Testing Club Convergence in COVID-19 Vaccine Doses Administered in the United States

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Abstract

The development of vaccines is considered an important public health tool to combat the spread of the COVID-19 virus globally. And this study examines whether convergence exists in COVID-19 vaccinations across U.S. states and territories. We employed the club convergence test and data on the number of COVID-19 vaccine doses administered daily from December 13, 2020, to October 11, 2022. This yields balanced panel data covering all 50 U.S. states, the District of Columbia (D.C.), and 8 U.S. territories with 39 412 observations. The empirical result shows a lack of support for the overall convergence in the data. We employed the club clustering algorithm to check whether club convergence exists in the sample. And the results identify two initial convergence clubs and a divergence group in COVID-19 vaccinations across U.S. states and territories. Finally, we performed a club merger test because of the possible overestimation of the number of clubs. This resulted in identifying one final convergence club and a divergence group in the sample. The evidence supporting the lack of overall convergence in the data implies that the states/territories with lower COVID-19 vaccination rates are not catching up with those with higher vaccination rates over time. Also, a convergence club means that states/territories in the club with lower vaccination rates are catching up with those with higher vaccination rates over time. Therefore, increasing vaccination rates might require specific interventions targeting states and territories within the convergence club.

Keywords: COVID-19, Convergence, Divergence, Panel data, Vaccine, United States

JEL Classification: C01, C54, F63, I1

1. Introduction

The outbreak of syndrome coronavirus 2, also known as the COVID-19 pandemic, in the last quarter of 2019 has kept the world on tenterhooks due to its severe life threat and high contagion rate. According to WHO (2022), the global weekly death from the COVID-19 virus rose to about 100,000 cases in January 2021. And the development of vaccines is considered an essential public health tool to relieve health and safety concerns and reopen economic activities globally (UNDP, 2021). After successful clinical trials, Pfizer announced the first COVID-19 Vaccine in the last quarter of 2020. This was followed by the release of Moderna and Johnson & Johnson vaccines in early 2021. Besides these three vaccines, other vaccines released in 2021 include Oxford -AstraZeneca, Janssen, Sputnik light, and many more globally. However, as noted by Tevdovsk et al. (2022), vaccination started only in 54 countries at the end of January 2021, which later increased to 160 countries at the end of March 2021. Since the release of the vaccines, the weekly global death cases have reduced to about 10000 cases as of November 2022 (WHO, 2022).

In the United States, the Center for Disease Control and Protection (CDC) only approves three vaccines to be administered nationwide: Pfizer, Moderna, and John & Johnson. The Pfizer vaccine received approval in early December 2020, while Moderna and Johnson & Johnson vaccines received approval in the first quarter of 2021. Subsequently, the CDC approved the monovalent booster dose in the third quarter of 2021, following evidence that the Vaccine's efficacy wanes over time due to new variants. [1] Subsequently, bivalent boosters were also recommended in the last quarter of 2022, at least 2 months after completing their series or the latest monovalent booster dose from age 5 and older. Hence, the share of the U.S. population fully vaccinated as of October 2022 is about 68%, translating to 227 million (CDC, 2022). The available data also show that 80% of the U.S. population have received at least one dose, while 49% have received the booster dose as of Oct.2022. To show more context, Figure 1 provides insights into the trend in COVID-19 vaccine doses administered daily in the U.S. from Dec. 2020-Oct. 2022 and Figures 2A and 2B reveal the total daily shot administered across all the U.S. states and territories in the same period. Figure 1 shows a declining trend in the number of shots administered

[1] According to the CDC recommendation, all U.S. population that received the primary doses are eligible to receive the booster.

across the U.S. population, as daily doses decrease faster than shots administered at the beginning. Also, Figures 2A and 2B show vast variations in the total shots of COVID-19 vaccines administered daily across the U.S. states and territories from Dec. 2020-Oct.2022.

