Can International Organizations Shape Technology Development?*

Zoe Xincheng Ge†

Mengfan Cheng‡

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Abstract

Technology development is unequal. Existing research suggests that the lack of credible and profitable market demand causes such unequal innovations, leading to the neglect of technologies with low market returns. We study how international organizations (IOs) can mitigate such inequalities. Specifically, IOs can leverage their central role in global aid procurement and provide information about the potential market demand, which helps channel investment into neglected technologies. Empirically, we investigate how the World Health Organization's (WHO) information provision on vaccine priority can shape R&D investment in infectious diseases. First, we study how the WHO sets priorities for vaccines. Using disease characteristics to explore the variation in the credibility of market demand across different diseases, we find that diseases with unequal geographic distribution receive higher priority from the WHO, while severe diseases are not listed as a high priority, confirming that the WHO provides information to substitute for the lack of credible market demand. Further, we evaluate the effects of this priority-setting strategy and find increased market entry of vaccine products listed as a high priority. However, we do not find increased R&D investment in high-priority diseases. This paper reveals the potential and constraints of information provision by IOs to correct for market failure in technology development.

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†Assistant Professor, School of Politics, Economic & Global Affairs, IE University. Email: xincheng.ge@ie.edu.

‡PhD Candidate, Department of Politics, New York University. Email: m.cheng@nyu.edu.

1 Introduction

Scientific development is biased in favor of the interest of capital. Knowledge that contributes to a higher market return tends to receive more attention and funding for research and development (R&D), while areas lacking market profitability tend to undergo a slower process of scientific development. The welfare of the less privileged population is often overlooked. For example, in the field of infectious diseases, despite the fact that malaria is deadlier than COVID-19 in Africa, malaria vaccine takes much longer to be developed than COVID-19 due to the concentration of malaria in poor regions (Wilkins and Paquette, 2021). Given their active role in promoting development, especially in middle- and low-income countries, can international organizations (IOs) facilitate overlooked scientific development?

One underlying cause of the inequality in innovation is a commitment problem (Barder et al., 2006). When a technology only serves a low-income community, the technology user cannot commit to a high enough price once the technology is developed. As a result, the innovator does not have incentives to invest in these unprofitable technology. In this paper, we investigate how IOs can solve this commitment problem by leveraging their central role in global aid procurement. Specifically, we study how IOs can strategically provide information about the priority of a technology to signal the potential market demand, which channels R&D investment into neglected technologies.

Empirically, we focus on the role of the World Health Organization's (WHO) in global health research. Studies on infectious diseases contributes to the efficient control of disease outbreaks. The development of vaccine technology and treatment medicine can greatly alleviate the severity of disease outbreaks. Yet, not all infectious diseases receive the same attention and resources. One example is the development of an Ebola vaccine called rVSV-ZEBOV (Branswell, 2020). The vaccine delivery technology is called vesicular stomatitis virus (VSV) and has been available since 1994. Yet, even though the testing in animals proved to be effective against the virus and showed no sign of negative consequences, the vaccine did not receive any grants until 2014, which was given by a Canadian defense program

as a tool to combat bioterrorism. Despite the great promise, there was a lack of funding for this vaccine candidate to enter the clinical trial stage, leading to another 5 years of delay before the vaccine was finally approved. During this prolonged period of Ebola vaccine development, two Ebola-related Public Health Emergency of International Concern (PHEIC) were declared, one in West Africa in 2014 and another in the Democratic Republic of the Congo in 2019, and involved an estimation of more than 13,000 deaths, demonstrating the dire consequence of unequal scientific development.

As neglected diseases like Ebola tend to be concentrated in middle and low income countries, there is a lack of credible market demand for medical products targeting these diseases. While governments have incentives to purchase these medical products, the budget constraint makes it difficult for these governments to credibly commit to a price that is high enough for the investment in these products profitable to pharmaceutical firms. As a result, parmaceutical firms invest in chronic diseases or infectious diseases that are common in rich countries, such as seasonal flu, which provide steady and predictable revenues for these firms (Branswell, 2020).

We argue that the WHO can leverage its central role in the UN procurement for medical products to provide a credible commitment of market demand for vaccines targeting neglected diseases. To do so, the WHO collaborates with other UN procurement agencies such as the United Nations International Children's Emergency Fund (UNICEF) and Gavi, the Vaccine Alliance (Gavi). Specifically, the WHO is responsible for the quality control of the procurement products, while the UNICEF is in charge of delivering the medical products, and Gavi provides the financial support. By pooling their expertise and financial resources together, these procurement agencies can create a credible market for medical products targeting low-income countries, which addresses the problem of fragmented small markets in low-income countries.

Once empowered by the crediblity of market creation, the WHO can strategically design its information provision about the priority of vaccine and medical products to channel

investment into neglected diseases. By setting a higher priority for medical products targeting diseases that lacks market demand, the WHO can signal to pharmaceutical firms of a potential market for products targeting these diseases. By increasing the marginal benefit of investing in neglected diseases, this priority-setting strategy can increaes pharmaceutical firms' willingness to bear a higher cost in the development and manufacturing of medical products set as a higher priority by the WHO. As a result, the market entry of new products and R&D investment targeting neglected diseases increase.

To examine this argument, we look into one important priority-setting activity by the WHO: the priority of vaccine prequalification. Vaccine is one of the most cost-effective interventions (World Health Organization, 2009). However, the efficacy and safety of vaccines require constant regulation. Equipped with its expertise in public health, the WHO was delegated the authority of vaccine quality control by other United Nations (UN) procurement agencies. This procedure is called vaccine prequalification, which is a necessary condition for a vaccine to enter the UN procurement process. Hence, the WHO has the authority to grant credible market access to vaccine products.

First, we examine whether the lack of market demand leads to a higher priority set by the WHO. To explore the variation of market demand, we look into disease characteristics and argue that diseases with more unequal geographic distribution face a less credible market demand, while more severe diseases has a greater market demand. The emprical evidence shows that the WHO set higher priorities for unequal diseases, while severe diseases did not receive a higher priority. These results confirm that the WHO's priority-setting aims to balance out the unequal market demand for vaccines targeting different diseases.

Next, we examine the effect of vaccine priority on market entry of new vaccines. By matching the prequalified vaccines with the priority list, we find that after the publication of the priority list, the prequalified vaccines are more likely to be of a high priority, suggesting that the WHO's priority-setting attracts more market entry of new vaccines. To examine whether the WHO vaccine priority can shape R&D investment, we employ a difference-in-

differences specification. We use the publication of the vaccine priority list as the treatment and examine the treatment uptake by exploring the variation in the level of priority. To measure R&D investment in different diseases, we look into the research grants by the National Institutes of Health (NIH) and the European Research Council (ERC), the number of patents based on Google Patents, and the record of clinical trials based on an online database of clinical research studies around the world. Using regular expressions to detect diseases and the corresponding viruses, we categorize the funding, patents, and clinical trials into 38 types of vaccine-preventable diseases.[1] We do not find the boosting effect of the WHO priority on R&D investment. While the market creation through UN procurement can induce market entries of new vaccines, there is a limited effect on the earlier stages of vaccine development.

