

Differences in COVID-19 vaccination in the province of Ontario across Health Regions and socio-economic strata

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Abstract

The COVID-19 pandemic continues to be a worldwide public health concern. Although vaccines against this disease were rapidly developed, vaccination uptake has not been equal across all the segments of the population. In particular, it has been shown that there have been differences in vaccine uptake across different segments of the population. However, there are also differences in vaccination across geographical areas, which might be important to consider in the development of future public health policies against COVID-19. In this study, we examined the relationship between vaccination status (having received the first dose of a COVID-19 vaccine), and different socio-economic and geographical factors. Our results show that during the last three months of 2021, individuals in certain equity-deserving groups (visible minorities) were three times less likely to be vaccinated than White/Caucasian individuals across the province and that in some cases, within these groups individuals in low income brackets had significantly higher odds of vaccination when compared to their peers in high income brackets. Finally, we identified significantly lower odds of vaccination in the West Health Region of Ontario within certain equity-deserving groups. This study shows that there is an ongoing need to better understand and address differences in vaccination uptake across diverse segments of the population of Ontario that have been largely impacted by the pandemic.

26 Keywords

27 Covid-19, vaccination, survey, socio-economic factors, visible minorities.

28 Background

29 As of May of 2023 there have been 765 million confirmed cases of COVID-19 around the
30 world, including 6.8 million deaths¹. Although this disease is no longer categorized as a global
31 health emergency by the World Health Organization (WHO)², there is ongoing concern due
32 to continued transmission, surges in cases and deaths due to new variants³, and weaknesses in
33 health systems around the world that could be exploited by a novel virus or another public
34 health emergency in the future⁴.

35 In particular, a major weakness that has received attention during the pandemic has been
36 related to inequalities in vaccine uptake. The rapid development of vaccines against COVID-
37 19 initially brought the hope of a rapid end to the pandemic due to the start of vaccination
38 campaigns in certain parts of the world toward the end of 2020⁵⁻⁸) but inequalities in vaccine
39 uptake made these pharmaceutical interventions ultimately unable to replicate the experience
40 of smallpox, where vaccination on a global scale and was crucial to control this disease⁹.

41 This problematic is a multifaceted issue resulting from a combination of factors, among which
42 are failed public health measures¹⁰, inequality in vaccine access between high- and low-income
43 countries^{11,12}, and vaccine hesitancy¹³. Furthermore, it is well established that this issue has
44 affected in particular individuals in certain equity-deserving groups (e.g., Black, Asian, or
45 Indigenous) as well as individuals with socio-economic disadvantages¹⁴⁻²⁰.

46 Reasons given for this inequality have included medical mistrust due to systemic medical
47 racism^{16,21}, mistrust in vaccines¹⁴, and the influence of conspiracy theories²¹⁻²³. However, it
48 is important to also consider that vaccination uptake can be influenced by geographical (spa-
49 tial) factors. In this regard, differences in COVID-19 vaccination rates have been associated
50 with varied regional attitudes towards vaccination²⁴, spatial differences in vaccine access and
51 supply, vaccination location availability, and lack of prioritization of areas where vulnerable
52 groups reside^{7,25}. Other studies have also shown heterogeneity in vaccine uptake within small
53 governmental administrative units such as counties²⁶⁻²⁹, and that accounting for geographical
54 differences in vaccination can help predict patterns of booster uptake³⁰.

55 However, such analyses have been carried mostly in territories outside of Canada, where avail-
56 able studies have been focused in certain cities (such as Toronto³¹, or Montreal³²), or have
57 explored differences at a province-wide level¹⁸. Therefore, there is a need for studies that
58 explore spatial differences in vaccination within the Canadian territory and that consequently,
59 can help identify disparities that need to be addressed within specific areas in each province.

Between 2007 and 2019, Ontario provided healthcare access to its inhabitants using 14 intra-provincial divisions called the Local Health Integrated Networks (LHINs). However, this approach was complex and bureaucratic, resulting in excessive expenditures, disparities in mortality rates, and the deterioration of certain performance indicators such as wait times and readmissions^{33–35}. In an effort to improve the healthcare system of the province, in late 2019 the government dissolved the 14 LHINs and the areas they covered were incorporated into 6 Health Regions (North East, North West, Central, Toronto, West, and East)³⁵. Due to the relatively recent adoption of the Health Region model and its alignment with the onset of the COVID-19 pandemic, there is a need to analyze if there are ongoing disparities in health access under this approach that need to be addressed before they are exploited by a new disease or public health threat. In this regard, previous research has highlighted disparities in the level of activity of each Health Region³⁶. Therefore, analyzing differences in vaccination uptake within the Health Regions and can help identify which socio-demographic groups are the most vulnerable and what areas of the province deserve special attention by decision-makers.

Therefore, in this study we hypothesized that there were differences in vaccination uptake between the different Health Regions of Ontario between October of 2021 and January of 2022. By including socio-economic factors in our analysis, we aimed at identifying in which groups these differences were significant in order to provide an assessment of the current state of healthcare access in Ontario.

Methods

Data and Methods

We used data from the *Survey of COVID-19 related Behaviours and Attitudes*, a repeated cross sectional survey focused on the Canadian province of Ontario that was commissioned by the Fields Institute for Research in Mathematical Sciences and the Mathematical Modelling of COVID-19 Task Force under ethical guidance from the University of Toronto, and which ran between September 30th, 2021 and January 17th, 2022. The survey collected socio-economic information from participants (Table 1), their location (nearest municipality, as shown in Figure 1), the date of access to the survey, and asked information on vaccination status by using the question “Have you received the first dose of the COVID vaccine?”, with possible answers “yes” and “no”. The original dataset contained 39,029 observations (where each observation corresponded to a unique respondent).

