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Factors associated with COVID-19 vaccination rates in countries with different income levels: a panel analysis

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Abstract

Introduction Vaccines against coronavirus disease (COVID-19) are being developed and supplied at an unprecedented rate. However, disparities in income levels among countries has influenced the supply and vaccination rate. This imbalance poses a potential risk factor, especially if vaccine-resistant variants emerge and the pandemic persists. To effectively combat a global pandemic such as COVID-19, understanding the key factors that influence vaccination rates worldwide is essential. This study utilizes cross-country panel regression to examine the factors associated with vaccination rates in countries at different income levels.

Methods We analyzed weekly vaccination rates in relation to several COVID-related variables, including government suppression policies, vaccination coverage, and search trends from Google Trends. The data consistently spanned from March 2021 to February 2022. Random-effects panel regression models were employed to identify factors linked to weekly vaccination rates by income level. Independent variables included disease status, country characteristics, policy variables, and search trends.

Results Significant disparities in weekly vaccination rates were observed between income-level groups. High-income countries experienced considerable fluctuations during outbreaks, whereas, low- and lower-middle-income countries demonstrated steady increase over time. The random-effects model, stratified by income level, showed that the vaccination coverage and search trend for "COVID-19 vaccine" were commonly associated with higher vaccination rates across all income groups. However, other factors varied based on income level, and gross domestic product per capita was not significant in the regression based on income level.

Conclusion Vaccination rate and their associated factors differed across income levels. There is no universal strategy for boosting vaccination rates during a pandemic. Consequently, country specific approaches, including promotional programs to raise awareness and interest in vaccination, are essential for preparing for future pandemics.

Key messages

What is already known on this topic

The economic status of a country is a key factor associated with its COVID-19 vaccination rate.

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What this study adds

Individual interest in COVID-19 vaccination and vaccination coverage-related policies were positively associated with higher vaccination rates across all income levels. The stringency of COVID-19 mitigation strategies and actual vaccination rates were significantly associated with vaccination rates in high-income countries. In contrast, the Corruption Perceptions Index was significantly associated with vaccination rates in low- and lower-middle-income countries.

How this study might affect research, practice, or policy

An individual's interest in vaccination and disease can predict vaccination rates regardless of income level. Factors associated with vaccination rates vary according to the country's income level. The policy approach should be considered differently depending on the country's income level.

Keywords Public health, Communicable disease control, COVID-19

Introduction

The coronavirus disease (COVID-19) pandemic, which began in early 2020, has led to significant global public health and economic crises [1, 2]. In response, many countries implemented various political measures, including strict lockdowns, social distancing, and vaccination campaigns, to control the outbreak of the pandemic and minimize its impact [3–7]. According to the World Health Organization (WHO), 11 vaccines have been developed and employed since Pfizer's vaccine was first approved in December 2020, 9 months after the WHO declared COVID-19 a pandemic [8]. Vaccine distribution has generally been faster in high-income, and developed countries than in other countries [9]. Substantial differences in the vaccine distribution and vaccination rates have been observed across countries. This inequity in vaccine distribution is a potential barrier to ending the pandemic, affecting economic recovery because of the risk of vaccine-resistant variants emerging in countries with lower vaccination rates [9, 10]. The WHO, have described these vaccination disparities or inequities as threats to global health [11, 12]. It emphasized that achieving vaccine equity, particularly by accelerating vaccination efforts in low- or lower-middle-income countries (LMIC) with relatively lower vaccine distribution and inoculation, could expedite the end of the pandemic. Vaccine equity would increase the immunized population, protect health systems, enhance economic recovery, and reduce the risk of new variants [13, 14].

Over the past four years, vaccination has been the cornerstone of efforts to control COVID-19. Numerous studies have explored factors associated with vaccination rates across different countries throughout the COVID-19 pandemic. A previous systematic review on vaccine inequity summarized both macro- and micro-factors influencing COVID-19 vaccination [9]. Macroscopic studies included reviews focused on economic status, such as gross domestic product (GDP) or the human development index, and consistently reported a strong relationship between income and vaccine distribution. However, previous studies have mainly been conducted in developed countries, where vaccination has reasonably met global standards because of easy data accessibility. In addition, studies focusing on noneconomic factors, such as individual interests, policy stringency, or vaccination coverage, by grouping countries with relatively similar economic statuses, are lacking. Moreover, owing to the cross-sectional design of previous studies, most only showed the factors associated with vaccine distribution and vaccination at specific time points [15–19]. However, COVID-19 has revealed a highly complex history with several outbreaks in the past 3 years of the pandemic, implying a potential dynamic variation in the vaccination rate.

The COVID-19 pandemic has highlighted the need for coordinated global efforts to effectively control the emergence of new variants. Considering possible future pandemics, establishing a policy approach that facilitates rapid vaccination for protection from fatal variants during the early stages of a pandemic is crucial. To address this, we evaluated the impact of various factors on vaccination rates by employing panel data regression across countries with different income levels by combining global vaccination data, Google Trends data, and information on the characteristics of each country.

Material and methods

A framework for panel data

We constructed a balanced panel dataset from March 2021 to February 2022, using weekly analysis units. A total of 153 countries were included in this study. The study period captured the peak outbreak of the delta variant, which was classified as a health concern by the Center for Disease Control and Prevention in June 2021. Additionally, we accounted for the authorization of booster shots by the United States Food and Drug Administration in September 2021 [20, 21].

Our main focus, the vaccination rate, reflects the instantaneous vaccination status of a specific population. Therefore, it changes instantaneously based on medical needs, compared to the monotonically increasing proportion of the vaccinated population. We sourced vaccination rate from Our World in Data, which collects and integrates multiple data sources worldwide, including Johns Hopkins University, Oxford University, and the World Bank [22]. This platform provides comprehensive data on COVID-19 status, suppression policy, and demographic attributes by country, such as GDP or population size. To evaluate the factors influencing vaccination rate, we categorized variables into four categories of variables: individual interest, disease, socioeconomic status, and policy (Table 1).