This paper makes three contributions. First, it contributes to the literature on the international determinants of scientific development. While existing work has shown the importance of economic factors (Acemoglu, 2002; Acemoglu et al., 2015) and domestic politics (Drezner, 2001) in the development of science and technology, an emerging literature is focusing on the role of international politics. Milner and Solstad (2021) show that international competition accelerates the speed for states to adopt new technology, while Drezner (2019) highlights the importance of power distribution. Most closely related to this paper, Hai (2023) studies how states influence IOs' interpretation of scientific information to set the agenda in international negotiation. This paper reveals how international institutions can channel the direction of investment in scientific development.

Second, this paper speaks to the literature on IOs' strategic provision of information. Existing studies show that IOs' information provision is shaped by the need to persuade domestic policymakers (Fang and Stone, 2012), to influence the bargaining dynamics (Johns, 2007), and to compete with other IOs (Miyano, 2024). We show that IOs may also provide information to correct for market failure.

[1]Website: https://www.who.int/teams/immunization-vaccines-and-biologicals/diseases

Last, this paper adds to the understanding of the source of agenda-setting power in IOs. Existing studies have identified the influence of expertise (Haas, 1992; Pollack, 1997; Heinzel and Koenig-Archibugi, 2024), domestic audience (Bisbee et al., 2019; Kelley and Simmons, 2020), and bureaucrats (Arias, 2024) as the source for IOs' agenda-setting power. This paper adds to these studies by highlighting IOs' influence on the market as a new source for their ability to set the agenda (Gray, 2009, 2013).

2 A Commitment Problem in Technology Development

Technology development is unequal. While the direction of technology development can be determined by the profitability of the price effect and the market size effect in the production output assisted by the technology (Acemoglu, 2002), one of the reasons for the unequal directed technological change can be a commitment problem (Barder et al., 2006).

One key feature of the underdeveloped technology is that these technologies tend to serve the interest of the under-privileged population. Although the demand for these technologies may be high, when the technology users are concentrated in low-income countries and constitute the sole customer base, they are often unable to commit to a high price enough to make investment in developing the technology profitable for the innovator. Even if some rich governments may step in to support the provision of such technologies, these efforts may still fall short given the high cost of developing new technologies and the limited impact their absence has on populations in the developed world.

Vaccines and medical products targeting tropical diseases tend to be under-developed as these diseases are concentrated in certain regions of the world. The transmission of such diseases is reliant on region-specific climate and environment conditions, leading to limited negative consequence for the developed world. For example, the spread of meningococcal diseases in the meningitis belt is associated with higher dust concentration and lower temperatures. Diseases like malaria, dengue, and yellow fever relies on mosquitoes to spread,

which requires certain level of temperature and humidity for the vector to spread. As a results, these diseases rarely spread to the developed countries. As Figure 1 shows, some of the outbreaks of infectious diseases that are common in low-income countries, such as Dengue and Cholera, are rare events in high-income countries. While pharmaceutical firms can develop medicines targeting all infectious diseases around the world, the opportunity cost of focusing on any disease can be high if there is not a credible profitable market demand for that disease. As most pharmaceutical firms are located in rich countries with well-developed health systems, the product profiles of these firms mainly target the market in rich countries. Given the invisibility of these diseases to citizens in developed countries, governments have limited incentives to step in and provide financial support for the medical research on these diseases. Without enough financial support by the goverment, more resources are allocated to health research on diseases concentrated in rich countries (Adam et al., 2023).

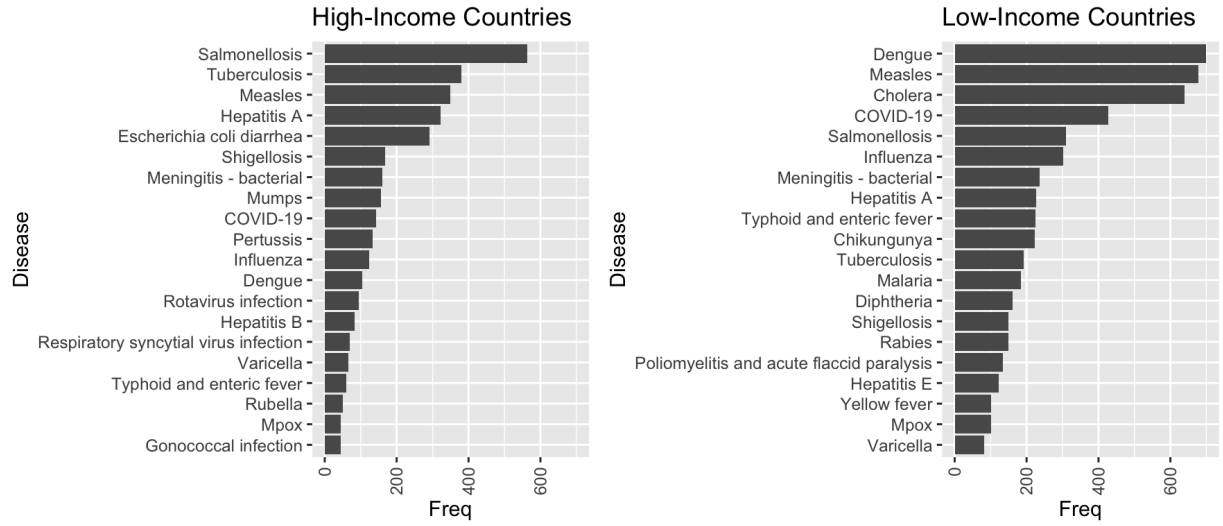

Figure 1: Top Disease Outbreaks in High and Low-Income Countries (1990-2023)
Note: High and low-income countries are defined based on whether a country is in the first and last quantile based on GDP per capita.

A similar situation applies to the climate adaptation technologies. Material innovation for flood barriers could be an efficient and low-cost option for low-income flood-prone regions, but more funding is available for big infrastructure projects like sea gates and undergrand

flood tunnuels. Similarly, big infrastructure projects in developed countries are more visible to voters and more profitable to firms, while the material innovation serving the low-income populations are less visible and tend to be overlooked.

In this paper, we focus on the role of the WHO in vaccine development. We argue that the WHO can leverage its central role in the UN procurement for medical products to commit a credible market demand to vaccine developpers and manufacturers. By strategically providing information about the priority of vaccines, the WHO can channel R&D investment into neglected diseases. The next section provides a background of the relationship between the WHO and technology development and lays out the work that the WHO engages in for vaccine development and production.