Preliminary analyses of the data included the removal of outliers (**should we still do this? it’s only 19 observations with income >110k and household of 1, but we are not even using such income bracket in the analysis because we re-grouped the data, and the household size variable has 90% missing rate**), of observations where respondents did not provide answers in all the covariates of interest, matching the city of each observations with its corresponding LHIN and Health Region, and removing observations from

97 areas with low representation (107 observations corresponding to the North West and North
 98 East Health Regions). After all the preliminary analyses indicated above, the total number of
 99 observations used for analysis was 3,549 which included the East, Central, Toronto, and West
 100 Health Regions covering the period between October 1st, 2021 and December 12th, 2021. The
 101 original dataset, clean dataset, and details on the data cleaning process are described in detail
 102 in the [GitHub repository](#) for this paper.

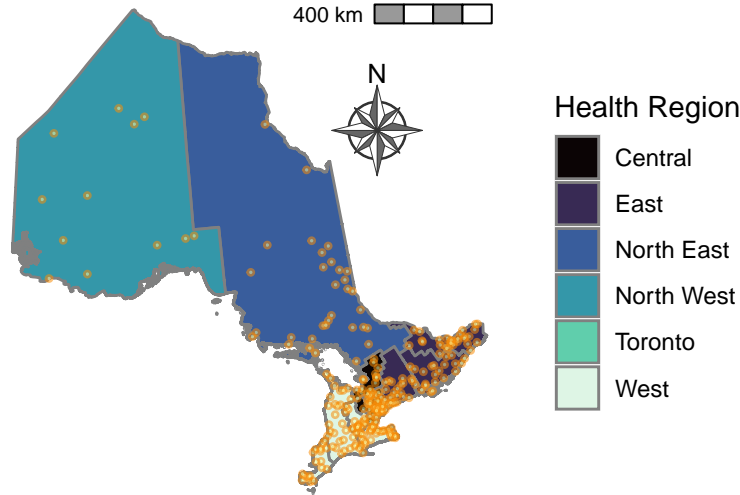


Figure 1: Geographic representation of the data collected by the *Survey of COVID-19 related Behaviours and Attitudes*, collected by the Fields Institute in Ontario. The municipalities (cities) from where survey participants provided answers (in the clean dataset) appear as points. The Health six Regions are color-coded. Internal boundaries within certain Health Regions indicate areas that belonged to the Local Integrated Health Networks (LIHNs), the geographic areas for healthcare in Ontario before the adoption of the Health Regions.

103 Statistical analyses

104 We used a logistic regression model to examine the impact of the Health Regions in vaccina-
 105 tion rates while considering the socio-economic factors and months covered by the survey
 106 (Table 1) and certain interactions (Race and Health Region and Race and income), as previous
 107 studies have shown that socio-economic factors and their interactions are significant predictors
 108 of intent of vaccination and vaccination status³⁷⁻³⁹. Because we identified differences in repre-
 109 sentativity between the survey data and the estimates from the Census, we used an iterative
 110 proportional fitting procedure (*raking*)⁴⁰ to correct the data using data from the Census and
 111 Health Region population totals; and fitted the regression model to the uncorrected and cor-

rected data. Details regarding the correction can be found in the Appendix. All analyses were conducted in R 4.2.2 using the packages `survey`⁴¹, `tidyverse`⁴², `quarto`⁴³, `modelsummary`⁴⁴, and `gtsummary`⁴⁵.

Results

Sample Characteristics

Table 1 shows the characteristics of the data from the Fields COVID-19 survey used for analysis. The sample contained **6,236** observations, from which 24.8% (1,547) corresponded to individuals that reported not having received the first dose of the vaccine. Vaccination rates ranged between 71-79% across household income brackets, age groups, Health Regions, and the months considered in the survey. However, the highest vaccination rates in each category were reported by individuals in the highest income bracket (79%), those between 16 and 34 years of age (77%), individuals that lived in the East Health Region (77%), and during January of 2022 (78%). Differences were higher between racial/ethnic groups, where the higher vaccination rate was reported by White/Caucasian individuals (84%), against vaccination rates between 63-66% reported in the case of Arab/Middle Eastern, Black, Indigenous, Latin American individuals, and those that reported belonging to “Other” racial groups, which included Southeast Asian, Filipino, West Asian, and minorities not identified elsewhere.

Table 1: Descriptive Statistics of the Fields COVID-19 Survey (by Vaccination Status)

Variable	no, N = 1,547 ¹	yes, N = 4,689 ¹	p-value ²
Income (CAD)			<0.001
60000 and above	542 (21%)	1,996 (79%)	
25000-59999	347 (25%)	1,046 (75%)	
under 25000	658 (29%)	1,647 (71%)	
Age Group			0.002
16-34	645 (23%)	2,117 (77%)	
35-54	411 (24%)	1,305 (76%)	
55 and over	491 (28%)	1,267 (72%)	
Health Region			0.3
Toronto	593 (26%)	1,709 (74%)	
Central	372 (26%)	1,083 (74%)	
East	236 (23%)	783 (77%)	
West	346 (24%)	1,114 (76%)	
Month			<0.001
October	469 (27%)	1,263 (73%)	
November	376 (28%)	980 (72%)	
December	181 (24%)	565 (76%)	

January	521 (22%)	1,881 (78%)	
Race			<0.001
White/Caucasian	354 (16%)	1,871 (84%)	
Arab/Middle Eastern	111 (34%)	220 (66%)	
Black	159 (34%)	303 (66%)	
East Asian/Pacific Islander	94 (19%)	404 (81%)	
Indigenous	112 (37%)	194 (63%)	
Latin American	99 (34%)	195 (66%)	
Mixed	177 (30%)	411 (70%)	
Other ³	315 (34%)	606 (66%)	
South Asian	126 (21%)	485 (79%)	

¹n (%)

²Pearson's Chi-squared test

³Southeast Asian, Filipino, West Asian, and minorities not identified elsewhere according to the Census.