We incorporated data from Google Trends to represent factors of individual interest. Google Trends provides relative search volumes for specific keywords in selected countries and sub-regions [23, 24], which we used as a proxy variable for population interest [25, 26]. The relative search volume is scaled from 0–100, depending on the popularity of specific search terms in a given region. Additionally, Google Trends offers both cross-sectional comparisons of relative search volume between countries during a given period and weekly volume trends within individual countries, showings the change in interest over time. The relative search volume for each keyword is influenced by the search language, which may cause a bias in countries with two or more official languages. Therefore, we used the relative search volume of pre-specified "Topic" to solve the linguistic limitations, which is validated for various languages by the Google Trends team. Consequently, there are two Google Trends Topics included as a predictor: "COVID-19 Vaccines" and "COVID-19 Diagnosis."

We considered the stringency index and vaccination coverage as policy-related factors. The Oxford Coronavirus Government Response Tracker project provides the stringency index, a composite measure of nine subitems, including school closures, workplace closures, cancellation of public events, restriction on gathering, closure of public transport, stay-at-home requirements, public information campaigns, restrictions on internal movement, and international travel controls [27]. A higher index value indicates stricter mitigation policy at a given time in a country. Vaccination coverage is summarized based on the eligibility for vaccination for three essential groups: key workers, the clinically vulnerable, and the elderly.

Weekly COVID-19 deaths were considered and obtained from Our World in Data. According to a previous systematic review, high willingness to vaccinate is associated with sociodemographic factors and risk perceptions [28]. Weekly deaths varied by country, and the COVID-19 variants reflected the severity of the outbreak, indicating the need for vaccination. We used GDP per capita, population, population density, the proportion of the population aged $\geq$65 years, and the Corruption Perceptions Index (CPI) as socioeconomic factors. The proportion of the population aged $\geq$65 years was included to control for the association between the proportion of the older population, who had been prioritized for vaccination in most countries, and the vaccination rate. The CPI reflects the perceived levels of public-sector corruption in each country and is introduced as a proxy variable for a country's efficiency of governance [29]. In addition, the proportion of essential vaccine administration was considered an index of the perception of vaccination among the population.

Countries were divided into three groups based on the World Bank income level classification: low- and lower-middle-income (low), upper-middle-income (mid), and high-income (high) [30]. We used ISO country codes to the data and excluded regions and countries without matching ISO codes. In addition, countries without key input variables such as GDP or population, those with $<$80% of Google's reported market share, and those with omitted data during the 52 weeks were excluded.

Data analysis

We employed a panel data regression model that considered both longitudinal and cross-sectional associations to investigate the association between various factors and COVID-19 vaccination rates across countries with different income levels. We performed the Im, Pesaran, and Shin (IPS) test or the Harris-Tzavalis test, depending on the number of entities and periods, to ensure data stationarity for the panel regression [31, 32]. A regression model was used to account for differences in income levels, which significantly affected the vaccination rate. We performed the growth curve model fitting for the panel regression to capture the different slopes of the variables among the 153 countries. Although the Hausman test preferred the use of a fixed effects model, we performed a growth curve model fitting (a random effects model; see Supplementary Materials) to capture the different intercepts and slopes of responses according to population interests. In addition, model fitting was performed to ensure that country-level variables including population and GDP, which are highly correlated with vaccine distribution, were not omitted [33]. Moreover, we included weekly new deaths by dividing them into within- and between-country variations because they could vary with both the country and timing (overall standard deviation

Table 1 Description of variables and sources of data

Type	Name	Description	Source
Dependent variable	Weekly COVID-19 new vaccination rate	The seven-day average number of daily doses administered per 10,000 individuals	Our World in Data
Independent variable: Individual interest in COVID-19	COVID-19 diagnosis among countries	The relative search volume of Google Trends Topic "COVID-19 Diagnosis" searched by region from March 2021 to February 2022	Google Trends
	COVID-19 vaccine among countries	The relative search volume of Google Trends Topic "COVID-19 Vaccine" searched by region from March 2021 to February 2022	
	COVID-19 Vaccine-related adverse events among countries	The related search term in Google Trends Topic "COVID-19 Vaccine" searched by region from March 2021 to February 2022, which means that people searched for "adverse event" immediately after searching for "COVID-19 Vaccine"	
	COVID-19 Diagnosis within a country	The output of Google Trends Topic "COVID-19 Diagnosis" searched by time for the specific country from March 2021 to February 2022	
	COVID-19 Vaccine within a country	The output of Google Trends Topic "COVID-19 Vaccine" searched by time for the specific country from March 2021 to February 2022	
Independent variable: Mitigating policy factors	Stringency index	The Oxford Coronavirus Government Response Tracker (OxCGRT) calculates a stringency index, a composite measure of nine of the response metrics (0 ~ 100): school closures, workplace closures, cancellation of public events, restrictions on public gatherings, closures of public transport, stay-at-home requirements, public information campaigns, restrictions on internal movements, and international travel controls	Our World in Data
	Vaccination coverage	Countries are coded into six categories: No availability, availability of one to three of the following: key workers/clinically vulnerable groups/elderly groups, availability for all three groups plus partial additional availability (select broad groups/ages), and universal availability (range: 0–5)	
	Time from first vaccination	Time from the first dose administered in a specific country (day)	
Independent variable: Disease-related factor	Weekly new deaths per 100,000 individuals	The seven-day average number of daily confirmed deaths from COVID-19 per 100,000 people	Our World in Data
Independent variable: Socioeconomic factor	Population	Population of a specific country (log-transformed in the model)	Our World in Data
	Population density	Population per square kilometers	
	GDP per capita	The gross domestic product (GDP) per capita in U.S. dollars (log-transformed in the model)	
	The proportion of those aged ≥ 65 years	The proportion of the total population aged ≥ 65 years in a specific country	
	Corruption perceptions index	The index that scores and ranks countries by their perceived levels of public sector corruption (range: 0–100)	Transparency International
	Essential vaccination rate	The proportion of children of the relevant age category who receive the seven key vaccines (DPT3, measles, polio, Hep3B, Haemophilus influenzae type b, pneumococcal conjugate vaccines, and rotavirus vaccine), conditional on inclusion in the national vaccine schedules	Our World in Data

(SD) 0.34; between SD 0.21; within SD 0.27). This study accounted for rapid variations in the disease status of each country by dividing the number of new deaths per week into within- and between estimators to interpret the coefficients. Consistent with previous studies on COVID-19 that introduced a 7-day lag to reflect the incubation period of the disease, this study also introduced a 7-day lag in the vaccination model because factors such as population behavior or suppression policies may not immediately affect vaccination decisions [34]. For instance, many countries use reservation systems for vaccinations rather than walk-in vaccinations. We analyzed the sensitivity of the lag time with no lag and a 4-week lag to consider the potential differences in policy responses and behavior by country. We used the Stata software (version 17.0; StataCorp LP, College Station, TX, USA).