3 World Health Organization and Technology Development

The WHO is a specialized agency of the United Nations (UN) in charge of promoting international public health. Prior to the creation of the WHO, the first effort of international cooperation on global health started from the International Sanitary Conference in 1851. The priorities of the International Sanitary Conference in the late nineteenth and early twentieth centuries focused on preventing the spread of a limited list of diseases—cholera, plague, and yellow fever—from Asia and the Middle East to Europe and North America (Fidler, 2005). The establishment of the WHO expanded the narrow scope in this old regime and embraced new goals, policy orientation, and strategy to address global health. More specifically, the WHO embraced the goal of Health for All, which covers not only the eradication and containment of infectious diseases, but also the improvement of overall health outcomes, especially in the developing world. Meanwhile, the WHO's policy orientation transformed from old regimes' focus on balancing economic interests of great powers with health risks to the pure focus on improving health outcomes through disease eradication and universal

primary health care. Lastly, the WHO's strategy compared to the old regime involves active application and dissemination of scientific advancements, such as antibiotics and vaccines.

In terms of its relationship with scientific development, the WHO engages in three aspects of activities: to guide, develop, and deliver health policies based on scientific evidence. The first is to set the agenda to guide the research focus to gaps and priorities that are responsive to local contexts. The second is to evaluate the quality of new scientific advancements by developing and disseminating the appropriate norms and standards for practice. The last is to translate the latest data, research, and evidence into real-world adoption. Therefore, the WHO plays a critical role in connecting the scientific community to real-world practitioners for the promotion of health for all populations around the world.

3.1 The WHO's Role in Quality Control

We focus on the case of vaccine technology, which is one of the most successful and cost-effective health interventions (World Health Organization, 2009).

One of the WHO's most important programs related to vaccine technology is the vaccine prequalification program. Different from chemical pharmaceuticals, vaccines are biological products and are derived from living organisms. Due to the inherent variability of living organisms, vaccines could be damaged from the contamination of materials or changing environments. Constant quality control and assessment are necessary to ensure the safety and efficacy of vaccine products. In response to this demand for quality-control, the vaccine prequalification program was initiated in 1987 as a quality-control service provided to the United Nations Children's Fund (UNICEF) and other UN procurement agencies to ensure the safety and efficacy of the procured products. The program started as a temporary and modest project which involved the testing of vaccine lots, review of summary lot protocols, and the inspection of manufacturing sites. As the demand, diversity, and complexity of vaccine products submitted for prequalification continued to grow, the prequalification procedure gradually became a long-term program, which become a necessary condition for

any vaccine products to enter the UN procurement.[2] The program has also gone through multiple reforms to increase its efficiency. Since 2002, the WHO has required the national regulatory authority (NRA) of the vaccine producing country to be functional—defined as the establishment of appropriate capacity for vaccine regulation—as a prerequisite for accepting submissions of vaccine prequalification by manufacturers from that country. This requirement has a great impact on strengthening vaccine regulation capacity in developing countries. In 2012, in response to the increased volume and cost of new vaccines, the WHO developed a streamlined prequalification procedure to reduce the timeline and resources for assessment. For example, the assessment reports by certain NRAs are recognized to avoid duplicative regulatory efforts.[3]

3.2 The WHO's Role in Market Creation

In addition to the quality evaluation of vaccine products, the WHO's work related to vaccine technology also involves guidance and market maintenance. To guide the direction of the development of vaccine products, the WHO publishes priority lists of vaccines eligible for prequalification.[4] This means a vaccine product must be on the list to be eligible for prequalification and to get access to UN procurement. The list categorizes vaccine types into high, medium, low and no priority, which is updated by the WHO in consultation with the UNICEF and the Revolving Fund of the Pan American Health Organization, a mechanism that provide technical support to national immunization programs through overcoming the barriers of price and access. Four criteria determine the priority of a vaccine: market demand, programmatic needs of the WHO, recommendation by the WHO's Strategic Advisory Group of Experts on immunization (SAGE), and supply security due to shortage.

In terms of market maintenance, the WHO collaborates with the UNICEF and Global Alliance for Vaccines and Immunization (GAVI) to predict, maintain, and create the market

[2]Appendix A describes the procedure for a vaccine product to obtain the prequalification status.

[3]The recognized NRAs include Australia, Belgium, Canada, France, Italy, the United States, and the European Medicines Agency.

[4]Website: https://extranet.who.int/prequal/vaccines/vaccines-eligible-who-prequalification

for vaccines. The vaccine market is small and concentrated from both the supply and demand perspective. More specifically, on the supply side, manufacturers of vaccines are mainly located in developed countries. On the demand side, however, many diseases are concentrated in low- and middle-income countries (LMICs). While vaccine sales to high-income countries generate more revenue, sales to LMICs are of much larger volume. Due to the geographic mismatch in the demand and supply of vaccines, it is challenging for manufacturers to predict which vaccine product to prioritize. Moreover, given that each vaccine product—even for the same type of disease—has its specificities, individual vaccines or vaccine types have their own individual markets, making the prediction of the pricing and procurement a complex task. Given the complex nature of vaccine market, the WHO's function of connecting vaccine manufacturers with the procurement agencies and donors in these agencies plays a critical role in ensuring a healthy vaccine market.

4 Hypotheses

The WHO can credible commit to a market demand because of its close ties with other UN procurement agencies like the UNICEF and the Gavi, which are in charge of vaccine delivery and financial support for the purchase of vaccines. With the credible market creation, we argue that the WHO can strategically design the information provision of vaccine priorities to channel R&D investment into neglected diseases. The information on vaccine priority serves as an agenda-setting tool and increase the salience of certain technologies. Bisbee et al. (2019) show that, as an international assessment mechanism of government performance, global performance indicators (GPIs) induced governments to shift the investment in social development that is not calculated in GPIs to targets that are measured in GPIs. The same logic may apply to firms' investment decisions. Once IOs categorize certain technologies as of higher priority than other related technologies, profit-driven firms speculate a higher probability of credible market demand for the product, which increases firms' expected return

from investment and motivates firms to channel investment in other technologies to the more salient ones. 2 shows a pathway through which the WHO can shape R&D investment.

Figure 2: How Does the WHO Shape R&D Investment?

To test this argument, we examine two empirical implications. First, what shapes how the WHO set priorities? If the WHO's priority-setting aims to solve the inability of low-income governments to commit to a profitable market demand for pharmaceutical firms, we should expect higher priority for diseases that lack a credible market demand.

To explore the variation in the credibility of market demand, we look into disease characteristics. One of the key factors for the lack of market demand is the geographic concentration of diseases in low-income countries. Instead, if a disease is evenly distributed across different countries, there is more demand for the corresponding vaccine product from different buyers. The presence of market competition could drive up the price and make it profitable for pharmaceutical firms to invest in its development. Hence, the uneven disease distribution reduces the crediblity of market demand and motivates the WHO to set a higher priority for these diseases.

