The landscape for vaccine candidates of COVID-19: is there any relationship between innovation and the business environment of countries?

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The insurgency of the new coronavirus (SARS-COV-2) has attracted the attention of the public, authorities and academics. To date, no chemical treatment has proven efficient in clinical tests to combat the virus. The hope for the reopening of socioeconomic activities is found in the discovery of vaccines that can immunize people on a large scale. According to the World Health Organization, there are 29 vaccine candidates in the clinical evaluation phase and 138 candidates in the pre-clinical evaluation phase. In the race to discover a vaccine, there are initiatives from several laboratories and research centers. However, some countries stand out with a concentration of initiatives. This leads us to question whether this ability to promote research, development and seek innovation in the health field is not only associated with the size of economies, but also with the quality of the business environment. Thus, the aim of the present study is to explore the relationship between innovation and economic freedom, using econometric methodology (e.g. Panel Data Analysis) combined with non-parametric methodology (e.g., Data Envelopment Analysis). Our results allow us to infer how additional economic freedom can increase innovation for different levels of economic freedom within the countries. By doing so, we can explore why there is concentrated vaccine initiatives in few countries and a better understanding of the landscape for vaccine candidates of COVID-19.

Keywords: COVID-19; vaccines; innovation; economic freedom

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El panorama de los candidatos a vacunas de COVID-19: ¿existe alguna relación entre la innovación y el entorno empresarial de los países?

La insurgencia del nuevo coronavirus (SARS-COV-2) ha atraído la atención del público, las autoridades y los académicos. Hasta la fecha, ningún tratamiento químico ha demostrado ser eficiente en las pruebas clínicas para combatir el virus. La esperanza de la reanudación de las actividades socioeconómicas se encuentra en el descubrimiento de vacunas que pueden inmunizar a las personas a gran escala. Según la Organización Mundial de la Salud, hay 29 candidatos a vacunas en la fase de evaluación clínica y 138 candidatos en la fase de evaluación preclínica. En la carrera por descubrir una vacuna hay iniciativas de varios laboratorios y centros de investigación. Sin embargo, algunos países se destacan - hay una concentración de iniciativas. Esto nos lleva a cuestionarnos si esta capacidad para promover la investigación, el desarrollo y buscar la innovación en el campo de la salud no sólo está asociada con el tamaño de las economías, sino también con la calidad del entorno empresarial. Por lo tanto, el objetivo del presente estudio es explorar la relación entre innovación y libertad económica, utilizando la metodología econométrica (Análisis de Datos de Panel) combinada con la metodología no paramétrica (Análisis Envoltorio de Datos). Nuestros resultados nos permiten inferir cómo la libertad económica adicional puede aumentar la innovación para los diferentes niveles de libertad económica dentro de los países. Al hacerlo, podemos explorar por qué hay iniciativas de vacunas concentradas en pocos países y una mejor comprensión del panorama de los candidatos a vacunas de COVID-19.

Palabras clave: COVID-19; vacunas; innovación; libertad económica

O cenário dos candidatos a vacina do COVID-19: existe alguma relação entre inovação e ambiente de negócios dos países?

A insurgência do novo coronavírus (SARS-COV-2) tem atraído a atenção do público, autoridades e acadêmicos. Até o momento, nenhum tratamento químico se mostrou eficiente em testes clínicos para combater o vírus. A esperança de retomada das atividades socioeconômicas está na descoberta de vacinas que possam imunizar pessoas em larga escala. Segundo a Organização Mundial da Saúde, há 29 candidatos à vacina na fase de avaliação clínica e 138 candidatos na fase de avaliação pré-clínica. Na corrida para descobrir uma vacina há iniciativas de vários laboratórios e centros de pesquisa. No entanto, alguns países se destacam - há uma concentração de iniciativas. Isso nos leva a questionar se essa capacidade de promover pesquisa, desenvolvimento e buscar inovação no campo da saúde não está associada apenas ao tamanho das economias, mas também à qualidade do ambiente de negócios. Assim, o objetivo do presente estudo é explorar a relação entre inovação e liberdade econômica, utilizando metodologia econométrica (Análise de Dados em Painel) combinada com metodologia não paramétrica (Análise Envoltória de Dados). Nossos resultados nos permitem inferir como a liberdade econômica adicional pode aumentar a inovação para diferentes níveis de liberdade econômica dentro dos países. Ao fazê-lo, podemos explorar por que há iniciativas de vacinação concentradas em poucos países e uma melhor compreensão do cenário para os candidatos a vacinas do COVID-19.

Palavras-chave: COVID-19; vacinas; inovação; liberdade econômica

Introduction

The emergence of a global health crisis has made the population pay more attention to research and development. Many hopes are placed on efforts to find a vaccine that can immunize the world population on a large scale. There are many uncertainties and the urges are great to resume normal coexistence, social activities and crowds of people.

