Covid-19 vaccination in the province of Ontario: A geographical and socio-economical analysis

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Abstract

Keywords

Background

The COVID-19 pandemic continues around the world with more than 600 million confirmed cases as of November of 2022[1]. During the first months of the pandemic in early 2020, non-pharmaceutical interventions such as masking and social distancing were the only methods available to manage the spread of the disease; however, the rapid development of vaccines permitted their approval and use in some countries towards the last month part of 2020. For example, in the US and Canada vaccine campaigns began in mid-December of 2020[2,3]. Although it has been estimated that vaccines against COVID-19 have prevented around 14 millions of deaths worldwide[4], the rollout of COVID-19 vaccines has faced multiple challenges since its inception.

Indeed, multiple obstacles that have complicated vaccination efforts against COVID-19 have been identified: inequality in vaccine access, vaccine hesitancy, and differences in vaccination rates across different segments of the population[5–7]. In the case of Canada, lower vaccine uptake has been associated with socio-economic factors such as younger age, educational level, presence of children in the household, lack of a regular healthcare provider, ethnic origin, and financial instability[8–11].

Additionally, vaccination is influenced by changes in geography. In this regard, it has been shown that there have been spatial differences in COVID-19 vaccination rates due to regional differences in attitudes towards vaccination[7], geographical differences in vaccine access and supply, vaccination location availability, and lack of prioritization of vulnerable groups[3,12].

Studies that analyze geographical variations in vaccine uptake are important as they can help inform public health decision-makers to design policies to that consider spatial changes to address vaccination disparities. In this regard, previous geographical (spatial) analyses of vaccination rates have shown that variations in vaccine uptake can occur within small governmental administrative units (e.g., counties in the case of the US)[13–16], and that geographical analyses can be predictive of booster uptake patterns[17].

In Canada, studies that have used a spatial approach to analyze vaccine uptake have shown disparities in vaccination rates across low and high income neighborhoods in the city of Toronto[18], among adolescents from deprived neighborhoods in the city of Montreal[19], and have also highlighted disparities in vaccination status depending on age, income, and ethnic origin at the provincial level[8]. However, there is limited information on differences in vaccination status inside the provinces. Such analysis is important as it can help identify inequalities that may exist within these geographical areas while providing a granular view of intra-provincial differences that can help understand the barriers for vaccine uptake.

In this study we examined self-reported COVID-19 vaccination status within the province of Ontario using a combination of socio-economic factors(such as ethnic origin, age, and income) and geographical analysis (at the level of the Health Regions) in order to determine intra-provincial disparities in vaccine uptake and address the ongoing need of socio-economic information that can provide a rationale for the disparities in vaccination observed within some racial groups[20].

Methods

Data source: survey overview

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 which ran from Sept 30, 2021 until January 17, 2022 and that was comissioned by the Fields Institute for Research in Mathematical Sciences (henceforth Fields) and the Mathematical Modelling of COVID-19 Task Force. The survey was conducted by a third-party service provider (RIWI Corp.), under ethical guidance from the University of Toronto.

Briefly, the survey was deployed used random domain intercept technology, where if users clicked on a registered but commercially inactive web link or typed in a web address for a site that was dormant, they had a random chance of that link being temporarily managed by the company that administered the survey and instead of coming across a notification about the status of the site("this page does not exist"), the survey was deployed to the user[21]. Users then decided whether to anonymously participate, and those that participated were able to exit the survey at any time. After the survey closed, regardless if it was complete or incomplete, access was denied to any further users with the same internet protocol (IP) address and the domain entry point rotated such that if a user were to attempt to access the survey again, share the link, or enter via the same address using an alternative IP address, the survey would not deploy. This effectively meant that a user could participate only once in the survey.

Additionally, users who indicated they were under the age of 16 were exited from the survey, no record was created, and these users were unable to navigate back to the "age select" screen. The personal identifier information from each user was automatically scrubbed and replaced by a unique ID. Respondents were drawn exclusively from the province of Ontario, as per their devices meta-data.