Hypothesis 1. *Diseases with more uneven geographic distribution receive a higher priority.*

Another important disease characteristic is disease severity. Diseases with more frequent outbreaks and infected cases attract more media attention, which gives more pressure on rich goverments and international organizations to provide aid for mitigation. These pressure may constitute credible market demands, and it is not necessary for the WHO to prioritize the diseases to signal the market deamnd. Hence, the severity of a disease may not necessarily increase the priority set by the WHO.

Hypothesis 2. *Disease severity does not necessarily affect WHO priority.*

The second empirical implications is about the effect of the WHO vaccine priority on investment in vaccine development. The WHO priority list of vaccines prequalification not only includes innovative vaccine technologies that are still under patent and target previously unaddressed diseases like Ebola and malaria, but also promotes the manufacturing of generic vaccines like measles and measles-mumps-rubella (MMR) vaccines and diphtheria-tetanus-pertussis (DTwP) vaccines. If this priority-setting strategy works, we expect to see more entries of vaccine products into the UN procurement if their vaccines types are listed as a high priority. This is especially true for those generic off-patent vaccines as the entry barrier is lower without the need to invest in initial R&D investment. In this case, the pharmaceutical firms need to prove the bioequivalence of their product with the original vaccines. Further, we expect to see that the publication of the priority list increases in R&D investment in diseases listed as high priority by the WHO.

Hypothesis 3. *Vaccines with a higher priority are more likely to enter the UN procurement.*

Hypothesis 4. *After the publication of the priority list, diseases listed as higher priority experience increases in R&D investment.*

5 How Does the WHO Set the Priority?

5.1 WHO Priority on Vaccines

The WHO published two priorty lists for vaccine prequalification in 2017 and 2023, respectively. The lists categorize vaccine types into high, medium, low, and no priority. As Hypothesis 1 and 2 focuses on disease-level characteristics, we aggregate and convert the priority categories at the vaccine level into the disease level. One empirical complexity in this process is the case of combination vaccines, which combine vaccines targeting different diseases into one shot. Examples include DTaP for diphtheria, tetanus, and pertussis and MMR for measles, mumps, rubella. For these vaccines, one priority category apply to mul-

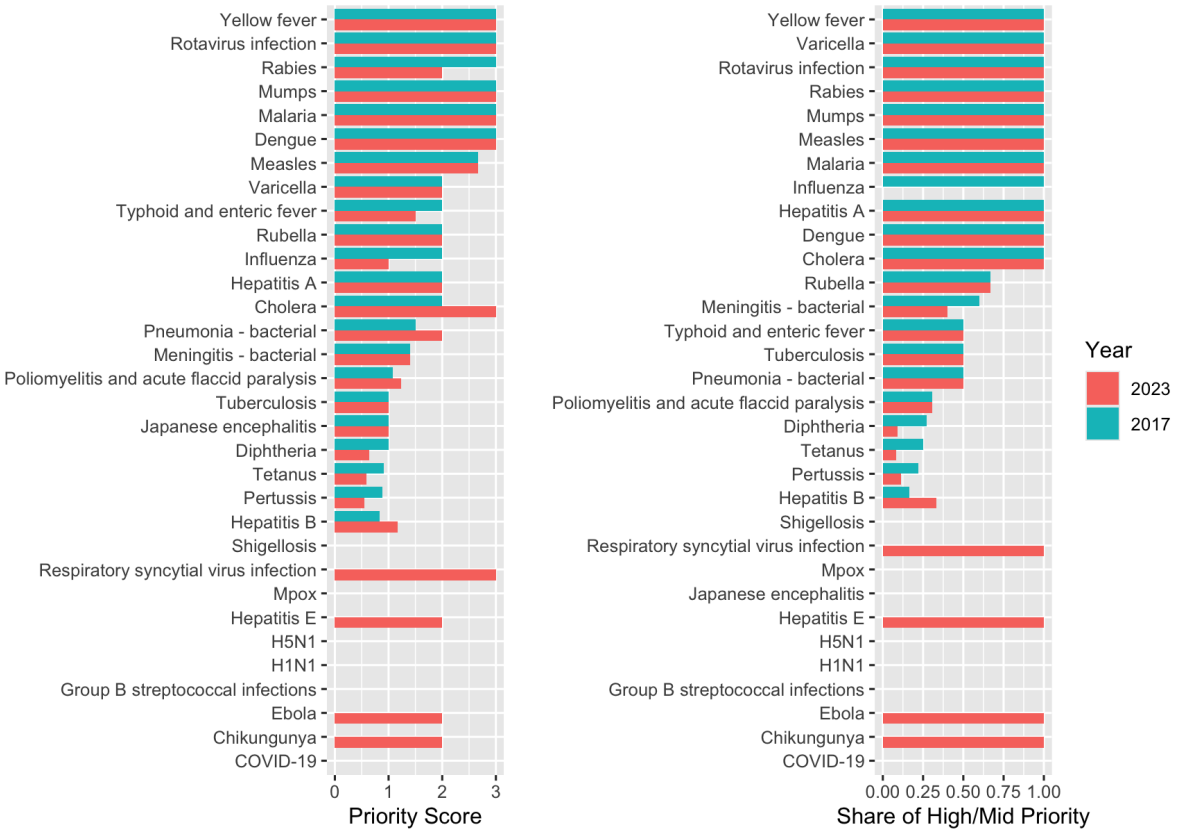

Figure 3: Disease Priority: 2017 vs. 2023

tiple diseases. This leads to some diseases to receive different priority categories, making it less straightforward to create a measure of priority at the disease level. To address this complexity, we create two disease-level priority measures. First, we create the priority score by assigning points to each category at the vaccine level[5] and taking the average of these points at the disease level. The second measure uses the share of vaccines that are categorized as high and medium priority. Figure 3 shows the priority measures for each disease in the 2017 and 2023 priority list.

[5]High priority has 3 points. Medium priority has 2 points. Low priority receives 1 point. No priority is 0 point.

5.2 Disease Inequality and Severity

To create measures of disease distribution, we use the Global Infectious Diseases and Epidemiology Network (GIDEON) database, which monitors and collects data on outbreak events of infectious diseases. We use vaccine-preventable diseases as the sample[6] and construct two set of variables at the disease-year level. First, to measure the unequal distribution of disease outbreaks, we use the GINI index approach, where we replace the income variable in traditional GINI index with the outbreak occurrence related to a certain disease in a year. The index ranges between 0 and 1, which higher number indicating more unequal distribution.[7] To further capture the idea that the credibility of market demands lies in where the outbreaks concentrate, we examine the number of outbreaks in developing countries and developed countries and the share of outbreaks in developing countries. Second, to measure disease severity, we use the total number outbreaks a disease have in a certain year.

Figure 4 shows the annual average of the disease inequality and severity variables in the period from 2015 to 2021. We can see that while Ebola is the most unevenly distributed disease, it is not so severe based on the number of annual occurance. In contract, COVID-19 is the most severe disease and has a relatively even distribution given its wide spread.