Results

The panel analysis included data from 153 countries. The panel demographics at baseline (March 2021) are presented in Table 2. There were 67 countries in the low- and lower-middle-income groups, 35 in the upper-middle-income group, and 51 in the high-income group. The dependent variables for each subgroup remained stationary throughout the study period. In March 2021, 0.33% and 1.43% of the total population were vaccinated in low- or lower-middle-income and upper-middle-income countries, respectively, compared to 9.09% in high-income countries were vaccinated during the same period. Figure 1 shows the geographical disparities in individual interests, stringency index of mitigation policy, and vaccine coverage as of March 2021. Figure 1A indicates that people in higher-income countries are more likely to be interested in COVID-19 vaccines than those in low- and lower-middle-income countries. Figure 1B indicates the level of stringency of COVID-19 mitigation strategies in suppressing the disease, with high-income countries implementing stricter policies such as work and school lockdowns than lower-income countries. Finally, Fig. 1C depicts vaccine coverage in March 2021, demonstrating higher coverage in high-income countries to low- or lower-middle-income and upper-middle-income countries.

Figure 2 shows the changes in the weekly average number of vaccinated people per million population over time across income levels of the countries. High-income countries had the highest vaccination rates and showed rapid changes over time, as shown in Fig. 2. Their vaccination rates increased until July 2021, decreased from

Table 2 Panel demographics at the baseline in March 2021

Variables (Mean, SD)	Low- and lower-middle-income countries (*N* = 67)	Upper middle-income countries (*N* = 35)	High-income countries (*N* = 51)
New vaccination per week per 10,000 individuals	2.26 (5.52)	9.97 (18.72)	30.87 (21.36)
Percentage of the total population vaccinated	0.33 (1.35)	1.43 (4.37)	9.09 (11.23)
Disease factor			
Weekly new deaths per 100,000 individuals	0.04 (0.11)	0.31 (0.42)	0.31 (0.38)
Socio-economic factors			
Population (10 million)	58.4 (174)	22.9 (43)	21.3 (48.9)
Population density per km^2	129.15 (190.11)	142.90 (260.72)	354.27 (1,132.28)
GDP per capita (1,000 USD)	4.63 (3.79)	13.88 (4.69)	40.92 (19.70)
The proportion of individuals aged ≥ 65 years (%)	4.27 (2.31)	8.13 (3.80)	14.99 (5.88)
Corruption Perceptions Index	31.10 (9.81)	41.17 (10.46)	63.96 (14.37)
Essential vaccination rate (%)	83.69 (14.50)	92.70 (7.37)	94.40 (5.56)
Mitigating policy factors			
Stringency index (range: 0–100)	47.33 (21.28)	51.50 (26.94)	64.26 (14.42)
Vaccination coverage	0.84 (1.12)	1.27 (1.35)	2.52 (0.99)
Time from first vaccination to panel entry (days)	10.03 (18.27)	22.03 (22.86)	59.70 (24.85)
Individual interest			
COVID-19 Diagnosis among countries	5.42 (4.26)	10.14 (7.29)	31.29 (24.85)
COVID-19 Vaccine among countries	13.62 (15.41)	20.69 (14.40)	28.95 (19.29)
COVID-19 Vaccine-related adverse events among countries	0.84 (1.19)	0.94 (1.73)	1.21 (1.29)
COVID-19 Diagnosis within a country	24.46 (21.65)	22.31 (14.29)	32.16 (21.99)
COVID-19 Vaccine within a country	24.95 (21.49)	31.49 (23.04)	43.69 (26.11)