Multivariate Regression

Figure 2 presents the estimates (as odd ratios) from the logistic regression models for vaccination status using the socio-demographic factors collected by the survey, and their interactions. Generally speaking, lower odds of vaccination were identified in both cases in individuals characterized by a low household income, or that identified as part of equity-deserving groups. However, the magnitude of the estimates differed between the uncorrected and corrected models and more importantly, certain estimates were not deemed to be statistically-significant after the correction, in contrast to the estimates from the uncorrected model. Specifically, the corrected model showed no significant differences in vaccination odds between the age groups considered, the East Health Region, Latin American individuals with a household income under CAD 25,000, and Indigenous individuals living in the Central Health Region (Figure 2,B).

However, significantly lower odds of vaccination were identified in the corrected model for those with a household income under CAD 25,000 (OR=0.37, CI=[0.27,0.51]) and those with an income between CAD 25,000 and 59,999 (OR=0.58, CI=[0.42,0.81]). Additionally, individuals who identified as Arab/Middle Eastern, Black, Latin American, of mixed background, or that belonged to other racial groups (a category that included Southeast Asian, Filipino, West Asian, and minorities not identified elsewhere), had significantly lower odds of vaccination than those in the White/Caucasian group (ORs and CIs=0.28 [0.16,0.51], 0.27 [0.16,0.45], 0.40 [0.21,0.76], 0.53 [0.30,0.92], 0.23 [0.15,0.36]). Additionally, individuals that reported living in the Central and West Health Regions had higher odds of vaccination than those in the Health Region of Toronto (ORs and CIs=1.61 [1.10,2.34], and 1.59 [1.16,2.19], respectively).

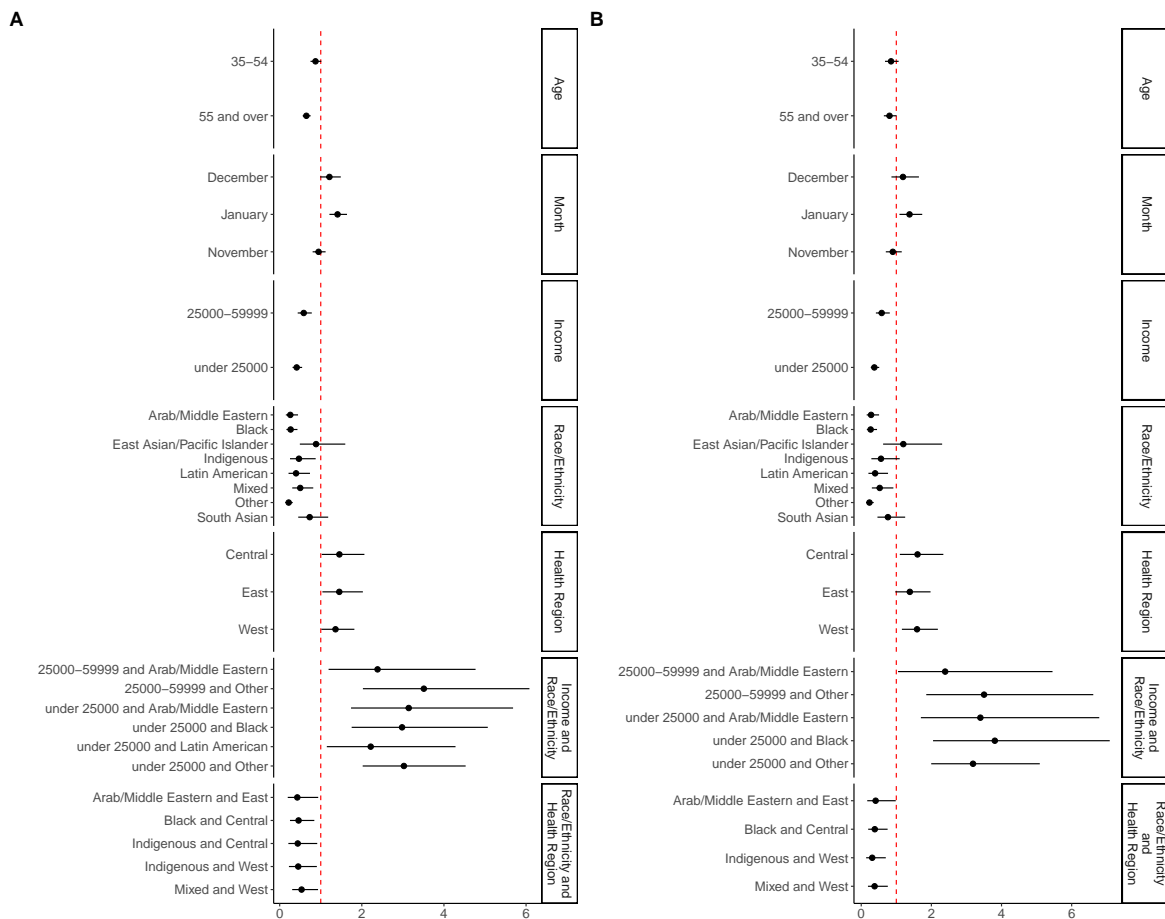


Figure 2: Coefficient estimates and confidence intervals for the uncorrected model. Only statistically significant interaction terms are shown. Full interaction terms can be found in Supplementary Figure A-3.

151 Interestingly, individuals in equity-deserving groups with a household income below CAD
 152 25,000 had higher odds of vaccination (when compared to those with a household income above
 153 CAD 60,000). This held true in the case of Arab/Middle Eastern (OR=3.4, CI=[1.70,6.79]),
 154 Black individuals (OR=3.81, CI=[2.05, 7.09]), or those in other racial or ethnic groups
 155 (OR=3.19, CI=[2.00,5.09]). Additionally, individuals with an income between CAD 25,000
 156 and 59,999 in the Arab/Middle Eastern and other racial ethnic groups had higher odds of
 157 vaccination (ORs and CIs=6.96 [2.67,18.16], and 3.5 [1.85,6.62]).