5.3 Results

After mapping the disease priority to disease distribution data,[8] we regress disease priority on disease characteristics. Table 1 presents the results. All disease distribution variables are standardized to allow for coefficient comparison, and these variables are lagged for one year to avoid simulneity bias. Columns (1) and (5) shows the coefficient estimates of disease inequality. For both measurements of disease priority, we find statistically significant and positive correlation between disease inequality and disease priority, suggesting that balancing

[6]https://www.who.int/teams/immunization-vaccines-and-biologicals/diseases

[7]For diseases with zero outbreaks in a year, the GINI index does not apply. We code the index as zero because the lack of outbreaks indicates the perfect equality of disease distribution.

[8]We treat vaccine-preventable diseases without a match in the priority list as no priority.

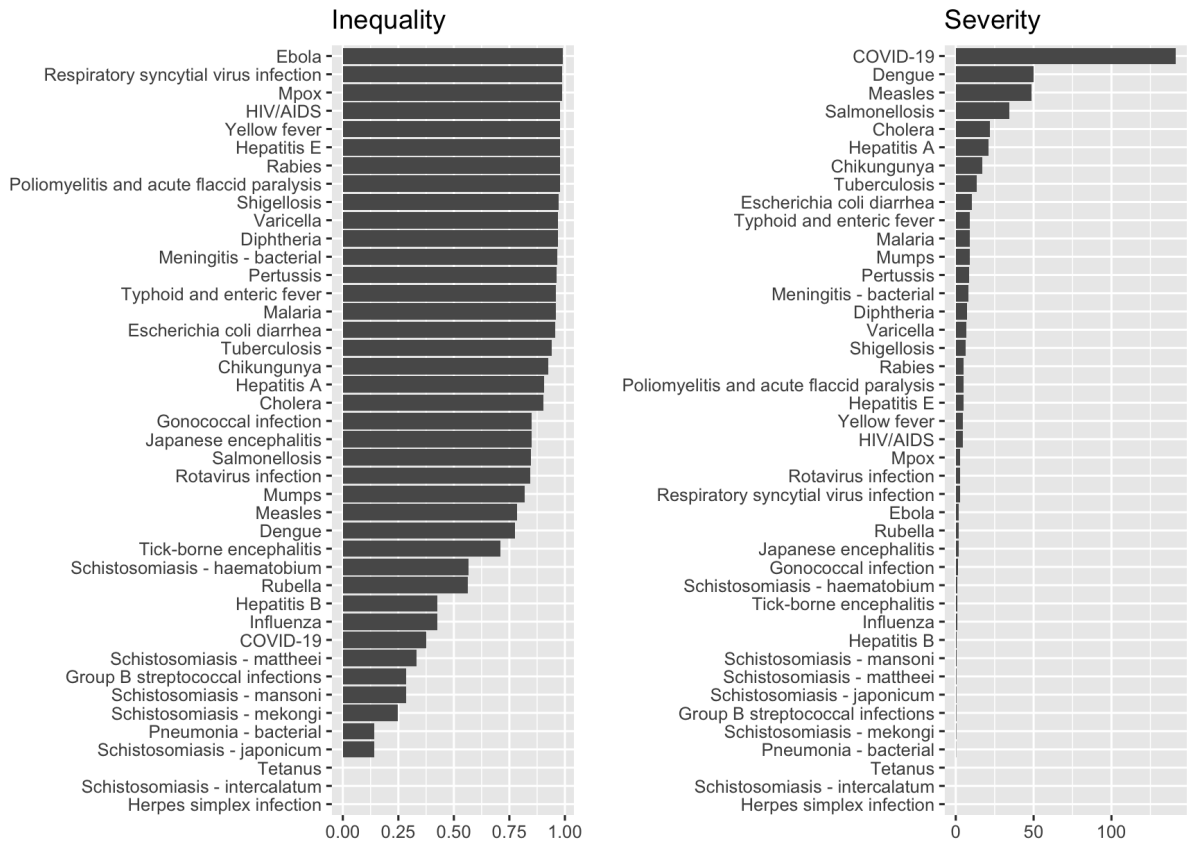

Figure 4: Disease Distribution: Annual Average (2015-2021)

out the lack of credible market demand is an important concern for the WHO's priority-setting. This provides support for Hypothesis 1.

Columns (2) and (6) shows the coefficient estimates for disease severity. We do not find any statistically significant relationship between disease severity and priority. In Column (3) and (7), we break down the outbreak events based on whether the oubreaks occur in developing countries or developed countries.[9] More outbreak events in developing countries increase the WHO priority, while more outbreaks in developed countries reduce the WHO priority. These results suggest that disease severity alone is not an important consideration in the WHO's priority-setting. What matters more is where the outbreak is. Last, in

[9]Using the World Bank classification of countries based on income levels (https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups), we treat high- and upper-middle-income economies as developed countries. We treat low- and lower-middle-income economies as developing countries.

Table 1: Disease Distribution and Priority

	Dependent variable:							
	Priority Index				Share of High and Medium Priority			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Inequality (GINI index)	0.317*				0.133**			
	(0.178)				(0.063)			
Severity: N. of outbreaks		−0.078				−0.026		
		(0.067)				(0.025)		
N. of outbreaks in developing countries			0.268***				0.101**	
			(0.099)				(0.044)	
N. of outbreaks in developed countries			−0.302***				−0.111***	
			(0.071)				(0.036)	
Share of outbreaks in developing countries				0.156				0.055
				(0.154)				(0.059)
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Observations	59	59	59	59	59	59	59	59
R^2	0.072	0.031	0.127	0.029	0.075	0.021	0.104	0.022
Adjusted R^2	0.039	−0.004	0.079	−0.006	0.041	−0.014	0.055	−0.013

Note: *p<0.1; **p<0.05; ***p<0.01
Standard errors clustered at the disease level in parentheses

Column (4) and (8), we examine the effect of the share of outbreaks in developing coutries. The coefficient estimates are positive but not statistically significant. These results confirm Hypothesis 2.

6 Does the WHO Priority Induce Market Entry of New Vaccines?

To examine the effect of the WHO priority on market entry of new vaccines, we take all the prequalified vaccines as the sample, which include 259 prequalified vaccines.[10] Ideally, we would like to know all the vaccine application for prequalification, which would allow us to investigate in how the publication of the vaccine priority list affects phamaceutical firms' interest in joining the UN procurement procedure, but the only publicly available data is the list of prequalified vaccines. Based on this dataset, we examine whether, after the publication of the vaccine priority list, the prequalified vaccine is more likely to be among those listed as of higher priorities. Specifically, we compare the prequalified vaccines before and after the year 2018, the year when the list took effect, and investigate whether the vaccines prequalified after 2017 are more likely to be of a higher priority.

[10]Website: https://extranet.who.int/prequal/vaccines/prequalified-vaccines. Our data was collected on February 17, 2024. There is one COVID-19 vaccine in the list, which is removed from the analysis because COVID-19 vaccine was not relevant in 2017.