GDP gross domestic product

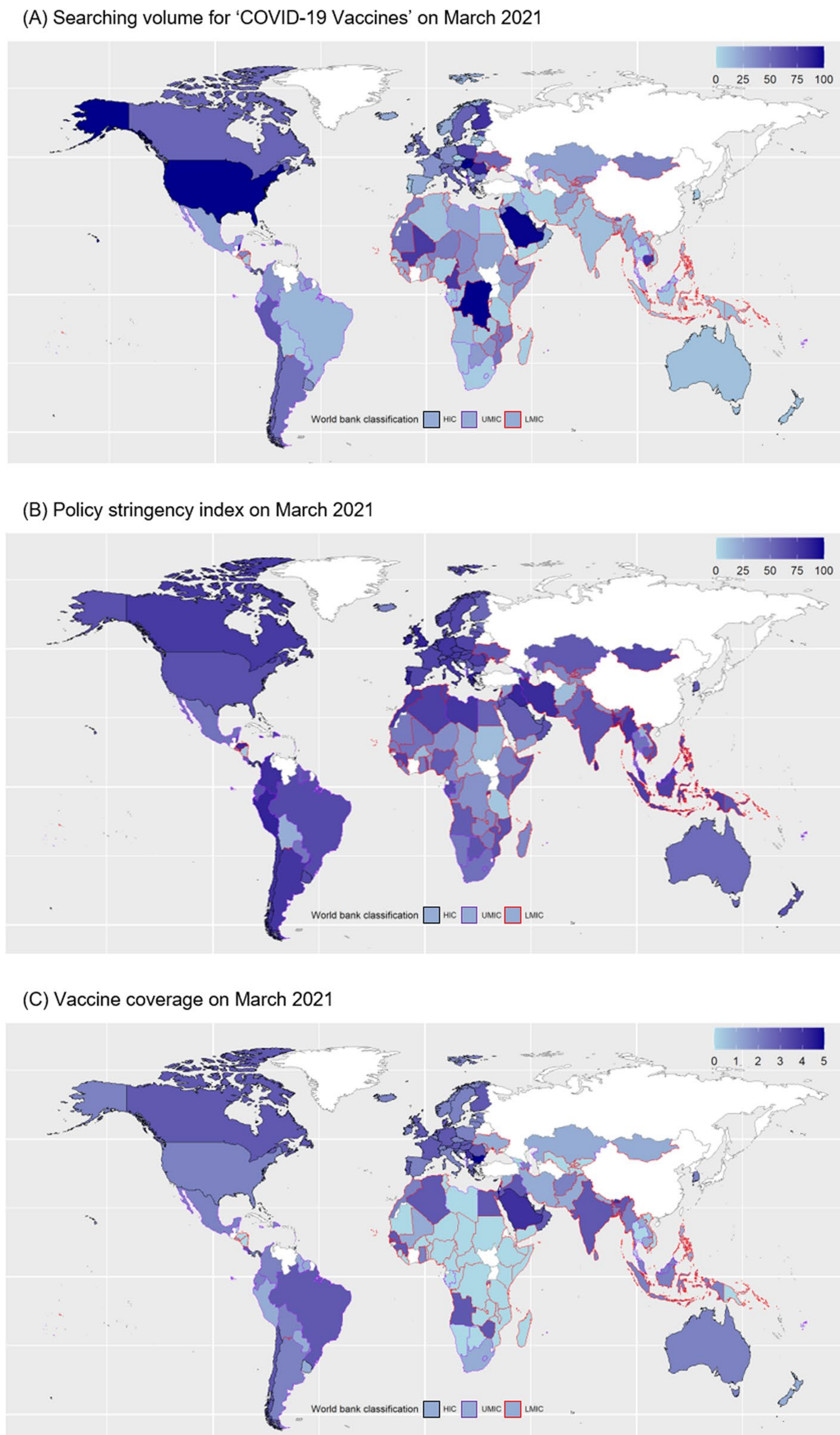

Fig. 1 Baseline characteristics by geographical region in March 2021

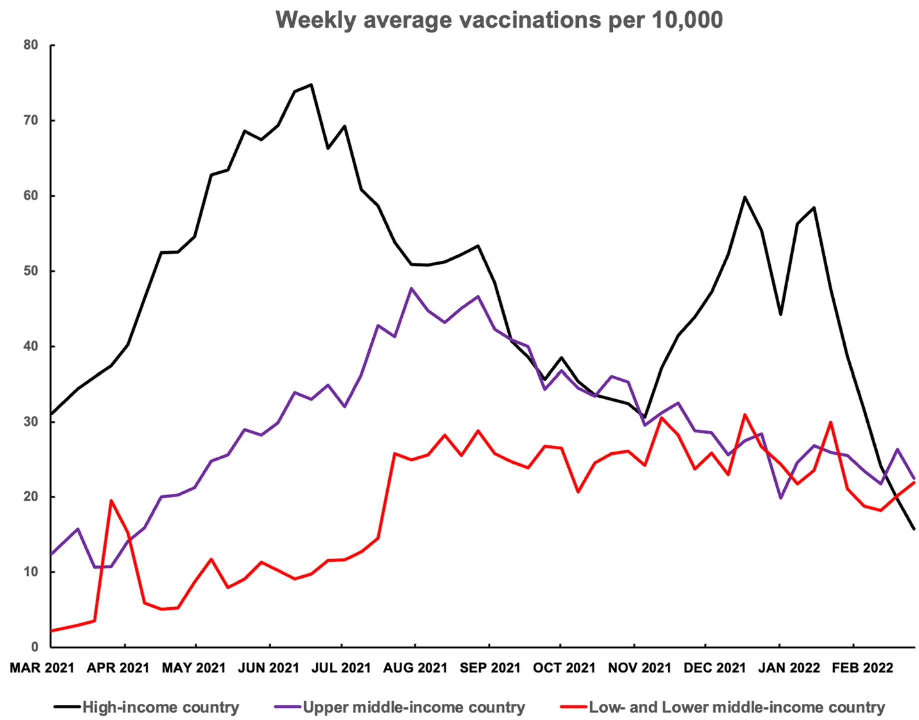

Fig. 2 Weekly average vaccinations per 10,000 individuals

July to November 2021, and increased rapidly from November 2021 to January 2022. By contrast, low- and lower-middle-income countries showed fewer fluctuations without a prominent peak during the panel period. Supplementary Fig. 1 shows the changes in the stringency of COVID-19 mitigation strategies over time, with high-income countries initially having higher stringency levels, but decreasing to levels similar to those of other countries by the end of the follow-up period. Concerning population interest, the relative search volume for COVID-19 vaccines increased slightly until the middle of 2021, then consistently decreased (Supplementary Fig. 2).

Table 3 presents the impact of various factors on vaccination rates across countries with different income levels as estimated from the panel analysis. A positive association was observed between searching for COVID-19 vaccines within the country was observed across all income groups. This indicates that countries with higher individual interests had higher vaccination rates, and more intensive searches led to higher vaccination rates. The association between vaccination rate and searching for "COVID-19 vaccine" increased by income level (0.341 in low- and lower-middle-income countries, 0.564 in upper-middle-income countries, and 0.678 in high-income countries). Adverse events were associated with a lower vaccination rate only in high-income countries. The coefficient of COVID-19 diagnosis within a country showed a positive association in high-income countries (0.1); however, it was negative in upper-middle-income countries (−0.131). The between-country estimator of COVID-19 diagnosis was negatively associated with the vaccination rate only in high-income countries (−0.202).