158 Finally, significantly lower odds of vaccination were identified (when compared to the Toronto
 159 Health Region) for Black individuals in the Central Health Region (OR=0.39, CI=[0.2,0.75]),
 160 Arab/Middle Eastern individuals in the East Health Region (OR=0.41 [0.17, 0.98]), and in
 161 the Indigenous and mixed groups in the West Health Region (ORs and CIs=[0.31 [0.14, 0.7]
 162 and 0.38 [0.19, 0.76], respectively).

163 Discussion

164 West Health Region includes the regions of Waterloo and Niagara, the counties of Wellington,
 165 Essex, and Lambton, and the cities of Hamilton, Haldimand, Brant, and Chatham-Kent.
 166 The Central Health Region includes the regions of Peel and Halton, the regional municipality
 167 of York, the district of Muskoka, the counties of Dufferin, Simcoe, Grey, and the city of
 168 Etobicoke.

169 had significantly higher odds of vaccination than those in the Health Region of Toronto

170 Between 2007 and 2019, healthcare in Ontario was managed by 14 different LHINs, which
 171 aimed to provide an integrated health system for the province. However, this approach faced
 172 chronic problems such as fragmented electronic health systems⁴⁶, the decline of performance
 173 indicators (e.g., increased unplanned emergency visits, number of patient readmissions), and
 174 inequities in health services access⁴⁷. Based on these problematics and with the intent of better
 175 organizing and delivering care, the provincial government moved to the Health Region model
 176 in late 2019³⁵.

177 In this study we hypothesized that differences in COVID-19 vaccination uptake were present
 178 between the Health Regions, aiming at determining which socio-demographic groups could be
 179 impacted by these disparities in order to provide decision-makers with information that could
 180 be used to develop policies focused on reducing or eliminating these differences and ensure
 181 that the Health Region model is able to fulfill its mission of improving health access for the
 182 inhabitants of Ontario.

183 Our results show differences in odds of vaccination in individuals across certain socio-
 184 demographic groups. Specifically, those who identified as Arab/Middle Eastern, Black, Latin
 185 American, having mixed racial or ethnic background, or that belonged to other groups not
 186 explicitly included in the survey (Southeast Asian, Filipino, West Asian, and minority groups
 187 not identified elsewhere) had vaccination odds that were between a third and a half of that

of individuals that identified as White/Caucasian (Figure 2). These results are consistent with previous studies that have shown lower vaccination rates in individuals with the same socio-demographic characteristics^{18-20,48}.

Lower vaccine uptake in the socio-demographic groups indicated above may be influenced in part, by vaccine hesitancy and refusal, which have been associated in equity-deserving Canadian individuals to concerns on vaccine safety, effectiveness, and experiences of racial discrimination in health settings^{39,49-51}. However, it has been shown that structural barriers also play an important role in vaccination uptake. In the case of equity-deserving individuals, such barriers include complex scheduling systems, language barriers, lack of adequate public transportation, and lack of accessible vaccination sites⁵². In this regard, it is interesting to note that vaccination venues were scarce in low socio-economic areas that had the highest burden of COVID-19 in Toronto and other regions of Ontario around the time covered by the survey^{7,53}, and that pharmacies in the Peel region (an area identified as a “hotspot” with high numbers of essential workers and multigenerational households) could not keep up with demand⁵⁴. However, to the best of our knowledge, there seems to be a very limited amount of studies in this area, indicating an ongoing need of future studies that examine the longitudinal impact of vaccine accessibility and structural barriers that affected equity-deserving groups within the province.

Although overall self-reported vaccination rates were found to be statistically significantly lower in various racial minority groups when compared to White/Caucasian individuals, the change in odds of vaccination within certain racial groups and income strata was actually positive, in contrast to the White/Caucasian group, where vaccination odds decreased in lower income brackets (when compared to the CAD 60,000 and over bracket, Supplementary Figure A-5). Specifically, individuals in low income brackets that belonged to Arab/Middle Eastern, Black, or other minority groups had higher odds of vaccination than their peers with an income above 60,000 CAD.

This result is likely due in part to the fact that individuals that belong racial minority groups tend to perform occupations that have been deemed as “essential” in the context of the pandemic^{55,56}, which include grocery store workers, gas station, warehouse, distribution, and manufacturing workers, all being occupations for which an income within the significant brackets identified in the analysis is to be expected. In Ontario, these workers had priority for COVID-19 vaccination⁵⁷; and interestingly, there is evidence of interventions by vaccination staff in certain parts of the province to encourage vaccination uptake by these individuals⁵⁴. These facts, combined with evidence of increased trends in vaccination in this group elsewhere⁵⁸, suggest that the type of occupation from individuals in equity-deserving groups played an important role in increasing the odds of vaccination in the province.

Additionally, significant higher vaccination odds were identified in the West Health Region when compared to the Health Region of Toronto (?@fig-model-corr). The West Health Region comprises the regions of Waterloo and Niagara, the counties of Wellington, Essex and Lambton, and the cities of Hamilton, Haldimand, Brant, and Chatham-Kent. In this case, these results could reflect the fact that in the survey, about half of the entries for this Health

Region corresponded to White/Caucasian individuals, who reported a vaccination rate of 83% (Supplementary Table A-6). However, the interaction effect of Health Region and race was also significant in the case of individuals identifying as South Asian or other minorities not included in the survey **?@fig-model-corr**. In this case, the results of the interaction term in the model indicate that the odds of vaccination for those within the South Asian and Other minority groups in the West Region decreased when compared to the other Health Regions (Supplementary Figure A-6).

According to Ontario Health, 13.2% of the population in the West Health Region identifies as a visible minority, whereas 2.5% identifies as Indigenous⁵⁹. Therefore, the estimated lower odds are likely to be explained from a socio-economic perspective. In fact, 50% of the answers from this region in the survey came from the former LHINs of Hamilton Niagara Haldimand Brant, and Erie St. Clair, both which are among the regions of Ontario with the highest proportion of their population (more than 20%) in the lowest income quintile⁶⁰ (Supplementary Table A-7). Interestingly, a disproportionate number of COVID-19 cases and low vaccination rate (under 50%) have been also reported in the South Asian community of Ontario⁶¹. These results provide context to the observed differences in vaccination among the Health Regions of the province, showing which equity-deserving and socio-demographic groups in certain regions need to be prioritized in future vaccination strategies. Moreover, these results provide a rationale for future studies that explore how vaccination uptake varies across different minority groups within Ontario and other Canadian provinces.