Given the disparities in daily doses of vaccines administered across the U.S. states and territories (as shown in Figures 2A and 2B), policymakers are most concerned about whether such differences increase or decrease significantly over time. And convergence hypothesis provides the empirical frameworks to understand this dynamic. The convergence hypothesis is related to the neoclassical growth theory often used to understand whether differences in economic indicators, such as per capita income across economies, countries, or regions, increase or decrease over time (Sala-i-Martin, 1996). Besides per capita income, the concept has also been applied to agriculture's total factor productivity index, per capita calorie intake, income inequality, poverty rate, carbon emission, crime rate, human development index, research & development, COVID-19 cases, and COVID-19 vaccination rates (Ogundari and Ito, 2015; Bai et al., 2019; Ogundari 2022; Apergis et al., 2018; Ravallion 2012; Sala-i-Martin 1996; Regmi et al., 2008; Jorda and Sarabia 2015; Churchill et al., 2022; Xu et al., 2022).

Four widely used tests for investigating convergence hypotheses are beta convergence, sigma convergence, cointegration and unit root test, and club convergence test. However, unlike the club convergence test, the inability of the other three methods to identify convergence when individuals can converge to multiple steady-state equilibria has been recognized as one of the limitations of these methods (Philip and Sul 2007). Also, Philip and Sul (2007) noted that the club convergence club test proposed by them is flexible concerning the time series properties of the variables under analysis and does not impose any particular assumption about them. This observation motivated the choice of the club convergence test in the present study. Hence, we test the convergence hypothesis using the methodology developed by Philip and Sul (2007). The method is closely related to the standard sigma convergence analysis that tests for the decline of the variable of interest over time in the cross-sectional dispersion.

The paper examines whether convergence exists in COVID-19 vaccinations across U.S. states and territories. And evidence supporting the convergence hypothesis means the disparities or differences in COVID-19 vaccinations across U.S. states and territories decrease over time, which implies higher vaccination rates. In contrast, divergence means the differences in COVID-

19 vaccinations across the U.S. states and territories increase over time, which implies lower vaccination rates. Alternatively, a decrease in the disparities in COVID-19 vaccinations across the U.S. states and territories suggests states and territories with the least vaccinated individuals administered more shots than those with the most vaccinated population over time, while an increase suggests otherwise.

And from a policy point of view, we believe the analysis of convergence in COVID-19 vaccinations provides important insights into public health efforts to achieve herd immunity against the virus through vaccinations in the United States.

[FIGURE 1 HERE]

[FIGURE 2A HERE]

[FIGURE 2B HERE]

2. Methodology

2.1. The data sources and description

The empirical analysis relied on the Center for Disease Control and Protection (CDC) data on the number of COVID-19 vaccine doses administered daily across the U.S., covering December 13, 2020, to October 11, 2022, thus making 668 days. The balanced panel data covers all 50 U.S. states, the District of Columbia (D.C.), and 8 U.S. territories, totaling 39 412 observations. And the data is publicly available through this link: https:// covid. cdc. gov/ covid- data- track er/#vacci natio ns_ vacc- total- admin- rate- total [4].

While Figure 1 provides insights into the trend in COVID-19 vaccinations in the U.S. from Dec. 2020-Oct. 2022, Figures 2A and 2B reveal the total daily shot administered across the U.S. states and territories in the same period. Most U.S. territories (PW, MH, MP, AS, VI, FM, GU, and WY) administered less than a million doses, as revealed in Figures 2A and 2B. [2] But among the U.S. states, North Dakota and Alaska administered the least shots with about 1.2 million doses. In comparison, California administered the most doses, with 82 million, followed by Texas and New York, with about 49 million and 44 million doses, respectively, as shown in Figures 2A and

[2] PW stands for Palan, GU stands for Guam, VI stands for Virgin Island, AS stands for American Samoan, FM stands for Federal States of Micronesia, MH stands for Marshal Island, MP Northern Mariana Islands.

2B. The implication is that there is strong heterogeneity in COVID-19 vaccinations between states/territories in the U.S. over time.

2.2. Empirical Model

As mentioned earlier, the study employed a club convergence test to investigate whether the convergence or divergence hypothesis is evident in COVID-19 vaccinations over time in the United States. And we test this hypothesis using the methodology developed by [15], which is closely related to the standard sigma convergence analysis that tests for the decline or increase of the variable of interest over time in the cross-sectional dispersion. The methodology is based on a general nonlinear time-varying factor model tagged log t-test for any given panel data set X_{it}, which accommodates transitional heterogeneity.