Stringent mitigation policies were associated with higher vaccination rates only in high-income countries (0.369). However, wider vaccination coverage was consistently related to a high vaccination rate, and the magnitude of the impact increased by the income group (1.459, 2.553, and 6.330 in the low-income, upper-middle-income, and high-income groups, respectively). Among the disease factors, countries with higher weekly deaths were likely to have lower vaccination rates than the other countries in the high-income group (−20.90). However, no such tendency was observed in the other income groups. In contrast, more people were administered the vaccine in a specific high-income country when more patients died (4.270). The same tendency, but with a higher coefficient magnitude within a country, was observed in low- or lower-middle-income countries (14.880). Only high-income member countries of the Organization for Economic Co-operation and Development (OECD) were likely to have higher vaccination rates than the non-OECD countries (13.570). Population and GDP were not associated with vaccination rates, whereas population density was associated with higher

Table 3 Factors associated with the new vaccination rate by income level

Variables	Coefficient (standard error)		
	Low- and lower-middle-income countries (*N* = 67)	**Upper middle-income countries (*N* = 35)**	**High-income countries (*N* = 51)**
Individual interest			
COVID-19 Vaccines			
Within a country	**0.341*** (0.030)**	**0.564*** (0.028)**	**0.678*** (0.028)**
Among countries	0.157 (0.118)	**0.328** (0.156)**	0.045 (0.090)
Adverse events among countries	−0.967 (1.422)	−0.368 (1.608)	**−2.246** (1.142)**
COVID-19 Diagnosis			
Within a country	−0.043 (0.027)	**−0.131*** (0.025)**	**0.102*** (0.027)**
Among countries	−0.546 (0.476)	−0.564 (0.396)	**−0.202*** (0.056)**
Mitigating policy factors			
Stringency index	0.023 (0.052)	0.022 (0.045)	**0.358*** (0.046)**
Vaccination coverage	**1.459** (0.594)**	**2.553*** (0.558)**	**6.330*** (0.776)**
Time from first vaccination	**0.064*** (0.008)**	**0.044*** (0.007)**	**−0.031*** (0.007)**
Disease-related factors			
Weekly new deaths per 100,000			
Within a country	**14.880*** (5.752)**	1.249 (1.156)	**4.270** (1.773)**
Among countries	0.570 (27.830)	−6.009 (11.010)	**−20.90*** (7.827)**
Socio-economic factors			
OECD (ref. non-OECD country)		−3.895 (8.627)	**13.570*** (4.006)**
Population	−0.926 (1.125)	2.412 (1.476)	−0.749 (0.886)
Population density	0.016 (0.011)	**0.024** (0.010)**	0.001 (0.001)
GDP per capita	0.291 (1.302)	3.906 (5.933)	2.785 (4.336)
The proportion of those aged ≥ 65 years	1.398 (1.316)	0.470 (0.655)	0.305 (0.315)
Corruption Perceptions Index	**0.536*** (0.201)**	0.301 (0.255)	0.0474 (0.132)
Essential vaccination rate	0.201 (0.126)	0.322 (0.296)	0.266 (0.233)
Constant	**−32.69 (21.94)**	**−122.8** (61.12)**	**−64.18 (49.91)**
Rho	0.106	0.209	0.0757

GDP gross domestic product, *OECD* Organization for Economic Co-operation and Development

* *P*-value < 0.1

** *P*-value < 0.05

*** *P*-value < 0.01

vaccination rates in upper-middle-income countries. Moreover, in low-income and lower-middle-income countries, higher CPI, which indicates less perceived corruption in the public sector, was associated with higher vaccination rates.

From the sensitivity analyses using all countries in a single model adjusting for income level as a categorical variable, searching for the COVID-19 vaccine both within and between countries was still associated with higher vaccination rates (Supplementary Table 1). Moreover, the stringency of mitigation policies, vaccination coverage, and elapsed time since vaccination were also significantly associated with higher vaccination rates. Additionally, the proportion of individuals aged ≥ 65 years and the essential vaccination rate were associated with higher vaccination rates in the overall model, which remained non-significant in separate models fitted to each income group. The CPI, which was only significant in the LMIC model, was found to be associated with the vaccination rate in the overall model. Supplementary Tables 2 and 3 show the sensitivity analyses using lag times of 0 and 4 weeks for Google Trends, which generally remained consistent with the initial findings regarding the direction and magnitude of the coefficients.

Discussion

In this study, we assessed the impact of various factors on vaccination rates using panel regression models based on income level. Each income level group showed noticeable differences in vaccination patterns. Our regression model included individual interests, mitigating policy factors, disease-related factors (e.g., weekly new death), and socio-economic factors. The results showed that the directions of the relationship were consistent across the income-level groups in general. However, it is important to note discrepancies in contributing factors across the income groups. For example, CPI was significant only in LMICs, which indicated that the more corruption regarding governance perceived in LMICs, the fewer people would be vaccinated.

On the other hand, the stringency index showed positive association only in high-income countries, meaning more strict mitigation policies associated with higher vaccination rates, which might indicate that there could be underlying needs for governance or the healthcare system to implement the stringent mitigation policies successfully. Consequently, these findings suggest that there have been different structural barriers across the income group of countries, which require implementing different approaches. Despite discrepancies in other contributing factors, individual-level interest, and vaccination coverage consistently showed a positive relationship with vaccination rates in all income groups of countries. This implies that increasing public awareness and expanding vaccination coverage could be a universal approach to promoting vaccination rates.

Previous systematic reviews have reported that increasing knowledge, perceived risk of COVID-19, and perceived severity are key factors that boost vaccine acceptance [35]. Another umbrella review of systematic review found that vaccine hesitancy underscored the need for tailored interventions and credible information to promote acceptance [36]. Some studies have used Google Trends to identify the association between interests quantified by relative search volume and COVID-19-related research topics [37–39]. Maugery et al. [38] suggested that Google Trends provides insights into fears and concerns regarding vaccination. Maugeri et al. reported moderate-to-strong correlations between the search volume of vaccine-related terms and COVID-19 vaccination in Italy [38], consistent with our finding that individuals' interest in vaccination within a country was associated with vaccination, regardless of income level. This finding suggests that public awareness campaigns regarding vaccines could be helpful as a universal tool to increase vaccination rates within a country. Interestingly, the search volume for adverse events and diagnoses was associated with vaccination rates in high-income countries. In other words, a country with a higher search volume has a lower vaccination rate.