Survey responses

Socio-demographic factors

Socio-economic information selected for analysis from the survey answers included age group, income bracket, and race/ethnicity. Information about these socio-economic factors in the survey is provided in Table 1.

Table 1: Selected socio-economic factors from the survey

Variable	Values
Age group	16-24,25-34,35-44,45-54,55-64, 65+
Income bracket (CAD)	<15,000, 15,000-24,999, 25,000-39,999, 40,000-59,999, 60,000-89,999, >90,000
Race/ethnicity	Arab/Middle Eastern, Black, East Asian/Pacific Islander, Indigenous, Latin American, Mixed, South Asian, White Caucasian, Other

Furthermore, the information on vaccination status was provided by survey participants who answered the question “Have you received the first dose of the COVID vaccine?”, with possible answers “yes” and “no”.

Data cleaning

The original dataset contained 39,029 entries (where each entry corresponded to a set of answers provided by a unique respondent). Following a preliminary analysis, the dataset was cleaned in order to only contain the socio-economic information provided in Table 1 and vaccination status. The cleaning process also included removing outliers that were identified during the preliminary analyses. Specifically, we removed those respondents that indicated to be below 25 years of age, living in a household of size 1, and that reported an income above CAD 110,000. The next step consisted in processing the geographical information in the survey (city where the survey was responded) in order to match each city to its correspondent Health Region. Details of this process are given below.

Geographical location

For each survey participant certain data was automatically captured, including the nearest municipality (city). This resulted in a total of 578 different municipalities within the clean dataset. Due to our interest in analyzing the differences between Health Regions, we assigned the city of each entry to its correspondent Health Region following a multi-step process. Briefly, we used Local Health Integrated Networks (LHINs) to assign a Health Region to each entry in the survey. LHINs were the geographical divisions for health used by Ontario before the adoption of the Health Regions; because of the lack of a publicly available list of all municipalities within each Health Region, we used a dataset of long-term care homes and LHINs to match each city to LHIN, followed by matching each LHIN to a Health Region following the information provided on the Ontario Health Website, where the list of LHINs and corresponding Health Regions is available. In the case of municipalities that did not appear in the long-term dataset, we manually searched each city in the LHINs websites in order to provide geographical information. The raw dataset, clean dataset, details of the data cleaning process, and the addition of Health Region and LHIN information are described in detail in the github repository: https://github.com/aimundo/Fields_COVID-19/.

Following an assessment of the number of entries corresponding to each Health Region in the final dataset, only 107 observations (4.3% of the total) corresponded to cities located in the North West and North East Health Regions. Due to the low number of entries, we omitted these Health Regions from further analyses. Therefore, the total number of unique entries used for analysis was 3,551 which included the East, Central, Toronto, and West Health Regions.

Corrections

We identified differences between the proportions of all the socio-economic factors included in the analysis (Table 1) and the 2016 Canada Census data for Ontario. Additionally, because the Census divisions do not match the exact boundaries of the Health Regions, we also obtained population estimates for each Health Region from the Ontario Health website in order to correct for the population totals. We used an iterative proportional fitting procedure (*raking*)[22] to correct for socio-economic factors and Health Region populations using the R `survey` package. Details about the correction can be found in the Appendix.