In the race to discover a vaccine against SARS-COV-2, there are initiatives from several laboratories and research centers. However, when we consult the information provided by the World Health Organization, some countries stand out - there is a concentration of initiatives. This leads us to question whether this ability to promote research, development and seek innovation in the health field is not only associated with the size of economies, but also with the quality of the business environment. It is not, therefore, just a discussion about rich countries that have the capacity to obtain a vaccine and, eventually, their companies profit from it. The agenda is deeper and converges for reflection on the accumulation of physical capital, human capital and technological progress.

One of the most relevant questions for humanity is to know why there are rich as well as poor countries, which is one of the great subjects of economic development. This not only depends on the accumulation of physical and human capital, but also on technological change. If we associate the technological advance with innovation, then we may be able to establish some relationships between them. Innovation generates positive effects in a company's competitiveness, and this in turn increases a country' s comparative advantages, contributing to an increase in exports, and an improvement in the economy and social welfare.

The aim of the present study is to explore the relationship between innovation and economic freedom, using econometric methodology combined with non- parametric methodology (i.e., DEA). Our results allow us to infer how additional economic freedom can increase innovation for different stages of economic freedom within the countries.

The paper is organized as follows. Section 1 describes the vaccine race of COVID-19. Section 2 brings the theoretical foundation for the relationship between economic freedom and the ability to innovate. Section 3 presents the literature of applied papers using economic freedom indexes to study the causality relationship with innovation (as measured by GII) and runs the panel data tests to explore the causal relationship between economic freedom and innovation. Section 4 applies non-parametric analysis to test for different forms of efficient frontiers, and then compares the existence of catch-up and/or frontier-shift effects between 2013 and 2016. The final remarks section draws the implications from the results and brings some insights of the landscape for vaccine candidates of COVID-19.

1 The race for the Covid-19 vaccine

The insurgency of the new coronavirus (SARS-COV-2) has attracted the attention of the public, authorities and academics. What is scientifically known, so far, is that the lethality of the virus is not as high as it seemed in the first cases, but it is highly contagious and can be transmitted even if the patient is asymptomatic. Once infected, the person can progress to cases of hospitalization that require more than 20 days of intensive therapy with mechanical ventilation. Because of this, the vast majority of countries imposed restrictive measures on the free movement of people in order to avoid agglomerations and high levels of contamination that overload health systems, as advocated by Sjödin et al. (2020) for the case in Italy and Qiu, Chen and Shi (2020) analyzed for the case in China.

To date, no chemical treatment has proven efficient in clinical tests to combat the virus. The hope for the reopening of socioeconomic activities is found in the discovery of vaccines that can immunize people on a large scale, because otherwise, restrictions on the movement of people and activities that promote agglomerations will remain.

In a few moments in human history, there has readily been such a joint effort to find a vaccine. According to the World Health Organization, in its report "Draft landscape of COVID-19 candidate vaccines", dated August 13, 2020, there are 29 vaccine candidates in the clinical evaluation phase and 138 candidates in the pre-clinical evaluation phase.

In the most advanced development group, the initiatives focus on laboratories, companies and research centers in the following countries: Australia, Belgium, Canada, China, South Korea, France, Germany, India, Italy, Japan, Russia, United Kingdom, United States and the territory of Taiwan. Among these countries, China (the epicenter of the virus) and the United States are the ones that host the largest number of initiatives.

In the set of 138 candidates, in addition to the countries mentioned above (which concentrate initiatives), Brazil (with the University of São Paulo, Fiocruz and Instituto Butantã), Egypt, Spain, Kazakhstan and Israel, among others, were added.

It can be seen by the WHO (2020) that only a few countries concentrate in research. In those that are in more advanced stages, more developed countries stand out (with a few exceptions). A primary association would be with the GDP of these countries. However, there is a double causality between levels of research, development and innovation and the level of GDP. It would be worth asking whether the institutional environment could influence this greater capacity for research and innovation. Table 1 shows a set of indicators for countries whose COVID-19 vaccine candidates are at more advanced stages of development.

Table 1 | Countries with vaccine candidates undergoing clinical evaluation

Country	Number of vaccine candidate initiatives undergoing clinical evaluation	Position in the GDP ranking[1]	Income per capita[2]	Position in ranking the innovation[3]	Position in the ranking of economic freedom[4]
Australia	1	14	$46,230	18	5
Belgium	1	23	$49,090	21	44
Canada	1	10	$45,910	14	6
China	9	2	$13,520	24	144
France	1	6	$43,830	17	75
Germany	2	4	$51,810	9	17
India	2	7	$5,720	64	123
Italy	1	8	$40,040	28	86
Japan	1	3	$41,320	15	22
South Korea	1	11	$39,710	11	27
Russia	1	12	$23,450	42	153

United Kingdom	3	5	$43,100	3	10
United States	10	1	$58,970	4	11
Taiwan	1	-	-	-	14

Source: WHO, World Bank, Cornell University, INSEAD School of Business and the World Intellectual Property Organization, Heritage Foundation,

[1] GDP (current US$) for 2016

[2] GNI per capita, PPP (current international $)

[3] 2016 Global Innovation Index

[4] 2016 Index of Economic of Economic Freedom

Simple visual inspection of Table 1 is not enough. Richer and freer countries are roughly leading vaccine race, but exceptions call our attention: China, India and Russia. More than any other recent situation, the capacity to research and innovate is being required and, when this happens, it shows us the disparity between countries in the search for a vaccine that allows the full reopening of social and economic activities.

