, the developing countries in the global south are struggling on fiscal, monetary and external payments fronts(UNCTID, 2020). Collective actions and global solidarity, therefore, is the need of the hour. South-South Cooperation(SSC) & South-South Triangular Cooperation (SSTC) can be considered as the effective measures to ensure that the low-income developing countries can get equal access to the Covid-19 vaccines.

Upholding the spirit of global solidarity and in a drive to expedite the development, production, and equitable distribution of the vaccines to all the countries and to fight against the vaccine nationalism, COVAX programme was launched by the Global Alliance for Vaccines and Immunization, the Coalition for Epidemic Preparedness Innovations, WHO and UNICEF. The COVAX programme aims at inoculating around 20% of the population of the low-income countries (with per capita GNI of less than $4000) along with those which receives World Bank international development assistance. COVAX programme will ensure the availability of the vaccines to people of participating economies (including 92 low- and middle-income economies) simultaneously irrespective of their economic status. In doing so, Global Alliance for Vaccines and Immunization (GAVI) has ensured volume guarantees for some vaccine manufacturers before the approval and the market-wide guarantees, so as to encourage manufacturers in making investments in production capacity. Under the COVAX initiative the high-income economies were required to make payment for the vaccine doses that they wish to obtain in advance. Such advance payment will enable

the COVAX initiative to speed up the development and manufacturing the vaccines. However, the vaccine requirement for low-income countries will be funded by the COVAX Facility through Official Development Assistance, donations made by the private sector and philanthropy. In fact, the core principles of COVAX initiative are similar to the basic principles of the global solidarity which is free from any distortions, exploitations and restrictions. Majority of the developed economies such as United States, Germany, France, Italy, United Kingdom, Japan etc. have made significant donations of vaccines under the COVAX initiative in the spirit of global solidarity (see table A1 in the appendix). India has also played an important role in extending its support to the global cause by donating 52.027 millions of Covid-19 vaccines doses to the COVAX programme under 'vaccine maitri' initiative of the Government of India. Additionally, 15.127 million doses of the vaccines were donated voluntarily to different countries especially the neighboring countries such as Bangladesh, Myanmar, Nepal and Bhutan. The export of vaccines to 97 countries under (most of which are low-income developing countries from Asia, Africa, Caribbean and Latin America) upholds the spirit of SSC. The distribution of vaccines under COVAX initiative to different countries of the globe is also the example of SSTC. However, it is also to be kept in mind that the COVAX initiative is largely underfunded and has failed to prevent bilateral agreements between the Governments and the pharmaceutical companies (Ghosh, 2021). It has resulted in under supply of the vaccines to the COVAX initiative in the first instance and allowing the few advanced countries of the globe to hoard the vaccines which is only going to worsen the supply and pricing of the vaccines.

Appendix

Table A1: Top 10 Countries donated Covid-19 Vaccines under COVAX Initiative

Countries	Vaccine Donated under COVAX (in millions)
United States	237.6
Germany	92.1
France	61.3
India	52.027
Italy	42
Spain	39.6
United Kingdom	29.7
Japan	18.1
Canada	14.2
Netherlands	14.2

Source: Ourworldindata website

References

Arriagada, R., &Perrings, C. (2013). Paying for international environmental public goods. AMBIO, 40, 798-806.

Arce M, D. G. (2001). Leadership and the aggregation of international collective action. Oxford Economic Papers, 53(1), 114-137.

Development Initiatives (2016). Measuring aid to global public goods, Discussion paper, Retrieved from https://devinit.org/resources/measuring-aid-to-global-public-goods-gpgs/

Evenett, S. J., Hoekman, B., Rocha, N., &Ruta, M. (2021). The covid-19 vaccine production club. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/35244/The-Covid-19-Vaccine-Production-Club-Will-Value-Chains-Temper-Nationalism.pdf?sequence=1

Ferguson, K. & Caplan, A. (2020). Love thy neighbour? Allocating vaccines in a world of competing obligations, Journal of Medical Ethics, 1-4.

Ghosh, J. (2021). Vaccine apartheid: Global inequities in Covid-19 vaccine production and distribution. Retrieved from https://www.openglobalrights.org/vaccine-apartheid-global-inequities-in-covid-vaccineproduction-and-distribution/

Gibbon, D. (2013). Uses of Game Theory inInternational Relations. Retrieved from https://tuecontheoryofnetworks.wordpress.com/2013/02/11/uses-of-game-theory-in-international-relations/

Hirshleifer, J. (1983). From weakest-link to best-shot: The voluntary provision of public goods. Public Choice, 41(3), 371-386.

Lekon A D. (2003). The interplay of realism and idealism in the thought of Lionel Curtis: A critique of the conception of the 'first debate' in international relations [dissertation]. London School of Economics and Political Science; U.K.

McAdams, D., McDade, K. K., Ogbuoji, O., Johnson, M., Dixit, S., &Yamey, G. (2020). Incentivising wealthy nations to participate in the COVID-19 Vaccine Global Access Facility (COVAX): a game theory perspective. BMJ global health, 5(11).

McCarty, N., &Meirowitz, A. (2007). Political game theory: An introduction. Cambridge University Press.

Olson, M. (1965). The logic of collective action. Harvard University Press.

Palfrey, T. R., & Rosenthal, H. (1984). Participation and the provision of discrete public goods: A strategic analysis. Journal of Public Economics, 24(2), 171-193.

Prabhu, S. (2021).VaccineMaitri: Friendship gone wrong?Retrieved fromhttps://www.orfonline.org/expert-speak/vaccine-maitri-friendship-gone-wrong/

Rose, C. (2010). Game stories. Yale Journal of Law& Humanities., 22, 369-391.

Samuelson, P. A. (1954). The pure theory of public expenditure. The Review of Economics and Statistics, 387-389.

Sandler, T. (1998). Global and regional public goods: a prognosis for collective action. Fiscal Studies, 19(3), 221-247.

Sandmo, A. (2007). Global public economics: Public goods and externalities. Public Economics, 18-19.

Stiglitz, J. (1995). The theory of international public goods and the architecture of international

organizations, United Nations Background Paper No. 7, New York, United Nations,

Department for Economic and Social Information and Policy Analysis.

Stiglitz, J. (1999). Knowledge as a global public good, in Kaul et al. (Ed.): Global Public Goods:International Cooperation in the 21st Century, Oxford University Press, 308–325.

UNCTAD (2020). Report on South-South Cooperation at the time of COVID-19.Geneva: United Nations Conference on Trade and Development; Retrieved from: https://unctad.org/system/files/official-document/gdsinf2020d4_en.pdf