In the present study, X_{it} represents the daily doses of vaccines administered, with *i* representing the U.S. states, the District of Columbian, and territories and *t* representing the period covered by the data, which is daily data from Dec.13, 2020-Oct. 11, 2022. And as a first step, the decomposition of X_{it} can be specified as

$$X_{it} = \delta_{it}\mu_t \qquad 1$$

where $\mu_t$is a common component and δ_{it} represents the idiosyncratic one; X_{it} represents the COVID-19 vaccine doses administered daily across each U.S. state, District of Columbia (D.C.), and territory.

The testing for convergence involves analyzing whether δ_{it} converge to δ , which includes defining first the relative transition component specified below:

$$h_{it} = \frac{X_{it}}{N\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{N\sum_{i=1}^{N} \delta_{it}} \qquad 2$$

However, in the presence of convergence, h_{it} converge towards unity, while its cross-section variation (H_t) goes to 0 when T moves toward infinity as specified follows:

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2, as\ T \rightarrow \infty \qquad 3$$

We estimate a nonlinear time-varying factor model tagged log t-test using the specification below:

$$log(H_1/H_t) - 2log[log(t)] = \delta + \beta log(t) + \mu_t \qquad 4$$

$t = [rT] + 1, \ldots\ldots, T$ and $\beta = 2\hat{\alpha}$

$H_0: \alpha \geq 0$ and $H_A: \alpha < 0$

where β is the coefficient of $log(t)$; T is the time which is equivalent to the number of days covered in the data; h_{it} represents the transmission parameters; r represents the fraction of the time series in the (0.2, 0.3) interval; $\hat{\alpha}$ represents the least square estimate of α; μ_t represents the error term of the regression; the rejection of the null hypothesis of convergence at a 5% level of significance occurs when $t_\beta < -1.65$, which is tested by standard t-statistics.[3] Thus, following the suggestion by Philip and Sul (2007), we identify club convergence in the data using a robust clustering algorithm. Therefore, because of the possible overestimation of the number of clubs based on equation 4, Philip and Sul (2007; 2009) recommend performing club merging tests after running the algorithm using equation 4.

The procedure for performing the club convergence test, clustering, and club merger test can be summarized in the following steps(Philip and Sul 2009):

Step1-Cross-section sorting: This involves sorting states and territories in the panel decreasingly according to their observations in the last period

Step 2-Core-group formation: This involves finding the first group (G_k) of states and territories with test statistics of the log t regression greater than the critical value of -1.65 to detect whether convergence exists in each K-sized subgroup.

Step 3-Sieve states and territories for club membership: This step identifies the first convergence club in the sample by discovering that all panel members converge to a similar steady-state path following the core group G*.

Step 4-Recursion and stopping rule: This involves the formation of a subgroup on the remaining members that are not sieved in step 3 by performing the log t-test for this subgroup. And this step is repeated for the remaining sample to determine the next convergence club until the remaining sample members fail to converge.

[3] This is a one-sided null hypothesis: $\beta \geq 0$ against $\beta < 0$

Step 5-Club merging: This involves performing the log t-test for all pairs of the subsequent initial clubs by combining clubs that fulfill the convergence hypothesis jointly to form a new club. This is repeated until no clubs can be merged.

In the meantime, we estimated the parameters of equation 4 using the *psecta* command in Stata written by Du (2017).

3. Results

The test of the convergence in COVID-19 vaccinations across the U.S. states and territories is based on the log t-test shown in Equation 4. And the estimated t-statistics of -10.9243 was obtained, which is less than the critical value of -1.65. The implication is that the null convergence hypothesis in the overall data is rejected. This means empirical evidence supports the lack of convergence (which indicates the presence of divergence) in the COVID-19 vaccinations across the U.S. states and territories over time.

Given that studies have shown that despite the support for the divergence process in economic variables, it is still possible for states/countries to converge into multiple steady states or long-run equilibrium (Philip and Sul 2007). To this end, the study employed the club clustering algorithm to investigate the possible existence of club convergence in daily doses of vaccines administered across U.S. states and territories. Table 1 identifies 2 initial convergence clubs because the estimated t-statistics is greater than the critical value of -1.65 and a divergence group, given that the estimated t-statistics is less than the critical value. Accordingly, club 1 and 2 contains 21 and 16 states/territories, while the divergence group contains 22 states/territories.