2 Innovation and economic freedom

The early economic models emphasized the impact of technological change on the economic development of a country - see, for example, Schumpeter (1934), Solow (1957), Romer (1990), etc. The major problem has been to identify what, in the last resort, is its cause. If we associate the technological advance to innovation, we may try to establish some relationships. Because innovation generates positive outcomes in a company's competitiveness, it increases a country's comparative advantages, and ultimately improves its exports, GDP growth and social welfare.

The innovation process positively affects the company's profits, generating incentives to invest in its products. For which it will be necessary to remove barriers so that the results of the innovation be freely commercialized.

Bhagwati (1999) pointed out that the wealthiest countries are those where decisions on production, investment and innovation are less ruled by the state, having instead a greater trade and financial openness.

To establish some type of causal relationship between innovation and economic freedom, we use, in the first place, the GII, as elaborated by Cornell University, INSEAD and the World Intellectual Property Organization (2016).

The GII is a multidimensional index that encompasses two dimensions of the innovation generation: the necessary inputs for its "production" and their results. The first dimension considers the following variables: political environment, regulation environment, and business environment; education; research and development; technology; information and communication; general infrastructure; ecological sustainability; credit; investment; trade, competition, and market scale; knowledge workers; and, knowledge absorption and innovation chains. For the second dimension, the variables added are: knowledge creation; knowledge impact; knowledge diffusion; intangible assets, creative goods, and services; and online creativity.

The initial year for the GII, as made available by Cornell University, INSEAD and the World Intellectual Property Organization dates from 2013. This reduces the temporal dimension of the analyzed data.

In the case of economic freedom, we use the IEF as produced by the Heritage Foundation and The Wall Street Journal (2016), that encompass the following dimensions: property rights, freedom from corruption, fiscal freedom, government spending, business freedom, labor freedom, monetary freedom, trade freedom, investment freedom, and financial freedom.

To check for the existence of a relationship between GII and IEF, we used the data from these indexes, as calculated for 2013–2016, in a sample comprising 119 countries, matching the two respective rankings.

3 Panel data analysis: searching for casual relationship

Following Erkan (2015), we used, in the first place, the GII, elaborated by Cornell University, INSEAD and the World Intellectual Property Organization. In the case of economic freedom, we used the IEF, produced by the Heritage Foundation and the Wall

Street Journal. Following Bayar (2015), and Salman, Zampatti and Shukur (2013), we control for macroeconomic variables, obtained from World Bank's World Development Indicators, such as High-Technology Exports (HTE) in US$; Interest Rate Spread (IRS) and Gross Savings Rate (GSR) % of GDP.

The resulting theoretical model postulates positive impacts on Innovation (GII) for Economic Freedom (IEF), HTE and GSR and negative impact for IRS, as follows:

$$GII = f\,(IEF,\ HTE,\ IRS,\ GSR)$$

$$(+)\quad (+)\quad (-)\quad (+)$$

In order to verify the existence of a relationship between innovation and economic freedom. In the case of parametric analysis, we follow the approach of Ekram (2015) but, beforehand, adopting panel data econometric methodology. This allows us to combine the analysis of the temporal behavior of the series with the heterogeneity of the different countries composing the sample[1].

The sample includes 119 countries, starting in 2013, which is the first year of the GII calculation, and ending in 2015[2], which is the last year of data available from World Development Indicators.

Hausman Test pointed out the adoption of random effects model. The equation that we adopted is (all variables in natural logarithm):

$$LGII_{it} = \alpha + \beta_0 LIEF_{it} + \beta_1 LHTE_{it} + \beta_2 LIRS_{it} + \beta_3 LGSR_{it} + D2014 + D2015 + v_{it}$$

$$v_{it} = c_i + \varepsilon_{it}$$

where c_i is the unobservable individual-specific effect, D2014 is a dummy variable for year 2014, D2015 is a dummy variable for year 2015[3] and εit is the white noise.

[1] To check out if the relationships obtained from the panel analysis are statistically sound, we should run the appropriate unit root test to determine the existence of stochastic and deterministic trends in the sample adopted. If we could not reject the unit root hypothesis, we would proceed to cointegration tests for panel data to determine if there were significant long-term relationships, from the statistical viewpoint, between the innovation degree and the level of economic freedom.