Statistical analyses

We used a fixed-effects logistic regression model to estimate the probability of vaccination depending on the socio-economic factors described in Section and the Health Regions from Section , as previous studies have shown that socio-economic factors and their interactions are significant predictors of intent of vaccination and vaccination status[23–25]. The model appears in Equation 1,

$$
\begin{aligned}
\log\left(\frac{p(\text{vac})}{1-p(\text{vac})}\right) = \beta_0 + \beta_1(\text{Age group}) + \beta_2\ \text{Race} + \beta_3\ \text{Health Region} + \beta_4\ \text{Income}+ \\
\beta_5(\text{Health Region} \times \text{Income}) + \beta_6\ (\text{Age group} \times \text{Income}) + \beta_7\ (\text{Race} \times \text{Income})
\end{aligned}
\tag{1}
$$

Where $p(\text{vac})$ indicates the probability of having received the first dose of a Covid-19 vaccine, β_0 indicates the population intercept, $\beta_1 ... \beta_7$ indicate the coefficients for each of the fixed and interaction effects of age group, race, Health Region, and income. The the model was fitted using the function `svyglm` from the `survey` R package in order to incorporate the correction in sampling probability obtained from raking.

All analyses were conducted in RStudio (2022.12.0 Build 353), using R 4.2.2 and the packages `survey`[26],`tidyverse`[27], and `quarto`[28].

Results

Survey Results

Table 2 shows the descriptive statistics (uncorrected) from the Fields Covid-19 survey data for vaccination status and each of the covariates analyzed. The total number of entries from the survey in the dataset after cleaning was 3,551. Overall, 26.9% of survey respondents (958) reported not having received the first dose of the vaccine, whereas 73.1% (2,593) reported having received it. Regarding socio-economic factors, respondents who reported living in a household with an income under CAD 15,000 or above 90,000 represented approximately 50% of the total number of entries, with 71% and 75% of the respondents in each income bracket indicating to have received the first dose of the vaccine, respectively. The age group between 16-24 years had the highest representation in the survey responses (837, 23.6% of all responses), followed by the age group of those between 65 and over (692, 19.5% of the total); 73% of those in the 16 to 24 years age group reported to have received the vaccine, whereas 68% of those above 65 years indicated the same. The Health Region with the highest number of participants in the survey was Toronto, accounting for 1,342 entries (37.7%) and a 72% vaccination rate. Regarding race, individuals that identified as White/Caucasian represented 1313 (37%) of all entries and had the highest vaccination uptake with 82% of them indicating to have received the COVID-19 vaccine. On the other hand, those that identified as Indigenous had the lowest vaccine uptake with 60% indicating to have received the vaccine.

Table 2: Descriptive Statistics of the Fields Covid-19 Survey

Variable	**no**, N = 958	**yes**, N = 2,593
Income		
over_90000	238 (25%)	722 (75%)
15000_24999	160 (34%)	315 (66%)
25000_39999	140 (32%)	302 (68%)
40000_59999	113 (25%)	334 (75%)
60000_89999	67 (17%)	327 (83%)
under_15000	240 (29%)	593 (71%)
Age_group		
16_24	223 (27%)	614 (73%)
25_34	186 (27%)	498 (73%)
35_44	129 (25%)	385 (75%)
45_54	123 (27%)	327 (73%)
55_64	75 (20%)	299 (80%)
65_and_over	222 (32%)	470 (68%)
Health_Region		
Toronto	371 (28%)	953 (72%)
Central	224 (28%)	581 (72%)
East	135 (23%)	448 (77%)
West	228 (27%)	611 (73%)
Race		
white_caucasian	233 (18%)	1,080 (82%)
arab_middle_eastern	76 (36%)	138 (64%)
black	114 (38%)	184 (62%)
east_asian_pacific_islander	69 (23%)	234 (77%)
indigenous	76 (40%)	115 (60%)
latin_american	69 (38%)	111 (62%)
mixed	105 (34%)	205 (66%)
other	128 (35%)	239 (65%)
south_asian	88 (23%)	287 (77%)

[1] n (%)

Multivariate Regression

Table 3 shows the results of the logistic regression on vaccination status using socio-economic, geographical factors (by Health Region) and their interactions as predictors. The reference groups in each case were set as follows: 16 to 24 years (age group), White Caucasian (Race), Toronto (Health Region), Over CAD 90,000 (Income). Socio-economic factors with statistically significant odds ratios were the age group of 65 years and over (OR=0.44), persons who identified as Arab/Middle Eastern (OR=0.15), Black (OR=0.17), Indigenous (OR=0.27), Latin American (OR=0.24), South Asian (OR=0.4) and Other Race/Ethnicity (a group those that identified as Southeast Asian, Filipino, West Asian, and Minorities Not Identified Elsewhere, OR=0.17), and those that lived in a household with an income bracket between CAD 25,000-39,999 (OR=0.23).