The breakdown of the reported doses of vaccines administered across the 2 initial clubs and the divergence group is presented in the third row of Table 1. Hence, 125 million, 242 million, and 258 million doses of COVID-19 vaccines were administered among the countries in club 1, club 2, and the divergence group, respectively, from Dec. 2020-Oct.2022. This translates to 17224, 11670, and 17522 weekly doses per state/territory in club 1, club 2, and the divergence groups, respectively.

But the club convergence test may overestimate the number of club clusters (Philip and Sul 2007 & 2009), as the club clustering algorithm tends to find more members of clubs than their true members. In recognition of this, we attempt to merge the clubs following the work of Philip and

Sul (2009). The result of the club merging test is also presented in Table 1, which shows that the merging of club 1+2 could not be rejected while the merging of Club 2+3 is rejected. The implication is that states and territories in Clubs 1 and 2 fulfill the convergent hypothesis jointly to form a new club. In contrast, the merging of club 2 and the divergence group is rejected.

Following this, the lower panel of Table 1 provides the result of the estimated final convergence club following the club merging test and is used for subsequent discussions. And the table identifies 1 final convergence club consisting of 37 states/territories and a divergence group comprising 22 states/territories. The distribution of states/territories across the convergence club and divergence group shows that they are evenly spread across the geographical regions in the country. The breakdown of the reported vaccinations by clubs shows that states/territories in club 1 administered about 367 million doses, while those in the divergence group administered about 258 million doses. This translates to 14823 and 17522 weekly shots per state/territory in club 1 and the divergence groups, respectively.

[TABLE 1 HERE]

4. Discussion

The lack of overall convergence in the data means that U.S. states and territories with the least vaccinated population are not catching up with those with the most vaccinated or higher vaccination rates over time. In other words, the disparities or differences in COVID-19 vaccinations across the U.S. states and territories increase over time. The result is unsurprising, given that a similar conclusion was reported by Xu et al. (2022), where the authors found evidence supporting the overall divergence of COVID-19 vaccination rates across the OECD countries.

But using measles as a case study, it was reported that 94% of the population needed to be immune to interrupt the measles virus transmission chain (MAYO CLINIC 2021). And judging by this, the evidence supporting the lack of overall convergence in the COVID-19 vaccinations means more vaccinations still need to be administered to effectively boost immunity against the virus in the United States, given that less than 70% of the U.S. population is fully vaccinated (CDC, 2022).

The evidence supporting club convergence means there is the possibility of wrongly concluding a lack of convergence in the COVID-19 vaccine doses administered daily across U.S. states/territories. The implication is that states/territories within the convergence club with the least vaccinated population are catching up with those with the most vaccinated or higher vaccination rates over time. In other words, the disparities in COVID-19 vaccinations across the states and territories within the club decrease over time. The result is consistent with Xu et al. (2022), where they found evidence supporting club convergence of the COVID-19 vaccination rates across the OECD countries. In contrast, the existence of a divergence group means the disparities in COVID-19 vaccinations across the states/territories with the group increase over time. The result is not surprising, given that a similar result was obtained by Xu et al. (2022), where the authors found evidence supporting a non-convergent group of COVID-19 vaccination rates across the OECD countries.

These findings have important policy implications. First, the evidence of the overall lack of convergence in COVID-19 vaccinations administered across the U.S. states and territories shows that the COVID-19 vaccination rates are declining over time. Second, the existence of the convergence club and divergence group shows multiple behavior patterns are evident in the COVID-19 vaccinations across the country. For example, 37 and 22 states/territories demonstrate convergent and non-convergent (divergent) characteristics, underscoring multiple behavior patterns in COVID-19 vaccinations in the United States. Third, increasing vaccination rates might require specific intervention targeting states and territories within the convergence club and divergence group in the United States. This is important since policies are better channeled to the convergence club to magnify policy effectiveness. And this involves incorporating the characteristics of people in the states/territories to understand factors contributing to the formation of convergence clubs and divergence groups. But due to data limitations, this is beyond the scope of the present study.

5. Conclusions

The results of this paper demonstrate a lack of empirical support for the overall convergence in COVID-19 vaccines administered across the U.S. states and territories. The implication is that the disparities in the COVID-19 vaccine doses administered across the U.S. states and territories increase over time. In other words, the states/territories with lower COVID-19 vaccination rates are not catching up with those with higher vaccination rates over time.