[2] In Section 4, the sample period for the non-parametric approach is 2013-2016.

[3] We also tried a dummy for 2013, but the results remained practically the same.

3.1 Empirical findings

The results of the estimation show that the degree of economic freedom has a positive and statistically significant (5%) impact on the degree of innovation.

Table 2 | Random Effects Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
c	-1.119268	0.486046	-2.302800	0.0224
LIEF	0.818169	0.109361	7.481341	0.0000
LHTE	0.447826	0.090445	4.951369	0.0000
LIRS	-0.038294	0.019382	-1.975717	0.0497
LGSR	0.018516	0.033720	0.549104	0.5836
D2014	-0.007497	0.026372	-0.284267	0.7765
D2015	0.046798	0.028448	1.645050	0.1017

Source: authors

The degree of economic freedom also has a greater impact on innovation: a 1% increase in IEF will increase GII by 0.8%. The amount of high-tech exports has a positive and statistically significant (5%) effect on the degree of innovation: a 1% increase of high-tech exports will increase GII by 0.4%. The impact of IRS on the degree of innovation is negative, as expected by the theory: 1% increase in interest rate spread will decrease GII by 0.04%. The impact of the GSR is positive but statistically non-significant, even at 10%.

We cannot test for unit root nor for cointegration due to the reduced timespan of the sample and the great number of countries considered[4]. But, even so, we can infer that freer business environment help to improve innovation *coeteris paribus*. This helps us understand why few and specific countries lead the race for a vaccine.

On the other hand, the case of China and USA leading with the number of initiatives for a vaccine cannot be fully explained - despite China being 'ground zero' for SARS-COV-2. Thus, we need more tools to better understand this situation.

4 Data envelopment analysis and the efficient frontier

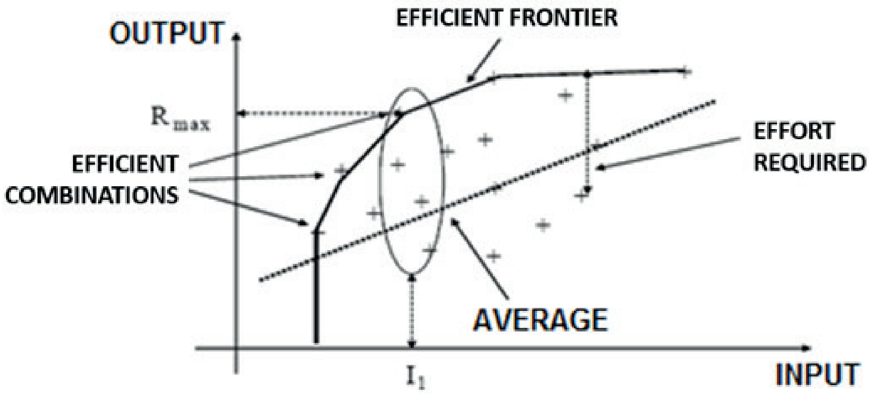
The non-parametric analysis works with the application of DEA[5] efficiency frontier oriented toward the product for the period 2013–2016. The formulation of the DEA model that is used in this paper follows Banker, Charnes and Cooper (1984), output-oriented - focus on (in) efficiency of the output generated given an input level. Papers using the Data Envelopment Analysis (DEA) represent technical advances if compared to indexes without a more explicit criterion. It can enlighten cases like China (discussed previously), Russia and India hosting companies or labs that lead the vaccine race (as shown in Table 1).

Methodologies of efficiency frontier work on the notion of production function, that is, the combinations of inputs and products, like a 'cake recipe': an amount of ingredients which are combined to generate the final product. Thus, it is possible to compare combinations between resources (inputs) and achieved results (products) as far as research, development and innovation ('RD&I') are concerned.

The efficiency frontier associates optimal combinations of product inputs, that is, cases of best practices in resource management. The cases inside the frontier are inefficient insofar as the 'invested resources' could possibly achieve a better product, as shown in Figure 1. One important issue: the efficiency discussed in DEA is relative and not in absolute terms because it relies on the dataset.

[5] We adopted the non-parametric approach of Data Envelopment Analysis (DEA) because of its 'cost-benefit' usage in this application. We are not so interested in explaining the (in)efficiency rather describe it. Thus, a Stochastic Frontier Analysis (SFA) would not improve the results for this specific application.