Bayati et al. [9] reviewed several studies on the macro determinants of inequality in COVID-19 vaccine distribution and consistently reported GDP as the primary determinant of vaccine distribution [15–18]. Generally, the income level of a country is a well-known facilitator of vaccine distribution and vaccination. As shown in Fig. 2, a relatively rapid increase in vaccination rate was observed in high-income countries during increased temporary demand in the study period, such as during the outbreak of delta variants or the authorization of booster shots, based on relatively sufficient medical resources and a smooth supply of vaccines. Pronkina et al. [40] reported a gap in the vaccination rate among European countries and insisted that this gap was affected by lower social capital rather than the first wave of the pandemic or general exposure to vaccines. Although GDP per capita was not significant in our analysis, our analysis showed the CPI was significant in LMIC, which reflects the efficiency of a country's governance [29], and whether the country is a member of OECD was also significant in high-income countries. Furthermore, according to the results from the overall model (Supplementary Table 1), after adjusting for income level, GDP per capita remained non-significant, whereas CPI was associated with a higher vaccination rate. This indicates that the population's willingness to be vaccinated can vary based on their general perception or trust in the public sector. This is consistent with previous findings on vaccine hesitancy due to the development process of the COVID-19 vaccine, which has been developed and approved much faster with minimal evidence than any other vaccine [41, 42]. Therefore, our findings could have supported previous findings regarding social capital by including CPI in our model.

Although there was no homogeneous definition of death from COVID-19, particularly death 'with' or 'due to' COVID-19 [43, 44], several studies have reported correlations between the stringency of COVID-19 mitigation strategies and COVID-19 outcomes, such as mortality and the number of confirmed cases [45–49]. Our results indicate a significant association between vaccination rates and the stringency of COVID-19 mitigation strategies, but only in high-income countries. This can be attributed to several factors, including better healthcare systems, infrastructure, and vaccine availability, all of which enable the successful implementation of stringent policies. For example, high-income countries have better capability to implement vaccine passports in combination with stringent mitigation policies due to relatively higher vaccine availability and vaccinated population than other countries, which may strengthen the association between stringency index and vaccination rate in high-income countries [50–53]. Furthermore, populations in these countries generally have a higher level of trust in government than populations in LMICs, as shown in CPI, making them more likely to adhere to strict mitigation policies such as lockdowns, social distancing, and vaccine mandates because they trust the government [54].

During the global pandemic, several studies on the factors associated with COVID-19 vaccination were published. Nonetheless, our study has distinct strengths owing to its design. Along with several outbreaks by different variants of COVID-19, vaccines have been introduced sequentially, and recommendations were changed over time. Therefore, it was necessary to use a panel regression approach that could be generalized rather than the correlation at a specific point of observation to assess the factors associated with the dynamically changing COVID-19 vaccines.

Despite these advantages, some limitations require caution when interpreting our findings. First, since only commonly observed and reported variables across various countries were analyzed, some relevant variables may have been omitted. In addition, several countries, including China, Japan, and Russia, were excluded because either the variables were not reported or the individual level interest factors were not generalizable, owing to the low market share of data sources. Additionally, the factors specific to Google and those associated with these countries may also have been excluded. However, because our study included most of the major variables of previous studies analyzed at the country level and most of the cultural regions, the impact of the omitted variables or excluded countries is expected to be limited. Second, there are limitations regarding the variables and regression model. Although we included a 1-week lag in Google Trends data to capture the relationship between search trends and vaccination rates, this cannot be interpreted as causality because the model was not designed for causal inference. Additionally, the varying time gaps between web bookings and actual vaccinations across countries make it difficult to determine an appropriate lag time. However, our model still demonstrated a strong association between search trends and vaccination rates across different lag times in sensitivity analyses. Third, time-varying factors may have influenced this association throughout the pandemic. While we included new weekly deaths as a proxy for changing pandemic conditions, we could not fully capture the evolving contributing factors to guide policy adjustments to improve vaccination rates; this warrants further research. Fourth, despite evidence indicating that Google Trends reflects the interests of the population, there may be bias as it is a proxy variable for interest. To minimize this bias, we assessed countries where Google's market share was greater than 80% of all search engines so that Google search users were representative of that country's population. Finally, the stringency index, which was used as a variable for overall quarantine policies such as social distancing, is an aggregated variable that summarizes the stringency of the policy. While this index captures the broader policy environment and facilitates standardized comparisons across countries, certain policies that significantly influence vaccination rates may not be fully represented. For example, studies from individual countries or regions (e.g., Israel, Hong Kong, Poland and Lithuania) suggest that policies like vaccine passports, which restrict access to public spaces for unvaccinated individuals, may have substantially impacted vaccination rates [51–53]. However, the stringency index used in our study does not explicitly account for implementing vaccine passports. Nonetheless, their impact may be indirectly captured by the index because the effectiveness of vaccine passports is closely tied to restricting unvaccinated individuals' access to public spaces—an aspect aligned with stringent mitigation strategies. Although we believe the potential bias from this limitation is likely minimal, the aggregated nature of the stringency index posed challenges in isolating the effects of specific policies, which remains a limitation of our study. Future research aiming to evaluate the impact of individual policies may benefit from more granular policy data, and developing standardized datasets on specific policies will be essential for assessing mitigation strategies and improving preparedness for future pandemics.

Conclusion

Simultaneous identification of the factors associated with vaccination rates by income class is essential to increase global vaccination rates. This study demonstrated that the factors associated with vaccination rates varied according to the income level. Unlike all other groups, governance contributed to the vaccination rate in low- or lower-middle-income countries, but the policy stringency was insignificant. This finding suggests the need for a tailored approach to increase vaccination rates to overcome future pandemics rapidly. Concurrently, our study showed that expanding vaccination coverage through a rapid supply and promotion of public awareness through public campaigns could be a universal approach, regardless of the country's income level. Nevertheless, the determinants of vaccination rates remain unknown, and further research on the differences in the factors associated with vaccination rates among countries is needed from an equity perspective.