Furthermore, we employed the club clustering algorithm to check whether sub-convergent clubs exist in the sample. And the results identify two initial convergence clubs and a divergence group in the COVID-19 vaccine doses administered daily across U.S. states and territories. But following the club merger test, we finally identified one club and a divergence group. This means that states/territories in the club with lower vaccination rates are catching up with those with higher vaccination rates over time. In contrast, divergence implies that the states/territories in the group with lower COVID-19 vaccination rates are not catching up with those with higher vaccination rates over time. The implication is that multiple behavior patterns are evident in the COVID-19 vaccinations across the country. Hence, efforts to increase vaccination rates might require specific interventions targeting states and territories in the club and the divergence group in the sample.

Recent empirical studies have identified factors influencing the spread of the COVID-19 virus, including population density, per capita income, poverty levels, and government policy intervention (Tevdovsk et al., 2022; Churchill et al., 2022). However, we believe incorporating these factors in future research might further enhance our understanding of factors contributing to forming the convergence club and the divergence group. This is important in informing policies on targeted interventions necessary to increase vaccination rates in the United States over time. Unfortunately, this is beyond the scope of the present study.

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Table 1: Estimated club convergence test

Outcomes	States	# Doses**	β-coefficient*	t-stat	Decision
	Initial classification				
Club 1 [21]	Arizona, Colorado, Florida, Federal States of Micronesia, Georgia, Illinois, Massachusetts, Maryland, Minnesota, Marshal Island, Michigan, North Carolina, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Texas, Virginia, Washington, Wisconsin	125M (17224)	0.1304 [0.1326]	0.9828	Convergent
Club 2 [16]	Alabama, Arkansas, District of Columbia, Hawaii, Kansas, Kentucky, Louisiana, Maine, Mississippi, New Mexico, Nevada, Oklahoma, South Carolina, Tennessee, Vermont, Puerto Rico	242M (11670)	0.0633 [0.3319]	0.1913	Convergent
Divergence Group [22]	Alaska, Americana Samoan, California, Connecticut, Delaware, Guam, Iowa, Idaho, Indiana, Missouri, Northern Mariana Island, Montana, North Dakota, Nebraska, Oregon, Palau, Rode Island, South Dakota, Utah, Virgin Island, West Virginia, Wyoming	258M (17522)	-1.2343 [0.0853]	-14.4744	Non-Convergent
	Club merger Test				
Club 1+2			-0.1736 [0.1108]	-1.5669	Accepted
Club 2+Divergence			-1.0802 [0.0866]	-12.4765	Rejected
	Final classification				
Club 1 [37]	Arizona, Colorado, Florida, Federal States of Micronesia, Georgia, Illinois, Massachusetts, Maryland, Minnesota, Marshal Island, Michigan, North Carolina, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Texas, Virginia, Washington, Wisconsin, Alabama, Arkansas, District of Columbia, Hawaii, Kansas, Kentucky, Louisiana, Maine, Mississippi, New Mexico, Nevada, Oklahoma, South Carolina, Tennessee, Vermont, Puerto Rico	367M (14823)	-0.1736 [0.1108]	-1.5669	Convergent
Divergence Group [22]	Alaska, Americana Samoan, California, Connecticut, Delaware, Guam, Iowa, Idaho, Indiana, Missouri, Northern Mariana Island, Montana, North Dakota, Nebraska, Oregon, Palau, Rode Island, South Dakota, Utah, Virgin Island, West Virginia, Wyoming	258M (17522)	-1.2343 [0.0853]	-14.4744	Non-Convergent

If t-stat >-1.65 *indicates convergence, and when t-statistics* <-1.65 *indicates divergence; If t-stat>-1.65, the respective clubs merged at a 5% significance level; *The figures in parentheses show standard error;** The figures in parentheses show the average doses of vaccines administered daily*