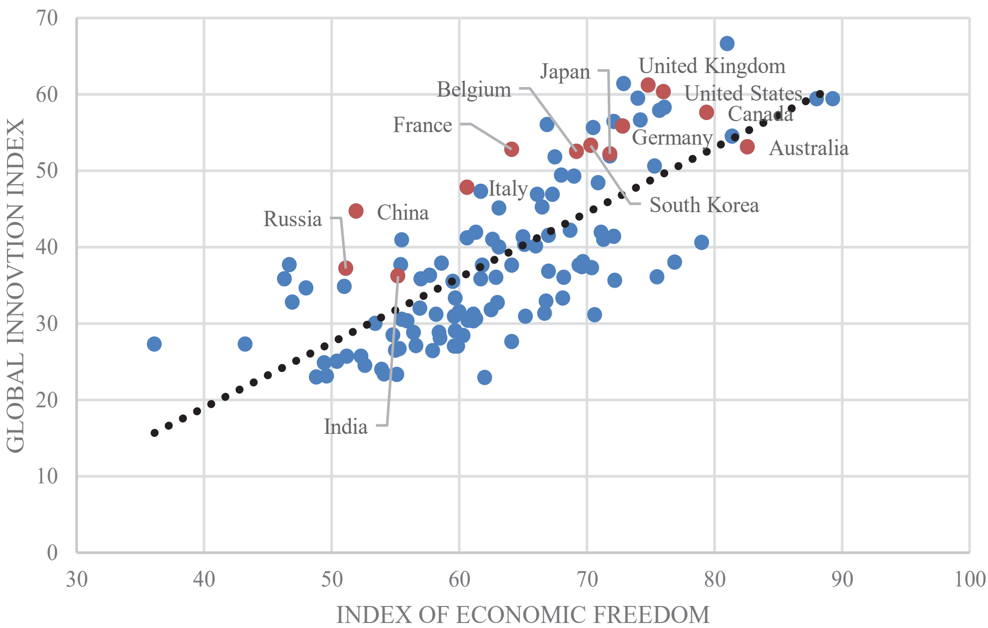
Figure 1 | Efficient Frontier



Source: Faria (2006, p.3)

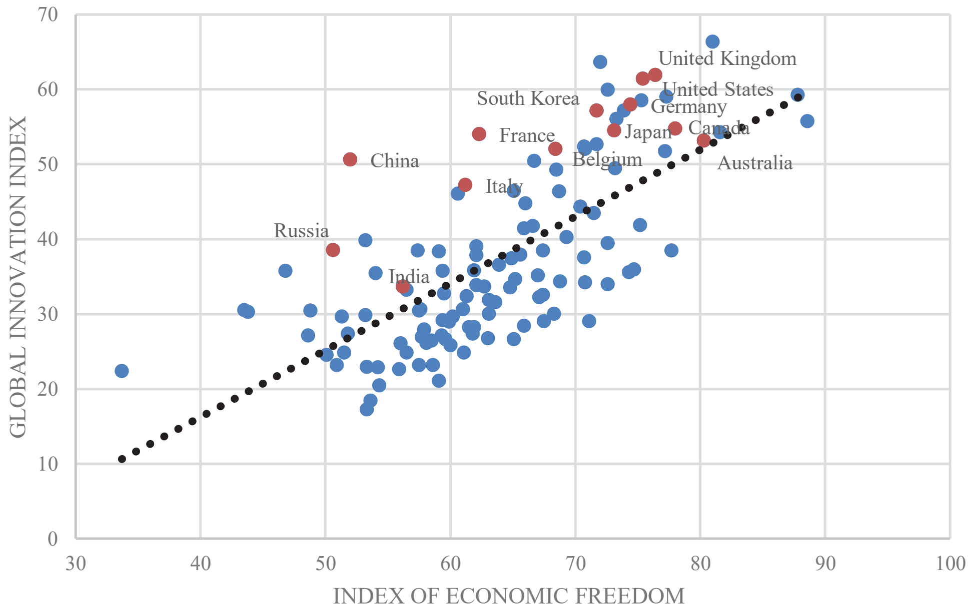
The variable adopted for the input is the IEF and the variable adopted for the product is the GII. Each country is a "decision unit". Beginning from different suppositions about the "function of production", it is possible to verify if the level of innovation has had increasing, constant or decreasing returns in relation to economic freedom. Figures 2 and 3 illustrate the combination of GII and IEF and the respective averages for 2013 and 2016.

Figure 2 | Scatterplot GII vs. IEF for 2013



Source: Cornell University, INSEAD School of Business and the World Intellectual Property Organization, Heritage Foundation

Figure 3 | Scatterplot GII vs. IEF for 2016



Source: Cornell University, INSEAD School of Business and the World Intellectual Property Organization, Heritage Foundation

It is possible to denote that, except for Australia in 2013, the selected countries have higher combination of innovation and economic freedom above the average line. Thus, compared to the average line, they have a higher innovation index for their respective levels of economic freedom. Particularly, China and France have relative high level of innovation related to their level of economic freedom.