There are some limitations to the present study. First, the data collection design, which allowed respondents to withdraw from the survey at any point, resulted in a high number of unique entries in the survey with multiple missing answers. Because we focused on entries that had complete observations in the covariates of interest for our analysis, it is possible that some information was not considered by excluding observations that had information in other variables (such as work from home, or number of persons in the household). However, we attempted to minimize this possibility by correcting the dataset using information from the Census. More granular corrections, which for example could be based on demographic information by municipality, could be used in the future to obtain a more accurate approximation to the population totals of the province. Moreover, our analysis did not consider the North West and North East Health Regions, due to the low number of entries from these areas in the survey (Figure 1). Although low representation from these areas is based on the fact that these regions only account for 5% of the total population of Ontario, these regions are the home to more than 100,000 individuals that identify as Indigenous⁵⁹, a minority group that has historically suffered from reduced access to health care and discrimination²¹. Therefore, there is a need for additional studies that focus on these low-populated Health Regions in Ontario where disparities in vaccination might be significant and understudied.

It is also worth mentioning that province-wide vaccination rates for the period of interest are somewhat different from those of the survey, particularly in the case of those 55 years of age and older, which in the survey had a vaccination rate of 72%, against a rate of 88.4% reported for the closest age bracket (50 years of age and older) reported by Public Health Ontario at

the start of the period covered by the data⁶². However, we found good agreement between the estimates from the model and overall vaccination rates reported for Canada, which have been relatively higher when compared to other high income countries⁶³, and with vaccination uptake rates across different age groups presented in other studies^{18,64}.

In other words, although vaccination rates obtained from the survey were slightly lower than the provincial estimates, these values still represented a valid approximation to overall trends; this notion is reinforced by the consistency in the proportion of vaccination rates (Table 1) and vaccination odds (?@fig-model-corr) across the period covered by the survey, which closely match the vaccination rates from Public Health Ontario and which indicate that due to the relatively high coverage achieved in the population at that point, vaccination rates increased by around 3% across all age groups during the three months covered by the survey⁶². It is also important to mention that to this day, differences in vaccination rates within the province continue. As of March of 2023 some regions still have less than 75% vaccination rate⁶⁵, and although data for the period analyzed in this study is not publicly-available, it is likely that differences in vaccination rates were higher at the time, being partially captured by the survey.

The results in this study are based on self-reported data, where bias might be present. However, because in the context of COVID-19 it has been shown that good agreement exists between self-reported and documented vaccination status⁶⁶, we believe that our data was able to provide a valid assessment of vaccination in the province. Finally, this study focused on first-dose vaccination status within a relatively short time window, and therefore can only provide a snapshot of the societal dynamics behind the pandemic. Nonetheless, the results presented here can serve as a starting point to motivate the collection of robust longitudinal data that can be used to quantify geographical and temporal differences within vulnerable segments of the population, and that can be used to inform the development of adequate public health policies within the province of Ontario or across other provinces that aim to minimize disparities in health access.

Conclusion

This study explored differences in COVID-19 vaccination across the province of Ontario during the last quarter of 2021 taking into consideration socio-economic factors, such as income and race, their interactions, and the Health Regions within the province. Our results show that during the period analyzed, differences in vaccination uptake existed across multiple equity-deserving groups in the province, and that these differences were significant in two of the Health Regions analyzed. It is important that future public health policies in Ontario take into consideration how to adequately reach individuals from equity-deserving groups that might live in areas of the province where access to healthcare might be difficult. Only in this way the goal of the Health Region model, which aims at reducing disparities, will become successful.

References

1. World Health Organization Coronavirus (COVID-19) Dashboard. Accessed May 11, 2023. <https://covid19.who.int/>
2. Rigby J, Satija B. WHO declares end to COVID global health emergency. *Reuters*. Published online May 8, 2023. Accessed May 11, 2022. <https://www.reuters.com/business/healthcare-pharmaceuticals/covid-is-no-longer-global-health-emergency-who-2023-05-05/>
3. Nations U. WHO chief declares end to COVID-19 as a global health emergency. *UN News*. Published online May 5, 2023. Accessed May 11, 2022. <https://news.un.org/en/story/2023/05/1136367>
4. Mackey K, Ayers CK, Kondo KK, et al. Racial and ethnic disparities in COVID-19-related infections, hospitalizations, and deaths. *Annals of Internal Medicine*. 2021;174(3):362-373. doi:10.7326/m20-6306
5. Microbe TL. COVID-19 vaccines: The pandemic will not end overnight. *The Lancet Microbe*. 2021;2(1):e1. doi:10.1016/s2666-5247(20)30226-3
6. Davis CJ, Golding M, McKay R. Efficacy information influences intention to take COVID-19 vaccine. *British Journal of Health Psychology*. 2022;27(2):300-319. doi:<https://doi.org/10.1111/bjhp.12546>
7. Bogoch II, Halani S. COVID-19 vaccines: A geographic, social and policy view of vaccination efforts in ontario, canada. *Cambridge Journal of Regions, Economy and Society*. Published online November 2022. doi:10.1093/cjres/rsac043
8. Tanne JH. Covid-19: FDA panel votes to authorise pfizer BioNTech vaccine. *BMJ*. Published online December 2020:m4799. doi:10.1136/bmj.m4799
9. Kayser V, Ramzan I. Vaccines and vaccination: History and emerging issues. *Human Vaccines & Immunotherapeutics*. 2021;17(12):5255-5268. doi:10.1080/21645515.2021.1977057
10. Li Q, Wang J, Tang Y, Lu H. Next-generation COVID-19 vaccines: Opportunities for vaccine development and challenges in tackling COVID-19. *Drug Discoveries & Therapeutics*. 2021;15(3):118-123. doi:10.5582/ddt.2021.0105
11. Gerretsen P, Kim J, Caravaggio F, et al. Individual determinants of COVID-19 vaccine hesitancy. Inbaraj LR, ed. *PLOS ONE*. 2021;16(11):e0258462. doi:10.1371/journal.pone.0258462
12. Yamey G, Garcia P, Hassan F, et al. It is not too late to achieve global covid-19 vaccine equity. *BMJ*. Published online March 2022:e070650. doi:10.1136/bmj-2022-070650
13. Nafilyan V, Dolby T, Razieh C, et al. Sociodemographic inequality in COVID-19 vaccination coverage among elderly adults in england: A national linked data study. *BMJ Open*. 2021;11(7):e053402. doi:10.1136/bmjopen-2021-053402