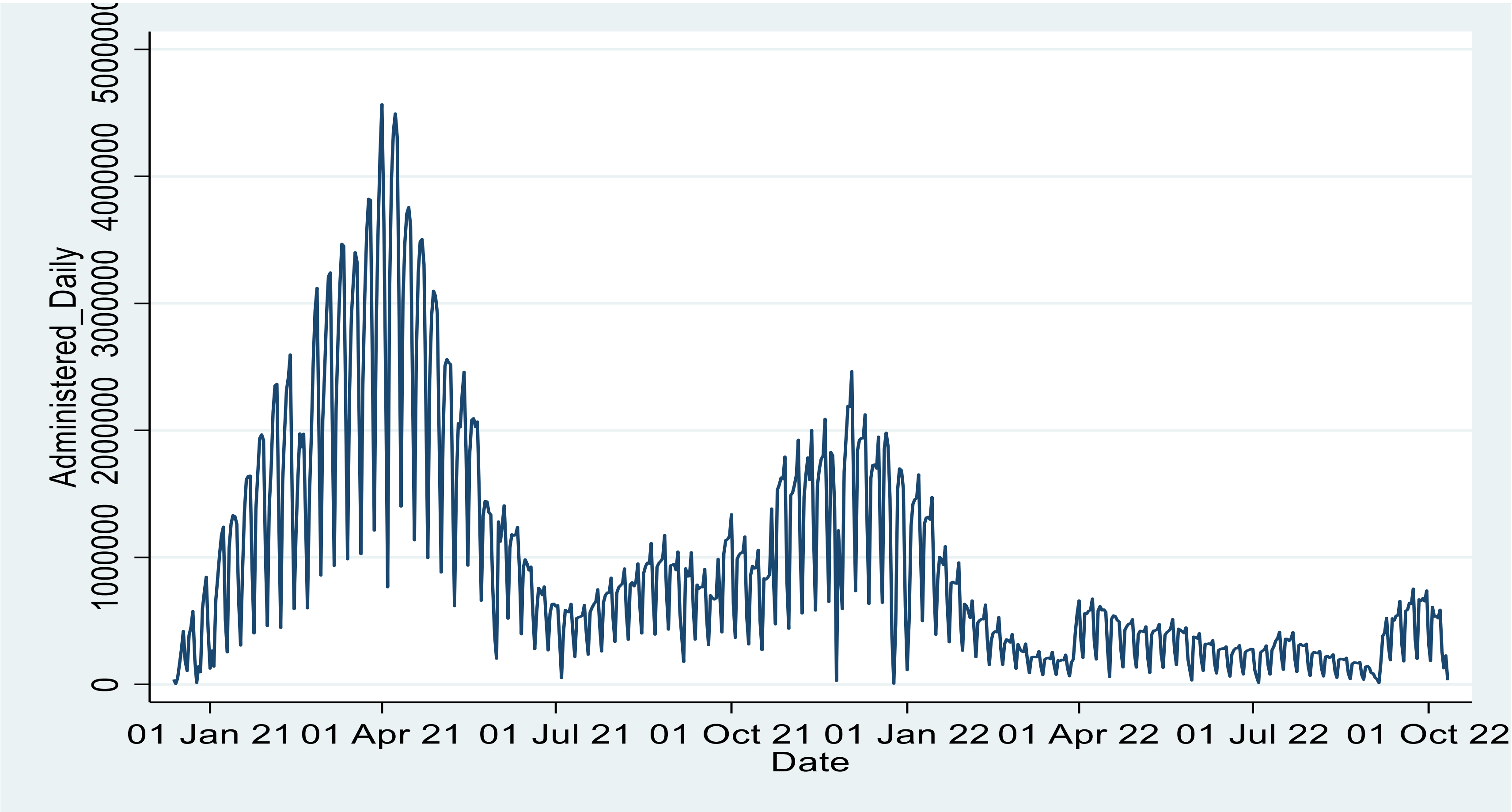

Figure 1: Trends in the number of COVID-19 Vaccine doses administered daily in the U.S. national and jurisdictional covering Dec.13, 2020-Oct. 12, 2022 (CDC 2022)