Another important aspect refers to the concept of efficiency when analyzing the data. It is a relationship between resources ('inputs') and results ('outputs'). Being efficient does not mean being 'the best performer at all times' but rather 'doing the best with the available resources'. If a country has few inputs ('low economic freedom') it will have few outputs ('low innovation') and, in this fashion, it can be efficient anyways.

One of the limitations of the original Data Envelopment Analysis is that the assumed production function has constant returns to scale. Charnes, Cooper and Rodes (1987) assume constant returns to scale and all Decision-Making Units (DMUs) in an optimal operation scale. However, this claim is incompatible with several economic activities and even for the government, which provides public goods, it is not convincing. That is why

Banker, Charnes and Cooper (1984) reject the assumption of constant return to scale in favor of variable returns to scale so that the DMUs do not need to operate in optimal scale, which is the most usual case due to constraints in either the input or the product.

In particular, the RD&I process has complex ecosystems as pointed out by Groen and Van Meeteren (2020). Many of them are affected by science and technology policies and subsidies from the government – as explained by Salmelin (2013) for European Union – which distorts incentives. As there are high chances of economies or diseconomies of scale, a function which exhibits variable returns to scale should be used. Also, economic freedom can affect innovation in many ways and, therefore, we assume a variable return to scale 'production function'. We used data for GII 2013 and 2016 and IEF for 2013 and 2016.

As countries suffer from institutional restrictions (it is not very easy to change business environment in the short-run), we adopted the Banker, Charnes and Cooper's (1984) product-oriented DEA model – the BCC (Banker, Charnes and Cooper) – with focus on the (in)efficiency of the generated product given a level of used inputs -, since product orientations is more adequate to analyze the efficiency of produce innovation from the 'resources' given by the institutional environment (e.g. 'economic freedom'). Table 3 and Figure 4 show the objective values ('efficiency scores') calculated by the DEA-BCC model for 2013 and 2016. The score varies from 0 ('completely inefficient') to 1 ('efficient').

Table 3 | Objectives values ('Efficiency scores of innovations') for 2013 and 2016

COUNTRY	2013	2016	COUNTRY	2013	2016
Albania	0.559006	0.47623	Lithuania	0.681327	0.64746
Algeria	0.547821	0.514039	Luxembourg	0.909462	0.889824
Argentina	0.967326	0.796432	Madagascar	0.434272	0.438822
Armenia	0.641456	0.581607	Malawi	0.563246	0.542844
Australia	0.797297	0.80345	Malaysia	0.837614	0.685895
Austria	0.857494	0.829588	Mali	0.596538	0.463335
Azerbaijan	0.569713	0.529233	Malta	0.90709	0.837836
Bahrain	0.572388	0.552185	Mauritius	0.594048	0.557367
Bangladesh	0.541357	0.445136	Mexico	0.648937	0.584657
Belarus	0.856328	0.665917	Moldova	0.859915	0.709665