Regarding the interaction effects, the interaction of the Central Health Region and income bracket between 15000 to 24999 CAD was statistically significant (OR=0.4). In age group and income, significant effects were estimated for those 65 years and older with a household income between CAD 25000-39999 (OR=7.21), and with an income between CAD 40000-59999 (OR=3.12). In the case of race and income, significant effects were estimated for individuals that identified as Arab/Middle Easterners with a family income between 15000 and 24999 (OR=5.68) or income under CAD 15000 (OR=4.21), Black individuals with a family income under CAD 15000 (OR=4.26) or between CAD 15000-24999 (OR=3.35); additionally, there were statistically significant interaction effects in the case of those that identified as belonging to a race not identified elsewhere (“Other”) within multiple income brackets: under CAD 15000

(OR=3.73), between 15000 and 24999 (OR 11.2), between 25000 and 39999 CAD (OR=4.67), and with income CAD 40000-59999 (OR=9.58). Finally, there was a significant interaction effect for South Asian individuals with an income under CAD 15000 (OR=3.10).

Table 3: Multiple Regression Analysis-Predictors of Vaccination Status

Characteristic	**OR**	**95% CI**	**p-value**
Age Group			
16_24	—	—	
25_34	0.58	0.26, 1.28	0.2
35_44	0.72	0.33, 1.57	0.4
45_54	0.53	0.25, 1.13	0.10
55_64	0.94	0.42, 2.09	0.9
65_and_over	0.44	0.22, 0.86	0.017
Race			
white_caucasian	—	—	
arab_middle_eastern	0.15	0.07, 0.35	<0.001
black	0.17	0.09, 0.34	<0.001
east_asian_pacific_islander	0.83	0.40, 1.75	0.6
indigenous	0.27	0.11, 0.62	0.002
latin_american	0.24	0.10, 0.58	0.002
mixed	0.49	0.23, 1.03	0.059

(continued)

Characteristic	**OR**	**95% CI**	**p-value**
other	0.17	0.10, 0.31	<0.001
south_asian	0.40	0.20, 0.79	0.009
Health Region			
Toronto	—	—	
Central	1.12	0.69, 1.82	0.6
East	1.07	0.59, 1.93	0.8
West	1.21	0.72, 2.04	0.5
Income			
over_90000	—	—	
15000_24999	0.42	0.15, 1.19	0.10
25000_39999	0.23	0.08, 0.69	0.009
40000_59999	0.49	0.16, 1.43	0.2
60000_89999	0.84	0.26, 2.72	0.8
under_15000	0.40	0.16, 1.02	0.055
Health Region * Income			
Central * 15000_24999	0.40	0.17, 0.97	0.043
East * 15000_24999	1.43	0.54, 3.74	0.5
West * 15000_24999	0.63	0.28, 1.43	0.3

(continued)