Table 2 shows the results. The dependent variables in the first three columns are whether the vaccine is listed in the high category, while the dependent variables in the last three columns are whether the vaccine is listed in the high and medium categories. Column (1) and (4) confirms Hypothesis 3: the vaccines prequalified after 2018 are more likely to be among those listed as high priorities. Column (2) and (5) uses only vaccines produced by Western pharmaceutical firms as the sample, and Column (3) and (6) uses non-Western vaccines as the sample. These results suggest that the increased market entry of high-priority vaccines are mostly driven by non-Western vaccines. This suggests that pharmaceutical firms in developing countries may have more incentives to develop off-patent generic vaccines and take advantage of the vaccine market created through the UN procurement.

Table 2: Did the Publication Lead to More High-Prioirty Vaccines Being Prequalified

	Dependent variable:					
	High			High & Medium		
	All	Western	Non-Western	All	Western	Non-Western
	(1)	(2)	(3)	(4)	(5)	(6)
Post 2018	0.220**	−0.058	0.389***	0.201**	0.082	0.272*
	(0.094)	(0.112)	(0.120)	(0.099)	(0.115)	(0.142)
Constant	0.196**	0.324***	0.121	0.467***	0.559***	0.414***
	(0.083)	(0.118)	(0.078)	(0.113)	(0.126)	(0.138)
Observations	258	98	160	258	98	160
R^2	0.050	0.004	0.150	0.039	0.006	0.071
Adjusted R^2	0.046	−0.007	0.145	0.035	−0.004	0.065

Note: *p<0.1; **p<0.05; ***p<0.01
Standard erros clustered at the vaccine type level in parentheses

To examine the results in Table 2 is driven by some omitted variables, we conduct a placebo test using the priority categories based on the vaccine priority list published in 2023 as the dependent variable. The vaccines prequalifed after 2018 should not reflect the priority-setting activity in the future. Hence, we should see insignificant coefficient estimates for the post 2018 indicator. Column (1) in Table 3 shows that vaccines prequalified after 2018 are still more likely to be listed as high priority in the future priority list. This could be because of the unmet demand for the high-priority vaccines. In column (3) and (4), we control for

the priority category in the 2017 list, and the coefficient estimates for the post 2018 indicator are both insignificant. Hence, the placebo test provides further support that the publication of the priority list can induce market entry of high-priority vaccine products.

Table 3: Placebo Test Using Future Priority List

	Dependent variable:			
	High		High & Medium	
	(1)	(2)	(3)	(4)
Post 2018	0.197**	0.064	0.167	0.070
	(0.098)	(0.052)	(0.108)	(0.093)
High Priority in 2017		0.605***		
		(0.163)		
High & Medium Priority in 2017				0.479***
				(0.152)
Constant	0.152**	0.034	0.370***	0.146
	(0.076)	(0.029)	(0.112)	(0.134)
Observations	258	258	258	258
R^2	0.044	0.431	0.026	0.238
Adjusted R^2	0.041	0.426	0.022	0.232

Note: *p<0.1; **p<0.05; ***p<0.01
Standard erros clustered at the vaccine type level in parentheses

7 Does the WHO Priority Induce R&D Investment?

7.1 R&D Investment in Infectious Diseases

To measure R&D investment in infectious diseases, we collect data from multiple sources. For research grants, we use funding issuance records published on the Research, Condition, and Disease Categorization (RCDC) system[11] by National Institute of Health (NIH). This dataset is available from 2008 to 2023. As the NIH awards grant to organizations mostly within the US with a small proportion of foreign awardees, this dataset allows us to observe government support for different infectious diseases with a focus on the US, where a big portion of pharmaceutical firms are located. We also use the Dashboard of the European

[11]Website: https://report.nih.gov/funding/categorical-spending/rcdc

Research Council (ERC) funded projects and evaluated proposals, which is one of the most prestigious grants in Europe. The ERC grant is available between 2007 and 2024. Second, we collect the patent records from Google Patents.[12] Third, we collect the clinical research trials data from ClinicalTrials.gov, a website maintained by the National Library of Medicine (NLM) in the US. The website publishes self-reported clinical trials from over 200 countries. The NLM does not approve or review any of the registered trials. Investigators may choose to publish their studies for different reasons. They may be required by domestic law and academic journal submission rules to publish their clinical studies on a public database. Also, the WHO stated in 2006 that clinical trials happening anywhere around the world must have some information available on ClinicalTrials.gov or other similar databases. Researchers are further incentivized to publish their information to attact subjects because patients who have no access to fully grown treatment may actively search and sign up for on-going clinical trials on this website. The registration reports date and location of trials as well as the conditions under study. We leverage these information and matched 24,073 trials from 2000 to 2023 to vaccine-preventable diseases in our analysis.

One empirical challenge with these datasets is that they do not report records based on disease categories.[13] To overcome this challenge, we use regular expression to identify disease names and the corresponding virus related to each disease from the title or abstract of the project that are granted the funding and the conditions of the clinical trial. This allows us to match 38 vaccine-preventable diseases. We apply this approach for the NIH funding, the ERC grants, and the clinical trials data. For google patents, we use the disease-related keyword search and then download all the records shown in the search results.

After identifying the relevant grants and trials, we aggregate the NIH funding amount, ERC grant number, patent records, and trials to the disease-year level. By examining the

[12]Website: https://patents.google.com/

[13]For the RCDC data, some of the grants are reported at the disease level, while others are reported in more general categories, such as vaccine related, infectious diseases, and emerging infectious disease. In these cases, we look into project titles to identify the relevant diseases.

correlation between disease distribution and these different dimensions of R&D investment,[14] we find that more unevenly distributed diseases tend to receive less R&D investment, while diseases with more outbreaks events tend to receive more R&D investment. In addition, more outbreaks in developed countries encourage more investment, while outbreaks in developing countries do not. A great proportion of outbreaks in developing countries discourages investment. Overall, despite the low statistical siganicance, these patterns confirm that scientific development is biased in favor of the interest of capital.

7.2 Empirical Specification

To examine how the WHO priority shape R&D investment in infectious diseases, we use a difference-in-differences specification, which is shown in the following equation.

$$Investment_{it} = \gamma_i + \lambda_t + \beta_2 Priority_i \times Post_t + X_{i,t-1}\beta + \epsilon$$

$Investment_{it}$ refers different measures of R&D investment at the disease-year level. Specifically, we examine the amount of NIH funding, the number of ERC grant, the number of Google patents records, and the number of clinical trials related to disease i in year t. $Post_t$ indicates whether a year is after 2017, which is the year when the first Vaccine Prequalification Priority List was published.[15] $Priority_i$ is the disease-level share of high and medium priority and priority index as are discussed in Section 5.1. γ_i is the disease fixed effect, which captures the disease-specific characteristics that may affect the overall level of R&D investment. λ_t is the year fixed effects and captures the time-specific factors that contributes

[14]The results are presented in Table B.1 and Table B.2. The dependent variables are in logarithm. Consistent with the specification in Table 1, all disease distribution variables are standardized and lagged for one year.