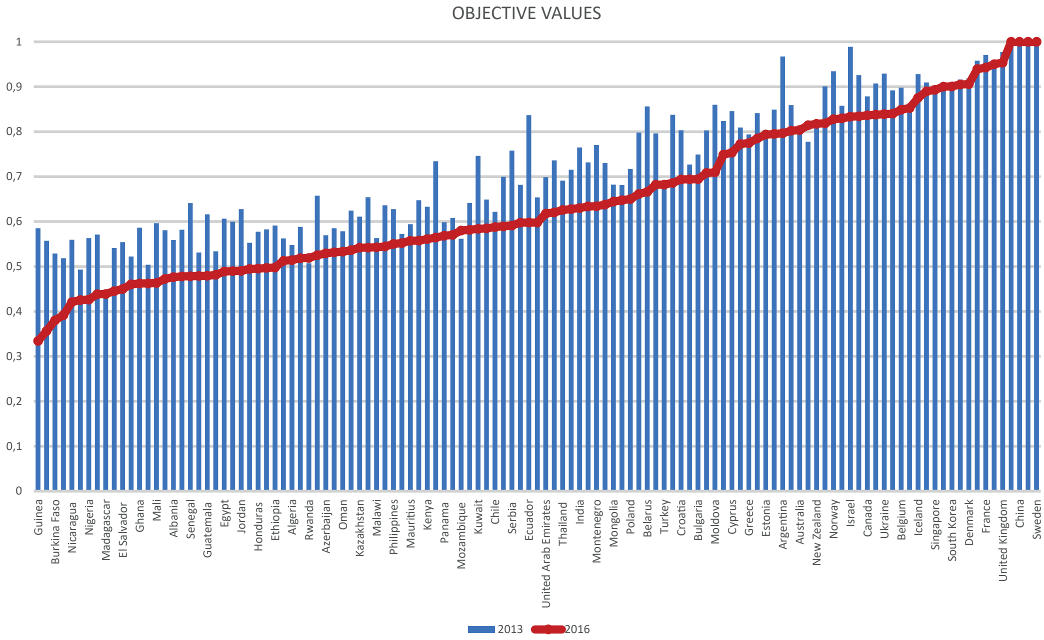
Belgium	0.898087	0.848841	Mongolia	0.681991	0.644288
Botswana	0.522067	0.460208	Montenegro	0.770546	0.63406
Brazil	0.736123	0.620271	Morocco	0.607988	0.570218
Bulgaria	0.749307	0.694223	Mozambique	0.561854	0.579992
Burkina Faso	0.52877	0.380331	Namibia	0.552744	0.494433
Cambodia	0.562579	0.512538	Nepal	0.580746	0.472403
Cameroon	0.570882	0.438209	New Zealand	0.818318	0.817496
Canada	0.878412	0.836391	Nicaragua	0.559482	0.420842
Chile	0.621593	0.587965	Niger	0.518465	0.391592
China	1	1	Nigeria	0.563025	0.426396
Colombia	0.636317	0.544413	Norway	0.934588	0.827762
Costa Rica	0.731818	0.633559	Oman	0.578297	0.53298
Côte d'Ivoire	0.503773	0.462366	Pakistan	0.493176	0.425332
Croatia	0.803063	0.693652	Panama	0.598537	0.568568
Cyprus	0.845647	0.753397	Paraguay	0.582511	0.496697
Czech Republic	0.809236	0.772358	Peru	0.624324	0.536215
Denmark	0.918771	0.905713	Philippines	0.62764	0.55003
Dominican Republic	0.654187	0.542073	Poland	0.717187	0.650012
Ecuador	0.83687	0.597679	Portugal	0.841313	0.784911
Egypt	0.606303	0.488722	Qatar	0.681883	0.597562
El Salvador	0.554281	0.44997	Romania	0.73011	0.637618
Estonia	0.803931	0.793432	Russia	0.848947	0.79488
Ethiopia	0.591225	0.497724	Rwanda	0.507335	0.518896
Finland	0.958037	0.939166	Saudi Arabia	0.798162	0.661244
France	0.970554	0.942491	Senegal	0.641257	0.478329
Georgia	0.585109	0.531515	Serbia	0.757574	0.591271
Germany	0.909973	0.900187	Singapore	0.891892	0.892911
Ghana	0.586485	0.462338	Slovakia	0.726834	0.693959
Greece	0.793963	0.77462	Slovenia	0.901067	0.818651

Guatemala	0.615939	0.4792	South Africa	0.715198	0.627685
Guinea	0.585033	0.334338	South Korea	0.898329	0.90056
Honduras	0.577513	0.49535	Spain	0.859081	0.802283
Hong Kong	0.891892	0.840121	Sri Lanka	0.588029	0.518525
Hungary	0.823578	0.748744	Sweden	1	1
Iceland	0.928184	0.875137	Switzerland	1	1
India	0.764935	0.630039	Tajikistan	0.653696	0.597769
Indonesia	0.657406	0.525176	Tanzania	0.533641	0.481532
Iran	0.777357	0.814306	Thailand	0.691152	0.625696
Ireland	0.916175	0.905047	Togo	0.557089	0.356313
Israel	0.9889	0.8334	Tunisia	0.734273	0.564159
Italy	0.926023	0.834217	Turkey	0.673557	0.682236
Jamaica	0.581796	0.477956	Uganda	0.599813	0.489656
Japan	0.86245	0.852495	Ukraine	0.929076	0.838846
Jordan	0.62782	0.490236	United Arab Emirates	0.698699	0.617749
Kazakhstan	0.610905	0.541796	United Kingdom	0.977327	0.953481
Kenya	0.632819	0.561144	United States	0.951252	0.95017
Kuwait	0.746176	0.583789	Uruguay	0.647351	0.557542
Kyrgyz Republic	0.531252	0.478934	Venezuela	1	1
Latvia	0.802693	0.70812	Vietnam	0.796177	0.682081
Lebanon	0.699593	0.589455			

Source: authors

Although the findings point out that only four countries are 'efficient' in 2013 and 2016 (China, Sweden, Switzerland and Venezuela), there are distinct levels of inefficiency. The DEA suggests that there was a change between 2013 and 2016. Inefficiency has increased for most of the countries according to Figure 4.