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

JYC, SHK, JSL, JHL, YC and EKL conceived of the presented idea. JYC and JSL collected the data for analysis. EKL and JL verified the analytical methods. JYC, JSL and SHK performed data management and analysis. JYC and SHK drafted manuscript and the other authors (JSL, JL, JHL, YC, and EKL) contributed review and editing. EKL supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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Data availability

The data supporting the findings of this study are openly available in Our World In Data at https://ourworldindata.org and Google Trends at https://trends.google.com. The R and STATA packages used in this study are publicly available and can be accessed via CRAN or an internal STATA repository, respectively.

Declarations

Ethics approval and consent to participate

This study does not involve human participants, material, or data. Therefore, it is not subject to ethical approval and informed consent in accordance with the Declaration of Helsinki and the guidance of the ethics committee at Sungkyunkwan University. All datasets used in the study are openly accessible, ensuring adherence to ethical research standards.

Consent for publication

Not applicable for this study, as it does not contain any individual data or identifiable personal information.

Competing interests

The authors declare no competing interests.

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References

1. Andersen KG, Rambaut A, Lipkin WI, Holmes EC, Garry RF. The proximal origin of SARS-CoV-2. Nat Med. 2020;26(4):450–2.
2. Zhou P, Yang XL, Wang XG, Hu B, Zhang L, Zhang W, et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. Nature. 2020;579(7798):270–3.
3. Arakpogun EO, Rodrigo P, Olan F. "You Shall Not Pass" without a jab: an institutional theory perspective to COVID-19 vaccine passport policies. Int J Environ Res Public Health. 2022;19(21):14105.
4. Książek R, Kapłan R, Gdowska K, Łebkowski P. Vaccination schedule under conditions of limited vaccine production rate. Vaccines (Basel). 2022;10(1):116.
5. Secco EL, Conte S. To lockdown or not to lockdown: analysis of the EU lockdown performance vs. COVID-19 outbreak. Front Med Technol. 2022;4:981620.
6. Muttamba W, O'Hare BA, Saxena V, Bbuye M, Tyagi P, Ramsay A, et al. A systematic review of strategies adopted to scale up COVID-19 testing in low-, middle- and high-income countries. BMJ Open. 2022;12(11):e060838.
7. Fink G, Tediosi F, Felder S. Burden of Covid-19 restrictions: National, regional and global estimates. EClinicalMedicine. 2022;45:101305.
8. Organization WH. WHO Director-General's opening remarks at the media briefing on COVID-19. 2020. Available from: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020. [updated 11 March 2020].
9. Bayati M, Noroozi R, Ghanbari-Jahromi M, Jalali FS. Inequality in the distribution of Covid-19 vaccine: a systematic review. Int J Equity Health. 2022;21(1):122.
10. Rydland HT, Friedman J, Stringhini S, Link BG, Eikemo TA. The radically unequal distribution of Covid-19 vaccinations: a predictable yet avoidable symptom of the fundamental causes of inequality. Human Soc Sci Commun. 2022;9(1):61.
11. World Health Organization. Director-General's opening remarks at the media briefing on COVID-19. 2021. Available from: https://www.who.int/director-general/speeches/detail/director-general-s-opening-remarks-at-the-media-briefing-on-covid-19-7-june-2021.
12. World Health Organization. WHO Director-General's opening remarks at the media briefing on COVID-19. 2020. Available from: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020. [updated 11 March 2020].
13. World Health Organization. Vaccine equity. 2022. Available from: https://www.who.int/campaigns/vaccine-equity. [updated April 2022].
14. Organization WH. Vaccine equity. 2022. Available from: https://www.who.int/campaigns/vaccine-equity. [updated April 2022].
15. Basak P, Abir T, Al Mamun A, Zainol NR, Khanam M, Haque MR, et al. A global study on the correlates of Gross Domestic Product (GDP) and COVID-19 vaccine distribution. Vaccines (Basel). 2022;10(2):266.
16. Kazemi M, Bragazzi NL, Kong JD. Assessing inequities in COVID-19 vaccine roll-out strategy programs: a cross-country study using a machine learning approach. Vaccines (Basel). 2022;10(2):194.
17. de Oliveira BRB, da Penha Sobral AIG, Marinho MLM, Sobral MFF, de Souza MA, Duarte GB. Determinants of access to the SARS-CoV-2 vaccine: a preliminary approach. Int J Equity Health. 2021;20(1):183.
18. Duan Y, Shi J, Wang Z, Zhou S, Jin Y, Zheng ZJ. Disparities in COVID-19 vaccination among low-, middle-, and high-income countries: the mediating role of vaccination policy. Vaccines (Basel). 2021;9(8):905.
19. Ali Roghani. The relationship between macro-socioeconomics determinants and COVID-19 vaccine distribution. AIMS Public Health. 2021;8(4):655.
20. CDC. SARS-COV-2 variant classifications and definitions. Centers for Disease Control and Prevention; 2022. Available from: https://www.cdc.gov/coronavirus/2019-ncov/variants/variant-classifications.html. [updated Apr. 26. 2022].
21. FDA. FDA authorizes booster dose of Pfizer-BioNTech COVID-19 vaccine for certain population. U.S. Food and Drug Administration; 2021. Available from: https://www.fda.gov/news-events/press-announcements/fda-authorizes-booster-dose-pfizer-biontech-covid-19-vaccine-certain-populations. [updated September 22, 2021].
22. Coronavirus Pandemic (COVID-19). OurWorldInData.org. 2020. Available from: https://ourworldindata.org/coronavirus. [cited 2023–02–01].
23. COVID-19 Vaccines. 2022. Available from: https://trends.google.com/trends/explore?date=2021-03-01%202022-02-28&q=%2Fg%2F11j8_9sv06. [cited 2022–03–02].
24. COVID-19 Diagnosis. 2022. Available from: https://trends.google.com/trends/explore?date=2021-03-01%202022-02-28&q=%2Fg%2F11j8qdq0kc. [cited 2022–03–02].