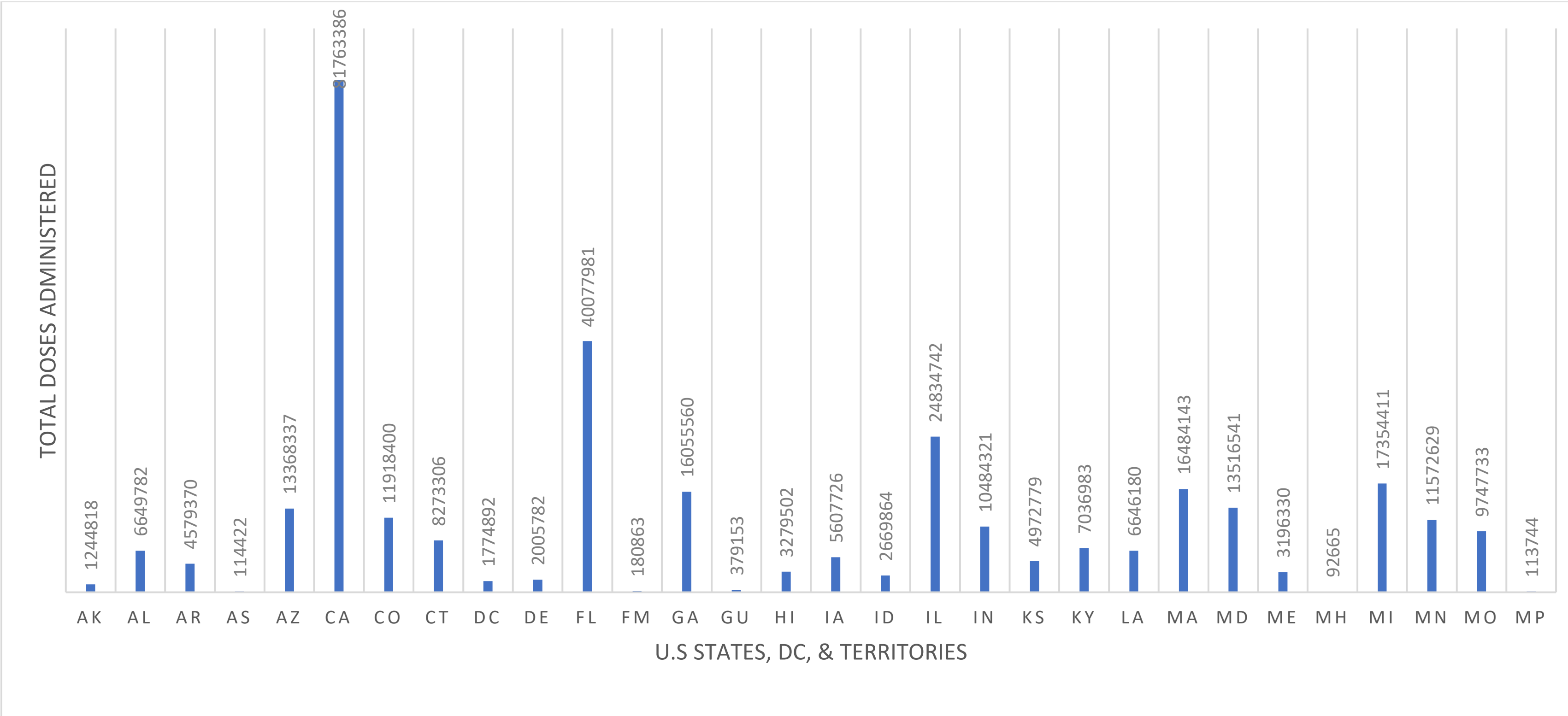

Figure 2A: Total COVID-19 vaccine doses administered by each U.S. state, District of Columbia (D.C.), and territory from Dec. 2020 to Oct.2022. Alaska (AK), Alabama (AL), Arkansas (AR), American Samoan (AS), Arizona (AZ), California (CA), Colorado (CO), Connecticult (CT), District of Columbia (DC), Delaware (DE), Florida (FL), Federal States of Micronesia (FM), Georgia (GA), Guam (GU), Hawaii (HI), Iowa (IA), Idaho (ID), Illinois (IL), Indiana (IN), Kansas (KS), Kentucky (KY), Louisiana (LA), Massachusetts (MA), Maryland (MD), Maine (ME), Marshal Island (MH), Michigan (MI), Minnesota (MN), Missouri (MO), Northern Mariana Island, Montana (MP)