Figure 4 | Comparison: Objectives Values for 2013 and 2016



Source: authors

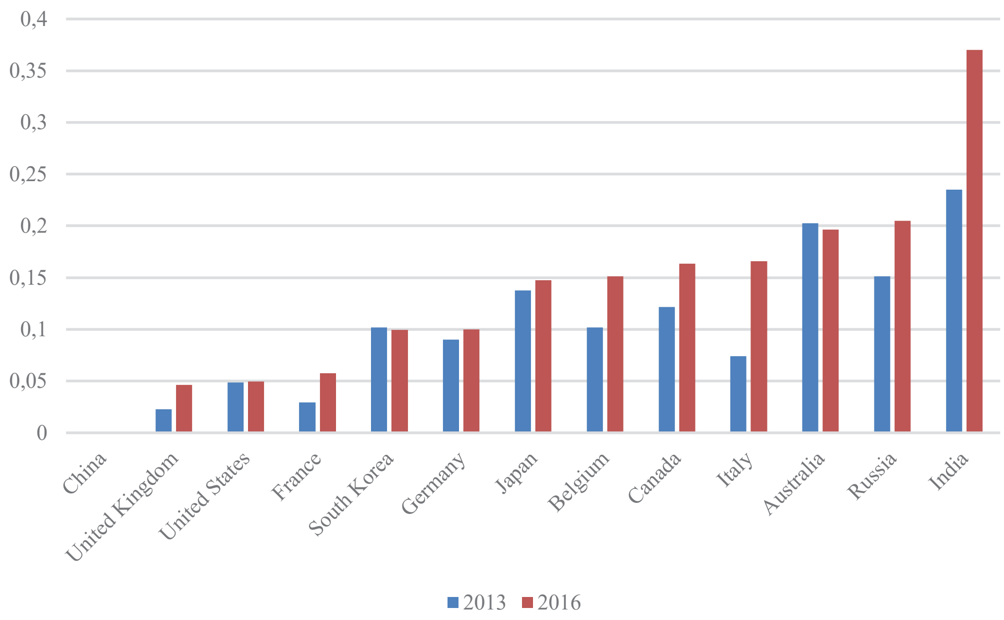
For the specific countries that lead the vaccine race, Table 4 presents the objective value and the 'effort required'. Let us assume that the difference between the efficiency score (equals 1) and the score of the respective country can be interpreted as a measurement of relative effort, as displayed in Figure 5. Then, the countries (particularly India – the largest inefficiency in the group) have to make an effort to be efficient, which does not necessarily mean spending more public resources on RD&I but rather spending better and/or enhance the business environment (such as rule of law, lower taxation, simpler regulation etc.). Although this is an instinctive advantage of the DEA analysis, it has some limitations. Since the results depend on the type of data used, the monitoring and evaluation of public policies tend to be more complex.

Table 4 | Efficiency scores of innovations and effort required for selected countries

DMU Name	Objective Value 2013	Effort required 2013	Objective Value 2016	Effort required 2016
China	1	0	1	0
United Kingdom	0.977327392	0.022672608	0.953481208	0.046518792
United States	0.951252288	0.048747712	0.950170226	0.049829774
France	0.970554252	0.029445748	0.942490619	0.057509381
South Korea	0.898329026	0.101670974	0.900559893	0.099440107
Germany	0.909973364	0.090026636	0.900186567	0.099813433
Japan	0.862450139	0.137549861	0.852494916	0.147505084
Belgium	0.898086526	0.101913474	0.848841006	0.151158994
Canada	0.878412471	0.121587529	0.836391437	0.163608563
Italy	0.926023303	0.073976697	0.834217038	0.165782962
Australia	0.797297297	0.202702703	0.803449841	0.196550159
Russia	0.848947049	0.151052951	0.794880184	0.205119816
India	0.764934947	0.235065053	0.630039377	0.369960623

Source: authors

Figure 5 | Effort required for obtain efficiency in the relationship between innovation and economic freedom



Source: authors

Final remarks

The scenario of the COVID-19 vaccine race is still uncertain. However, most likely, any discovery will come from one of the countries that are in the clinical stage of evaluation. It is a small group of countries whose largest number of initiatives are concentrated in the United States and China.

To justify that higher per capita income is the explanation of this inequality is very simplistic. India and China are part of this group and have comparatively low per capita income to other members, such as the United States and Germany. We considered that other variables explain the current scenario of countries in the search for a vaccine innovation.

The degree of economic freedom has been shown to be crucial to determine the level of innovation, possibly due to the removal of barriers to profit from new products or productive process. The amount of high-tech exports is also an important determinant of innovation, possibly due to the "learning by doing" effect.

The DEA analysis suggests that there was a change between 2013 and 2016, when inefficiency increased for most of the countries, but in both years the vaccine race leading groups of countries have higher combination of innovation and economic freedom above the average of the countries. Thus, compared to the average line, they have higher innovation index for their respective levels of economic freedom. Particularly, China and France seem to be performing better for their respective levels of economic freedom.

It is recommended that further research perform unit root and cointegration tests by increasing the timespan or reducing the number of countries of the sample. In addition, it would be beneficial to explore the efficiency change by its decomposition (changes in efficiency level and changes in technology) by using a Malmquist Index (e.g. for a broader period), which could explain the inefficiency over the years by a panel data analysis using objective values calculated by the Stochastic Frontier Analysis (SFA) methodology.

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