[15]There have been two published list of Vaccine Prequalification Priority. One was published in 2017 after the First Annual review of diseases prioritized under the Research and Development Blueprint. It covers the period from 2018 to 2020. The other one was published in 2023 after the WHO launched a global scientific process to update the list of priority pathogens and covers the period from 2024 to 2026. As the R&D investment may have a delay in the response to the publication of the priority list, we can only examine the effect of the first list.

to the R&D investment. For example, due to the American Recovery and Reinvestment Act of 2009 (ARRA), there were extra funding for health research in year 2009 and 2010. The year fixed effects can control for such changes in funding. $X_{i,t-1}$ are control variables related to disease distribution characteristics, which are all standardized and lagged for one year.

7.3 Results

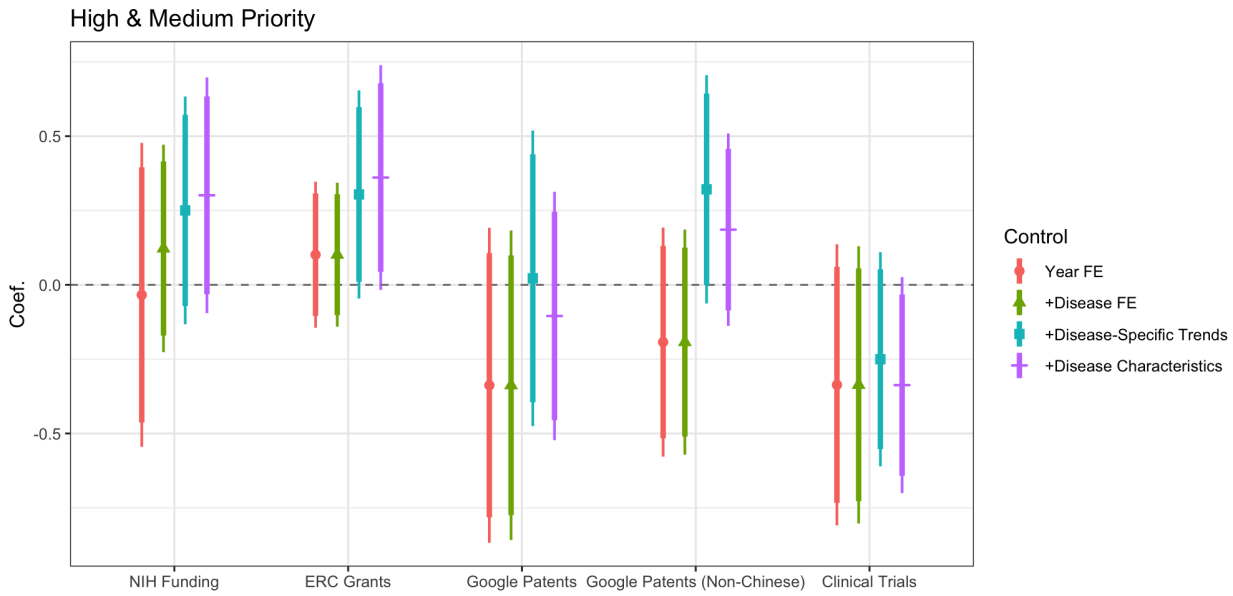

Figure 5: Vaccine Priority and R&D Investment

Figure 5 presents the regression results using the share of high and medium priority as the disease priority measure.[16] We present the coefficient estimates of the interaction between $Priority_i$ and $Post_t$ across different specifications. In the first one, we only include year fixed effects. Then we add disease fixed effects. Considering that the dependent variable may follow some trends, we control for disease-specific time trend. Last, we add disease characteristics.[17] In the fourth column of Figure 5, we present result with the number of Google patents without Chinese records as the dependent variable. This is to reduce the

[16] Figure B.1 presents the results using the priority index, which are mostly identical.

[17] We control for disease inequality, the number of outbreaks in developing countries, and the number of outbreaks in developed countries.

influence of Chinese patents due to the huge number of patent records in China.[18] Overall, Figure 5 presents no evidence of increased R&D investment after the publication of the vaccine priority list.

8 Conclusion

Can IOs induce investment in neglected technologies? One feature of neglected technologies is that they tend to serve the under-privileged population who may not be able to commit to a high enough price to make the investment into these technologies profitable for innovators. This paper studies how IOs can solve this commitment problem in technology development. We argue that IOs can leverage their central role in global procurement for aid to create a credible market demand for neglected technologies. Once empowered by the crediblity of market demand, IOs can strategically design their information provision about the priority of difference technologies to substitute for the lack of market demand. This strategy helps channel investment into neglected technologies.

Empirically, we focus on whether and how the WHO can shape the development of vaccine technonolgies. We find that the WHO's information provision on vaccine priority aims to substitute for the lack of credibility in market demand. In terms of the effect of this priority-setting strategy, we find that while the publication of vaccine priority list induced the market entry of vaccines listed as high priority, we do not find evidence that disease with a higher priority experienced increased R&D investment.

This heterogeneity in the effect of the WHO priority reveals both the potential and limit of the WHO's information provision to correct for market failure in technology development. On the one hand, the market creation through the UN procurement system is effective in attracting emerging pharmaceutical firms in developing countries to invest in generic off-patent vaccines. The entry of new vaccine products increases the pool of vaccine products

[18]Of the 48626 patent records related to the infectious diseases under study, 47.3% of the records are Chinese patents.

and could potentially drive down the price of vaccines to be sent to the population in need. On the other hand, the market demand in the UN procurement system may not be enough to induce investment in the initial development of vaccine technologies.

This paper reveals the potential and limit of international institutions in shaping scientific development. New institutional design is needed to promote the investment in these technologies. One of such efforts is the Advance Market Commitments (AMC), which uses innovative funding mechanism to provide vaccine makers a commitment of vaccine purchase based on a pre-specified price and amount once a vaccine is successfully developed. Pneumococcal vaccine is the first vaccine candidate under the AMC, along with COVID vaccine being the second and malaria vaccine under consideration. Future research is needed to understand how this strategy of market commitment shapes the scientific development, which will contribute to our understanding of the role of international institutions in technology development.

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A Procedure of Vaccine Prequalication

To start the prequalification process, manufacturers have to initiating the process by submitting an application to the WHO. However, for a manufacturer to be eligible, the corresponding NRA of the manufacturer must be classified as a functional NRA or WHO-listed authority operating at maturity level 3. This is to ensure the regulatory oversight of the product. After the submission, the WHO will screen the application based on the programmatic suitability (World Health Organization, 2014), which evaluates the characteristics of the vaccine candidate, such as heat stability, presentation, labeling, and shipping conditions. Only when the vaccine candidate is compliant with the compulsory characteristics can the product start the prequalification assessment.[19] The assessment includes a scientific evaluation of evidence, sample testing, and inspection of the manufacturing site. Once a vaccine product is considered to meet all the requirements, it will be included in the WHO List of Prequalified Vaccines.[20]

After a vaccine product passes the prequalification requirements, there is an annual evaluation to ensure the quality and continued compliance with the required standards of the product. If a product fails to meet the post-prequalification testing and reporting requirements, the WHO can withdraw the product from its list of prequalified vaccines. Manufacturer can also withdraw their product from the list due to discontinued production or commercialization.