14. Willis DE, Andersen JA, Bryant-Moore K, et al. COVID-19 vaccine hesitancy: Race/ethnicity, trust, and fear. *Clinical and Translational Science*. 2021;14(6):2200-2207. doi:[10.1111/cts.13077](https://doi.org/10.1111/cts.13077)
15. Skirrow H, Barnett S, Bell S, et al. Women’s views on accepting COVID-19 vaccination during and after pregnancy, and for their babies: A multi-methods study in the UK. *BMC Pregnancy and Childbirth*. 2022;22(1). doi:[10.1186/s12884-021-04321-3](https://doi.org/10.1186/s12884-021-04321-3)
16. Stoler J, Enders AM, Kloststad CA, Uscinski JE. The limits of medical trust in mitigating COVID-19 vaccine hesitancy among black americans. *Journal of General Internal Medicine*. 2021;36(11):3629-3631. doi:[10.1007/s11606-021-06743-3](https://doi.org/10.1007/s11606-021-06743-3)
17. Khubchandani J, Sharma S, Price JH, Wiblishauser MJ, Sharma M, Webb FJ. COVID-19 vaccination hesitancy in the united states: A rapid national assessment. *Journal of Community Health*. 2021;46(2):270-277. doi:[10.1007/s10900-020-00958-x](https://doi.org/10.1007/s10900-020-00958-x)
18. Guay M, Maquiling A, Chen R, et al. Measuring inequalities in COVID-19 vaccination uptake and intent: Results from the canadian community health survey 2021. *BMC Public Health*. 2022;22(1). doi:[10.1186/s12889-022-14090-z](https://doi.org/10.1186/s12889-022-14090-z)
19. Muhajarine N, Adeyinka DA, McCutcheon J, Green KL, Fahlman M, Kallio N. COVID-19 vaccine hesitancy and refusal and associated factors in an adult population in saskatchewan, canada: Evidence from predictive modelling. Gesser-Edelsburg A, ed. *PLOS ONE*. 2021;16(11):e0259513. doi:[10.1371/journal.pone.0259513](https://doi.org/10.1371/journal.pone.0259513)
20. Hussain B, Latif A, Timmons S, Nkhoma K, Nellums LB. Overcoming COVID-19 vaccine hesitancy among ethnic minorities: A systematic review of UK studies. *Vaccine*. 2022;40(25):3413-3432. doi:[10.1016/j.vaccine.2022.04.030](https://doi.org/10.1016/j.vaccine.2022.04.030)
21. Mosby I, Swidrovich J. Medical experimentation and the roots of COVID-19 vaccine hesitancy among indigenous peoples in canada. *Canadian Medical Association Journal*. 2021;193(11):E381-E383. doi:[10.1503/cmaj.210112](https://doi.org/10.1503/cmaj.210112)
22. Bogart LM, Ojikutu BO, Tyagi K, et al. COVID-19 related medical mistrust, health impacts, and potential vaccine hesitancy among black americans living with HIV. *JAIDS Journal of Acquired Immune Deficiency Syndromes*. 2021;86(2):200-207. doi:[10.1097/qai.0000000000002570](https://doi.org/10.1097/qai.0000000000002570)
23. Freeman D, Loe BS, Chadwick A, et al. COVID-19 vaccine hesitancy in the UK: The oxford coronavirus explanations, attitudes, and narratives survey (oceans) II. *Psychological Medicine*. 2020;52(14):3127-3141. doi:[10.1017/s0033291720005188](https://doi.org/10.1017/s0033291720005188)
24. Malik AA, McFadden SM, Elharake J, Omer SB. Determinants of COVID-19 vaccine acceptance in the US. *EClinicalMedicine*. 2020;26:100495. doi:[10.1016/j.eclinm.2020.100495](https://doi.org/10.1016/j.eclinm.2020.100495)
25. Nguyen KH, Nguyen K, Corlin L, Allen JD, Chung M. Changes in COVID-19 vaccination receipt and intention to vaccinate by socioeconomic characteristics and geographic area, united states, january 6 – march 29, 2021. *Annals of Medicine*. 2021;53(1):1419-1428. doi:[10.1080/07853890.2021.1957998](https://doi.org/10.1080/07853890.2021.1957998)