25. Barros JM, Duggan J, Rebholz-Schuhmann D. The application of internet-based sources for public health surveillance (infoveillance): systematic review. J Med Internet Res. 2020;22(3):e13680.
26. Zeraatkar K, Ahmadi M. Trends of infodemiology studies: a scoping review. Health Info Libr J. 2018;35(2):91–120.
27. Hale T, Angrist N, Goldszmidt R, Kira B, Petherick A, Phillips T, et al. A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker). Nat Hum Behav. 2021;5(4):529–38.
28. Terry E, Cartledge S, Damery S, Greenfield S. Factors associated with COVID-19 vaccine intentions during the COVID-19 pandemic; a systematic review and meta-analysis of cross-sectional studies. BMC Public Health. 2022;22(1):1667.
29. Lu W-M, Kweh QL, Nourani M, Lin C-Y. Political governance, corruption perceptions index, and national dynamic energy efficiency. J Clean Prod. 2021;295:126505.
30. World Development Indicators 2021. World Bank; 2021. Available from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.
31. Harris RDF, Tzavalis E. Inference for unit roots in dynamic panels where the time dimension is fixed. J Econom. 1999;91(2):201–26.
32. Im KS, Pesaran MH, Shin Y. Testing for unit roots in heterogeneous panels. J Econom. 2003;115(1):53–74.
33. Hausman JA. Specification tests in econometrics. Econometrica. 1978;46(6):1251–71.
34. Guo Y, Li B, Duan T, Yao N, Wang H, Yang Y, et al. A panel regression analysis for the COVID-19 epidemic in the United States. PLoS ONE. 2022;17(8):e0273344.
35. Abate BB, Tilahun BD, Yayeh BM. Global COVID-19 vaccine acceptance level and its determinants: an umbrella review. BMC Public Health. 2024;24(1):5.
36. Rahbeni TA, Satapathy P, Itumalla R, Marzo RR, Mugheed KAL, Khatib MN, et al. COVID-19 vaccine hesitancy: umbrella review of systematic reviews and meta-analysis. JMIR Public Health Surveill. 2024;10:e54769.
37. Hu D, Lou X, Xu Z, Meng N, Xie Q, Zhang M, et al. More effective strategies are required to strengthen public awareness of COVID-19: evidence from google trends. J Glob Health. 2020;10(1):011003.
38. Maugeri A, Barchitta M, Agodi A. Using google trends to predict COVID-19 vaccinations and monitor search behaviours about vaccines: a retrospective analysis of Italian data. Vaccines (Basel). 2022;10(1):119.
39. Pullan S, Dey M. Vaccine hesitancy and anti-vaccination in the time of COVID-19: a google trends analysis. Vaccine. 2021;39(14):1877–81.
40. Pronkina E, Berniell I, Fawaz Y, Laferrère A, Mira P. The COVID-19 curtain: can past communist regimes explain the vaccination divide in Europe? Soc Sci Med. 2023;321:115759.
41. Machingaidze S, Wiysonge CS. Understanding COVID-19 vaccine hesitancy. Nat Med. 2021;27(8):1338–9.
42. Rosenthal S, Cummings CL. Influence of rapid COVID-19 vaccine development on vaccine hesitancy. Vaccine. 2021;39(52):7625–32.
43. Cioffi A, Cecannecchia C. Death, "With" COVID-19 and "Due to" COVID-19 from the medico-legal point of view. Med Sci Law. 2022;62(4):296.
44. Slater TA, Straw S, Drozd M, Kamalathasan S, Cowley A, Witte KK. Dying 'due to' or 'with' COVID-19: a cause of death analysis in hospitalised patients. Clin Med (Lond). 2020;20(5):e189–90.
45. Sun J, Kwek K, Li M, Shen H. Effects of social mobility and stringency measures on the COVID-19 outcomes: evidence from the United States. Front Public Health. 2021;9:779501.
46. Spiliopoulos L. On the effectiveness of COVID-19 restrictions and lockdowns: pan metron ariston. BMC Public Health. 2022;22(1):1842.
47. Fuller JA, Hakim A, Victory KR, Date K, Lynch M, Dahl B, et al. Mitigation policies and COVID-19-associated mortality - 37 European countries, January 23-June 30, 2020. MMWR Morb Mortal Wkly Rep. 2021;70(2):58–62.
48. Yang P, Yang Z, Zhao C, Li X, Shao Z, Liu K, et al. Vaccination and government stringent control as effective strategies in preventing SARS-CoV-2 infections: a global perspective. Front Public Health. 2022;10:903511.
49. Park M-B, Ranabhat CL. COVID-19 trends, public restrictions policies and vaccination status by economic ranking of countries: a longitudinal study from 110 countries. Arch Public Health. 2022;80(1):197.
50. Cioffi A, Cecannecchia C. Can vaccine adherence against Sars-CoV-2 become a criterion for access to medical care? Med Leg J. 2023;91(1):30–2.
51. Kamin-Friedman S, Peled RM. Lessons from Israel's COVID-19 Green Pass program. Isr J Health Policy Res. 2021;10(1):61.
52. Qiu H, Zhao S, Cheung AW, Yeoh EK, Wong EL. Association of vaccine pass policy and omicron incidence with COVID vaccine uptakes in Hong Kong. J Travel Med. 2023;30(5):taad061.
53. Walkowiak MP, Walkowiak JB, Walkowiak D. More Time, carrot-and-stick, or piling coffins? Estimating the role of factors overcoming COVID-19 Vaccine hesitancy in Poland and Lithuania in the years 2021–2022. Vaccines (Basel). 2022;10(9):1523.
54. Han Q, Zheng B, Cristea M, Agostini M, Bélanger JJ, Gützkow B, et al. Trust in government regarding COVID-19 and its associations with preventive health behaviour and prosocial behaviour during the pandemic: a cross-sectional and longitudinal study. Psychol Med. 2023;53(1):149–59.

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