B Figures and Tables

[19]There are two categories of characteristics: mandatory and critical characteristics. Both categories are compulsory, but if a product deviates from the critical characteristics, the screening procedure will go through a review process involving the manufacturer and procurement agencies to determine whether to accept the application.

[20]Website: https://extranet.who.int/prequal/vaccines/prequalified-vaccines

Table B.1: Disease Distribution and Research Grants

	Dependent variable:							
	NIH Funding (Amount)					ERC (Number)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Inequality (GINI index)	−0.018				−0.001			
	(0.030)				(0.025)			
Severity: N. of outbreaks		0.036				0.022		
		(0.022)				(0.027)		
N. of outbreaks in developing countries			−0.052				−0.015	
			(0.071)				(0.042)	
N. of outbreaks in developed countries			0.081				0.035	
			(0.069)				(0.050)	
Share of outbreaks in developing countries				−0.058				−0.009
				(0.070)				(0.019)
Year FE	N	N	N	N	N	N	N	N
Disease FE	Y	Y	Y	Y	Y	Y	Y	Y
Disease-Specific Trend	Y	Y	Y	Y	Y	Y	Y	Y
Observations	485	485	485	485	599	599	599	599
R^2	0.958	0.958	0.958	0.958	0.780	0.780	0.781	0.780
Adjusted R^2	0.949	0.950	0.950	0.950	0.744	0.744	0.744	0.744

Note: *p<0.1; **p<0.05; ***p<0.01
Standard errors clustered at the disease level in parentheses

Table B.2: Disease Distribution, Patents and Clinical Trials

	Dependent variable:							
	Google Patents					Clinical Trials		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Inequality (GINI index)	−0.023				−0.025			
	(0.057)				(0.035)			
Severity: N. of outbreaks		0.085				0.062**		
		(0.075)				(0.029)		
N. of outbreaks in developing countries			−0.087				−0.057	
			(0.085)				(0.054)	
N. of outbreaks in developed countries			0.164				0.116*	
			(0.131)				(0.061)	
Share of outbreaks in developing countries				−0.060				−0.058
				(0.064)				(0.041)
Year FE	N	N	N	N	N	N	N	N
Disease FE	Y	Y	Y	Y	Y	Y	Y	Y
Disease-Specific Trend	Y	Y	Y	Y	Y	Y	Y	Y
Observations	680	680	680	680	793	793	793	793
R^2	0.907	0.910	0.911	0.908	0.902	0.903	0.904	0.903
Adjusted R^2	0.895	0.898	0.899	0.896	0.890	0.891	0.891	0.890

Note: *p<0.1; **p<0.05; ***p<0.01
Standard errors clustered at the disease level in parentheses

Table B.3: WHO Priority and Clinical Trials: by Funder Type

	Dependent variable:							
	Funded by Industries					Funded by NIH		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Priority (High & Medium)	0.461				0.063			
	(0.363)				(0.258)			
Priority (High & Medium) * Post	−0.354	−0.354	−0.321	−0.181	−0.195*	−0.195*	−0.247	−0.229
	(0.248)	(0.245)	(0.244)	(0.186)	(0.115)	(0.113)	(0.168)	(0.141)
Inequality (GINI index)				−0.017				0.009
				(0.031)				(0.025)
N. of outbreaks in developing countries				−0.091				−0.007
				(0.056)				(0.041)
N. of outbreaks in developed countries				0.153***				0.075*
				(0.055)				(0.040)
Year FE	Y	Y	N	N	Y	Y	N	N
Disease FE	N	Y	Y	Y	N	Y	Y	Y
Disease-Specific Trend	N	N	Y	Y	N	N	Y	Y
Observations	798	798	798	691	798	798	798	691
R^2	0.087	0.765	0.825	0.857	0.025	0.719	0.760	0.815
Adjusted R^2	0.061	0.746	0.801	0.836	−0.002	0.697	0.727	0.788

Note: *p<0.1; **p<0.05; ***p<0.01
Standard errors clustered at the disease level in parentheses

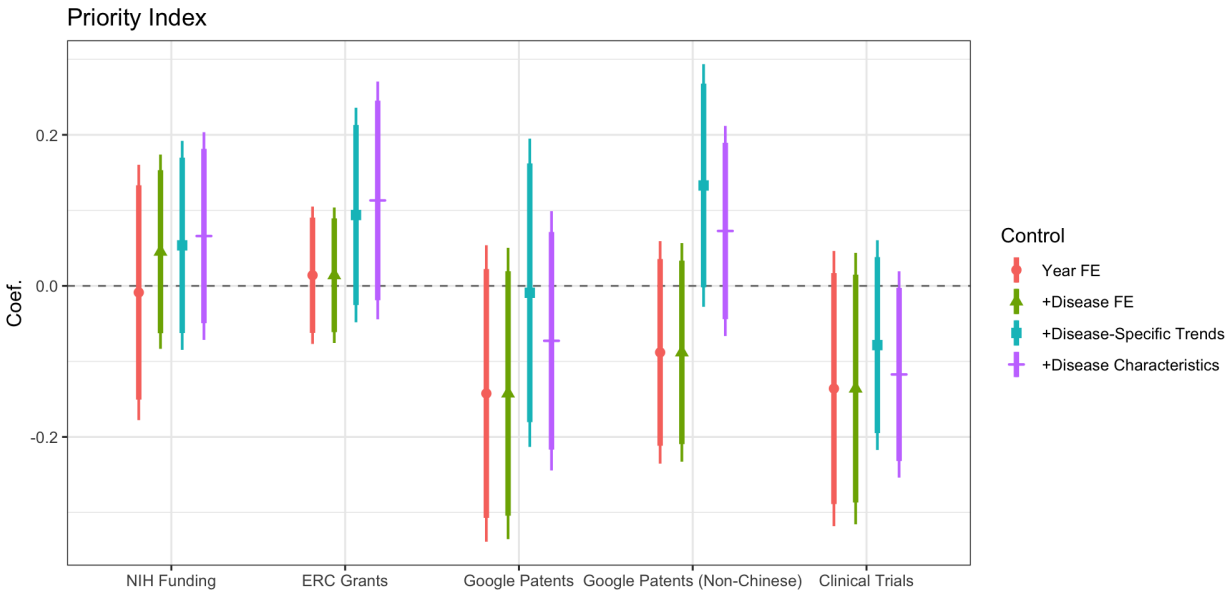

Figure B.1: Vaccine Priority Index and R&D Investment