26. Mollalo A, Tatar M. Spatial modeling of COVID-19 vaccine hesitancy in the united states. *International Journal of Environmental Research and Public Health*. 2021;18(18):9488. doi:[10.3390/ijerph18189488](https://doi.org/10.3390/ijerph18189488)
27. Yang TC, Matthews SA, Sun F. Multiscale dimensions of spatial process: COVID-19 fully vaccinated rates in u.s. counties. *American Journal of Preventive Medicine*. 2022;63(6):954-961. doi:[10.1016/j.amepre.2022.06.006](https://doi.org/10.1016/j.amepre.2022.06.006)
28. Tiu A, Susswein Z, Merritt A, Bansal S. Characterizing the spatiotemporal heterogeneity of the COVID-19 vaccination landscape. *American Journal of Epidemiology*. 2022;191(10):1792-1802. doi:[10.1093/aje/kwac080](https://doi.org/10.1093/aje/kwac080)
29. Bhuiyan MAN, Davis TC, Arnold CL, et al. Using the social vulnerability index to assess COVID-19 vaccine uptake in louisiana. *GeoJournal*. Published online December 2022. doi:[10.1007/s10708-022-10802-5](https://doi.org/10.1007/s10708-022-10802-5)
30. Wood AJ, MacKintosh AM, Stead M, Kao RR. Predicting future spatial patterns in COVID-19 booster vaccine uptake. Published online September 2022. doi:[10.1101/2022.08.30.22279415](https://doi.org/10.1101/2022.08.30.22279415)
31. Choi KH, Denice PA, Ramaj S. Vaccine and COVID-19 trajectories. *Socius: Sociological Research for a Dynamic World*. 2021;7:237802312110529. doi:[10.1177/23780231211052946](https://doi.org/10.1177/23780231211052946)
32. McKinnon B, Quach C, Dubé Ève, Nguyen CT, Zinszer K. Social inequalities in COVID-19 vaccine acceptance and uptake for children and adolescents in montreal, canada. *Vaccine*. 2021;39(49):7140-7145. doi:[10.1016/j.vaccine.2021.10.077](https://doi.org/10.1016/j.vaccine.2021.10.077)
33. Tsasis P, Evans JM, Owen S. Reframing the challenges to integrated care: A complex-adaptive systems perspective. *International Journal of Integrated Care*. 2012;12(5). doi:[10.5334/ijic.843](https://doi.org/10.5334/ijic.843)
34. Muratov S, Lee J, Holbrook A, et al. Regional variation in healthcare spending and mortality among senior high-cost healthcare users in ontario, canada: A retrospective matched cohort study. *BMC Geriatrics*. 2018;18(1). doi:[10.1186/s12877-018-0952-7](https://doi.org/10.1186/s12877-018-0952-7)
35. Dong L, Sahu R, Black R. Governance in the transformational journey toward integrated healthcare: The case of ontario. *Journal of Information Technology Teaching Cases*. Published online December 2022:204388692211473. doi:[10.1177/20438869221147313](https://doi.org/10.1177/20438869221147313)
36. Sethuram C, McCutcheon T, Liddy C. An environmental scan of ontario health teams: A descriptive study. *BMC Health Services Research*. 2023;23(1). doi:[10.1186/s12913-023-09102-6](https://doi.org/10.1186/s12913-023-09102-6)
37. Nguyen KH, Anneser E, Toppo A, Allen JD, Parott JS, Corlin L. Disparities in national and state estimates of COVID-19 vaccination receipt and intent to vaccinate by race/ethnicity, income, and age group among adults ≥ 18 years, united states. *Vaccine*. 2022;40(1):107-113. doi:[10.1016/j.vaccine.2021.11.040](https://doi.org/10.1016/j.vaccine.2021.11.040)
38. Shih SF, Wagner AL, Masters NB, Prosser LA, Lu Y, Zikmund-Fisher BJ. Vaccine hesitancy and rejection of a vaccine for the novel coronavirus in the united states. *Frontiers in Immunology*. 2021;12. doi:[10.3389/fimmu.2021.558270](https://doi.org/10.3389/fimmu.2021.558270)

39. Cénat JM, Noorishad PG, Farahi SMMM, et al. Prevalence and factors related to COVID-19 vaccine hesitancy and unwillingness in canada: A systematic review and meta-analysis. *Journal of Medical Virology*. 2022;95(1). doi:[10.1002/jmv.28156](https://doi.org/10.1002/jmv.28156)
40. Deming WE, Stephan FF. On a least squares adjustment of a sampled frequency table when the expected marginal totals are known. *The Annals of Mathematical Statistics*. 1940;11(4):427-444. doi:[10.1214/aoms/1177731829](https://doi.org/10.1214/aoms/1177731829)
41. Lumley T. *Complex Surveys*. John Wiley & Sons; 2011.
42. Wickham H, Averick M, Bryan J, et al. Welcome to the tidyverse. *Journal of Open Source Software*. 2019;4(43):1686. doi:[10.21105/joss.01686](https://doi.org/10.21105/joss.01686)
43. Allaire J. *Quarto: R Interface to 'Quarto' Markdown Publishing System*.; 2022. <https://CRAN.R-project.org/package=quarto>
44. Arel-Bundock V. modelsummary: Data and model summaries in R. *Journal of Statistical Software*. 2022;103(1):1-23. doi:[10.18637/jss.v103.i01](https://doi.org/10.18637/jss.v103.i01)
45. Sjoberg DD, Whiting K, Curry M, Lavery JA, Larmarange J. Reproducible summary tables with the gtsummary package. *The R Journal*. 2021;13:570-580. doi:[10.32614/RJ-2021-053](https://doi.org/10.32614/RJ-2021-053)
46. Auditor General of Ontario O of the, ed. Annual Report 2016. In: *Section 3.03: Electronic Health Records' Implementation Status*. Queen's Printer for Ontario; 2016. Accessed May 12, 2023. https://www.auditor.on.ca/en/content/annualreports/arreports/en16/v1_303en16.pdf
47. Auditor General of Ontario O of the, ed. Annual Report 2015. In: *Section 3.08: LHINs - Local Health Integration Networks*. Queen's Printer for Ontario; 2015. Accessed May 12, 2023. <https://www.auditor.on.ca/en/content/annualreports/arreports/en15/3.08en15.pdf>
48. Carter MA, Biro S, Maier A, Shingler C, Guan TH. COVID-19 vaccine uptake in southeastern ontario, canada: Monitoring and addressing health inequities. *Journal of Public Health Management and Practice*. 2022;28(6):615-623. doi:[10.1097/phh.0000000000001565](https://doi.org/10.1097/phh.0000000000001565)
49. Basta NE, Sohel N, Sulis G, et al. Factors associated with willingness to receive a COVID-19 vaccine among 23, 819 adults aged 50 years or older: An analysis of the canadian longitudinal study on aging. *American Journal of Epidemiology*. 2022;191(6):987-998. doi:[10.1093/aje/kwac029](https://doi.org/10.1093/aje/kwac029)
50. Cénat JM, Noorishad PG, Bakombo SM, et al. A systematic review on vaccine hesitancy in black communities in canada: Critical issues and research failures. *Vaccines*. 2022;10(11):1937. doi:[10.3390/vaccines10111937](https://doi.org/10.3390/vaccines10111937)