Characteristic	**OR**	**95% CI**	**p-value**
Central * 25000_39999	0.99	0.42, 2.31	>0.9
East * 25000_39999	0.96	0.36, 2.57	>0.9
West * 25000_39999	0.97	0.41, 2.29	>0.9
Central * 40000_59999	1.01	0.42, 2.40	>0.9
East * 40000_59999	0.86	0.33, 2.22	0.8
West * 40000_59999	0.64	0.27, 1.50	0.3
Central * 60000_89999	2.92	0.91, 9.33	0.071
East * 60000_89999	1.58	0.48, 5.18	0.4
West * 60000_89999	1.48	0.54, 4.04	0.4
Central * under_15000	0.80	0.39, 1.63	0.5
East * under_15000	1.11	0.46, 2.73	0.8
West * under_15000	0.66	0.31, 1.39	0.3
Age Group * Income			
25_34 * 15000_24999	0.97	0.30, 3.09	>0.9
35_44 * 15000_24999	0.68	0.21, 2.19	0.5
45_54 * 15000_24999	1.17	0.33, 4.10	0.8
55_64 * 15000_24999	2.81	0.63, 12.5	0.2
65_and_over * 15000_24999	1.54	0.50, 4.69	0.5

(continued)

Characteristic	OR	95% CI	p-value
25_34 * 25000_39999	2.68	0.80, 8.95	0.11
35_44 * 25000_39999	2.37	0.64, 8.78	0.2
45_54 * 25000_39999	2.12	0.63, 7.11	0.2
55_64 * 25000_39999	1.59	0.42, 6.05	0.5
65_and_over * 25000_39999	7.21	2.20, 23.6	0.001
25_34 * 40000_59999	2.18	0.66, 7.19	0.2
35_44 * 40000_59999	1.48	0.43, 5.04	0.5
45_54 * 40000_59999	2.57	0.72, 9.13	0.15
55_64 * 40000_59999	1.09	0.28, 4.18	>0.9
65_and_over * 40000_59999	3.12	1.03, 9.50	0.045
25_34 * 60000_89999	0.47	0.12, 1.89	0.3
35_44 * 60000_89999	1.05	0.17, 6.64	>0.9
45_54 * 60000_89999	0.93	0.20, 4.37	>0.9
55_64 * 60000_89999	0.56	0.13, 2.38	0.4
65_and_over * 60000_89999	2.51	0.66, 9.56	0.2
25_34 * under_15000	1.95	0.70, 5.45	0.2
35_44 * under_15000	1.32	0.45, 3.84	0.6
45_54 * under_15000	1.58	0.53, 4.73	0.4

(continued)

Characteristic	OR	95% CI	p-value
55_64 * under_15000	0.81	0.25, 2.68	0.7
65_and_over * under_15000	1.20	0.47, 3.04	0.7
Race * Income			
arab_middle_eastern * 15000_24999	5.68	1.56, 20.6	0.008
black * 15000_24999	3.35	1.15, 9.75	0.026
east_asian_pacific_islander * 15000_24999	1.82	0.52, 6.39	0.4
indigenous * 15000_24999	0.93	0.26, 3.31	>0.9
latin_american * 15000_24999	3.44	0.70, 16.9	0.13
mixed * 15000_24999	1.03	0.29, 3.67	>0.9
other * 15000_24999	11.2	2.79, 45.2	<0.001
south_asian * 15000_24999	1.92	0.59, 6.24	0.3
arab_middle_eastern * 25000_39999	1.54	0.38, 6.31	0.5
black * 25000_39999	1.90	0.61, 5.88	0.3
east_asian_pacific_islander * 25000_39999	0.63	0.17, 2.27	0.5
indigenous * 25000_39999	1.86	0.47, 7.41	0.4
latin_american * 25000_39999	1.55	0.39, 6.25	0.5
mixed * 25000_39999	0.95	0.23, 3.95	>0.9
other * 25000_39999	4.67	1.33, 16.4	0.016

(continued)