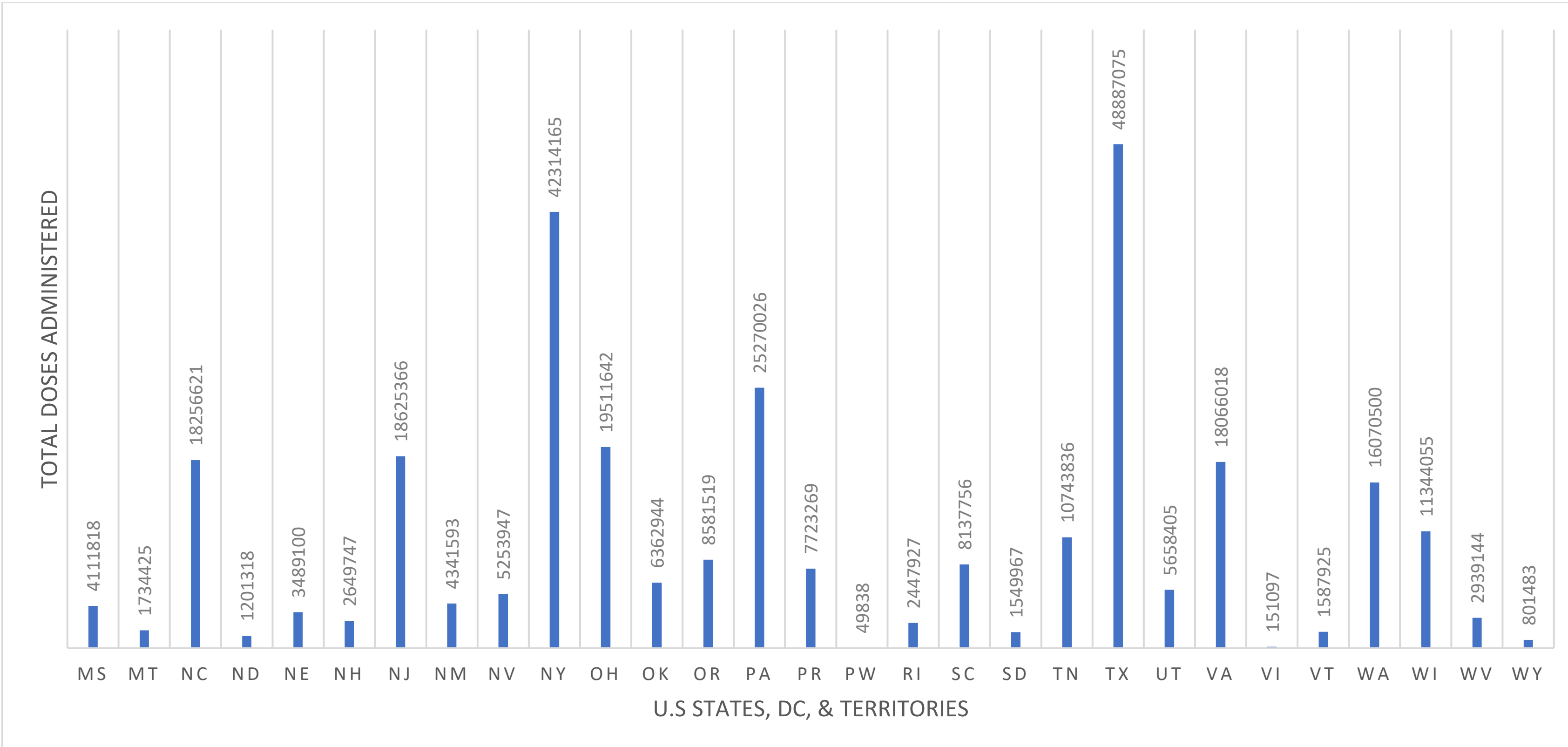

Figure 2B: Total COVID-19 vaccine doses administered by each U.S. state, District of Columbia (D.C.), and territory from Dec. 2020 to Oct.2022. Missouri (MS), Montana (MT), North Carolina (NC), North Dakota (ND), Nebraska (NE), New Hampshire (NH), New Jersey (NJ), New Mexico (NM), Nevada (NV), New York (NY), Ohio (OH), Oklahoma (OK), Oregon (OR), Pennsylvania (PA), Puerto Rico (PR), Palan (PW), Rhode Island (RI), South Carolina (SC), South Dakota (SD), Tennessee (TN), Texas (TX), Utah (UT), Virginia (VA), Virgin Island (VI), Vermont (VT), Washington (WA), Wisconsin (WI), West Virginia (WV), Wyoming (WY)