- 408 51. Cénat JM, Farahi SMMM, Bakombo SM, et al. Vaccine mistrust among black individuals in canada: The major role of health literacy, conspiracy theories, and racial discrimination in the healthcare system. *Journal of Medical Virology*. 2023;95(4). doi:[10.1002/jmv.28738](https://doi.org/10.1002/jmv.28738)
- 409
410 52. Njoku A, Joseph M, Felix R. Changing the narrative: Structural barriers and racial and ethnic inequities in COVID-19 vaccination. *International Journal of Environmental Research and Public Health*. 2021;18(18):9904. doi:[10.3390/ijerph18189904](https://doi.org/10.3390/ijerph18189904)
- 411
412 53. Iveniuk J, Leon S. *Uneven Recovery: Measuring Covid-19 Vaccine Equity in Ontario*. Wellesley Institute; 2021. Accessed May 12, 2023. <https://www.wellesleyinstitute.com/wp-content/uploads/2021/04/An-uneven-recovery-Measuring-COVID-19-vaccine-equity-in-Ontario.pdf>
- 413
414 54. Gill M, Datta D, Gregory P, Austin Z. COVID-19 vaccination in high-risk communities: Case study of brampton, ontario. *Canadian Pharmacists Journal / Revue des Pharmaciens du Canada*. 2022;155(6):345-351. doi:[10.1177/17151635221123042](https://doi.org/10.1177/17151635221123042)
- 415
416 55. Hawkins D. Differential occupational risk for COVID-19 and other infection exposure according to race and ethnicity. *American Journal of Industrial Medicine*. 2020;63(9):817-820. doi:[10.1002/ajim.23145](https://doi.org/10.1002/ajim.23145)
- 417
418 56. Côté D, Durant S, MacEachen E, et al. A rapid scoping review of COVID-19 and vulnerable workers: Intersecting occupational and public health issues. *American Journal of Industrial Medicine*. 2021;64(7):551-566. doi:[10.1002/ajim.23256](https://doi.org/10.1002/ajim.23256)
- 419
420 57. Mishra S, Stall NM, Ma H, et al. *A Vaccination Strategy for Ontario COVID-19 Hotspots and Essential Workers*. Ontario COVID-19 Science Advisory Table; 2021. doi:[10.47326/ocsat.2021.02.26.1.0](https://doi.org/10.47326/ocsat.2021.02.26.1.0)
- 421
422 58. Nguyen KH, Yankey D, Coy KC, et al. COVID-19 vaccination coverage, intent, knowledge, attitudes, and beliefs among essential workers, united states. *Emerging Infectious Diseases*. 2021;27(11):2908-2913. doi:[10.3201/eid2711.211557](https://doi.org/10.3201/eid2711.211557)
- 423
424 59. *Annual Business Plan 2022/23*. Ontario Health; https://www.ontariohealth.ca/sites/ontariohealth/files/2022-05/OHBusinessPlan22_23.pdf; 2022.
- 425
426 60. Buajitti E, Watson T, Kornas K, Bornbaum C, Henry D, Rosella LC. Ontario atlas of adult mortality, 1992-2015: Trends in Local Health Integration Networks. Published online 2018. <https://tspace.library.utoronto.ca/handle/1807/82836>
- 427
428 61. Anand SS, Arnold C, Bangdiwala SI, et al. Seropositivity and risk factors for SARS-CoV-2 infection in a south asian community in ontario: A cross-sectional analysis of a prospective cohort study. *CMAJ Open*. 2022;10(3):E599-E609. doi:[10.9778/cmajo.20220031](https://doi.org/10.9778/cmajo.20220031)
- 429
430 62. Ontario COVID-19 Data Tool. Accessed February 27, 2023. <https://www.publichealthontario.ca/en/data-and-analysis/infectious-disease/covid-19-data-surveillance/covid-19-data-tool?tab=vaccine>
- 431

- 432 63. Dubé E, Gagnon D, MacDonald N. Between persuasion and compulsion: The
case of COVID-19 vaccination in canada. *Vaccine*. 2022;40(29):3923-3926.
433 doi:[10.1016/j.vaccine.2022.05.053](https://doi.org/10.1016/j.vaccine.2022.05.053)
- 434 64. MacDonald NE, Comeau J, Dubé Ève, et al. Royal society of canada COVID-19 re-
port: Enhancing COVID-19 vaccine acceptance in canada. Blais JM, ed. *FACETS*.
435 2021;6:1184-1246. doi:[10.1139/facets-2021-0037](https://doi.org/10.1139/facets-2021-0037)
- 436 65. Ontario COVID-19 Data Tool. Accessed March 24, 2023. [https://www.
437 publichealthontario.ca/en/data-and-analysis/infectious-disease/covid-19-data-
surveillance/covid-19-data-tool?tab=maps](https://www.publichealthontario.ca/en/data-and-analysis/infectious-disease/covid-19-data-surveillance/covid-19-data-tool?tab=maps)
- 438 66. Stephenson M, Olson SM, Self WH, et al. Ascertainment of vaccination status
by self-report versus source documentation: Impact on measuring COVID-19 vac-
cine effectiveness. *Influenza and Other Respiratory Viruses*. 2022;16(6):1101-1111.
439 doi:[10.1111/irv.13023](https://doi.org/10.1111/irv.13023)