Characteristic	OR	95% CI	p-value
south_asian * 25000_39999	1.78	0.53, 5.98	0.4
arab_middle_eastern * 40000_59999	2.90	0.69, 12.1	0.14
black * 40000_59999	1.87	0.58, 6.03	0.3
east_asian_pacific_islander * 40000_59999	0.42	0.13, 1.35	0.15
indigenous * 40000_59999	1.12	0.29, 4.36	0.9
latin_american * 40000_59999	0.88	0.20, 3.82	0.9
mixed * 40000_59999	0.70	0.19, 2.64	0.6
other * 40000_59999	9.58	2.18, 42.1	0.003
south_asian * 40000_59999	1.35	0.41, 4.45	0.6
arab_middle_eastern * 60000_89999	3.83	0.82, 17.9	0.088
black * 60000_89999	1.83	0.42, 7.89	0.4
east_asian_pacific_islander * 60000_89999	2.59	0.59, 11.4	0.2
indigenous * 60000_89999	1.67	0.23, 12.2	0.6
latin_american * 60000_89999	0.73	0.14, 3.90	0.7
mixed * 60000_89999	1.17	0.20, 6.90	0.9
other * 60000_89999	0.97	0.21, 4.45	>0.9
south_asian * 60000_89999	1.87	0.45, 7.74	0.4
arab_middle_eastern * under_15000	4.21	1.13, 15.7	0.033

(continued)

Characteristic	OR	95% CI	p-value
black * under_15000	4.26	1.45, 12.5	0.008
east_asian_pacific_islander * under_15000	1.04	0.35, 3.08	>0.9
indigenous * under_15000	1.66	0.52, 5.33	0.4
latin_american * under_15000	2.54	0.72, 8.98	0.15
mixed * under_15000	0.93	0.20, 4.26	>0.9
other * under_15000	3.73	1.64, 8.45	0.002
south_asian * under_15000	3.10	1.10, 8.74	0.032

[1] OR = Odds Ratio, CI = Confidence Interval

Discussion

The rapid development of COVID-19 vaccines has been considered as a major achievement of modern medicine[29]. The availability of vaccines at the end of 2020 made some believe that they would be a determinant factor in a rapid ending of the pandemic[30]. However, despite previous successful vaccination campaigns that were crucial to control diseases such as smallpox and polio[31], vaccination efforts in the case of Covid-19 have faced multiple challenges that have complicated the achievement of global immunity.

Among the different challenges faced by Covid-19 vaccination efforts are the development of new variants due to inadequate public health measures[32] and inequity in vaccine access between low and high income countries[33]. However, it is also well established that even in the case of high income countries that have had ample access to vaccines since 2020, such as the US, the UK, and Canada, there have been challenges in vaccination efforts due to differences in vaccine uptake among different segments of the population. More specifically, lower vaccine uptake has been associated with socio-economic factors such as race (i.e., identifying as Black, Asian, Indigenous) and household income (typically within lower income brackets)[34–37]. Reasons given for this association have included medical mistrust due to systemic medical racism, mistrust in vaccines, and the influence of conspiracy theories[34,36,38–40].

In addition, vaccine uptake is influenced by geography as shown by different studies that have identified intra-regional differences in vaccine uptake[13,41,42]. However, the majority of studies that have analyzed spatial differences in vaccination have been carried outside of Canada, where spatial analyses have been focused at the country level[43].

In this regard, we explored spatial and socio-economic determinants of vaccination status in the province of Ontario. This province is of particular interest as it has seen recently major structural health changes with the dissolution of the Local Health Integrated Networks (LHINs) and their incorporation into larger Health Regions[44]. The idea behind the change was to address the inequalities that were identified under the LHIN approach[45], and in the case of Covid-19 vaccination.

Our results indicate that across the most densely populated Health Regions of Ontario, almost three quarters of the surveyed individuals reported having received the first dose of a Covid-19 vaccine (Table 2). However, the likelihood of vaccination significant differed between age, race, and income (Table 3). These results are consistent with other studies that have shown significant lower vaccination in individuals within low income brackets [citations here] . In our case, individuals with a household income below CAD 39,999 had a significantly lower probability of having received the vaccine when compared to individuals in high income households (with an income above 90,000 CAD)

- Influence of geography
- ontario and Health Regions
- Results
- Limitations

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