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Impacts of the COVID-19 Pandemic on Telecommuting and Travel

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Abstract

This chapter examines changes in telecommuting and the resulting activity-travel behavior during the COVID-19 pandemic, with a particular focus on California. A geographical approach was taken to "zoom in" to the county level and to major regions in California and to "zoom out" to comparable states (New York, Texas, Florida). Nearly one-third of the domestic workforce worked from home during the pandemic, a rate almost six times higher than the pre-pandemic level. At least one member from 35 percent of U.S. households replaced in-person work with telework; these individuals tended to belong to higher income, White, and Asian households. Workplace visits have continued to remain below pre-pandemic levels, but visits to non-work locations initially declined but gradually increased over the first nine months of the pandemic. During this period, the total number of trips in all distance categories except long-distance travel decreased considerably. Among the selected states, California experienced a higher reduction in both work and non-workplace visits and the State's urban counties had higher reductions in workplace visits than rural counties. The findings of this study provide insights to improve our understanding of the impact of telecommuting on travel behavior during the pandemic.

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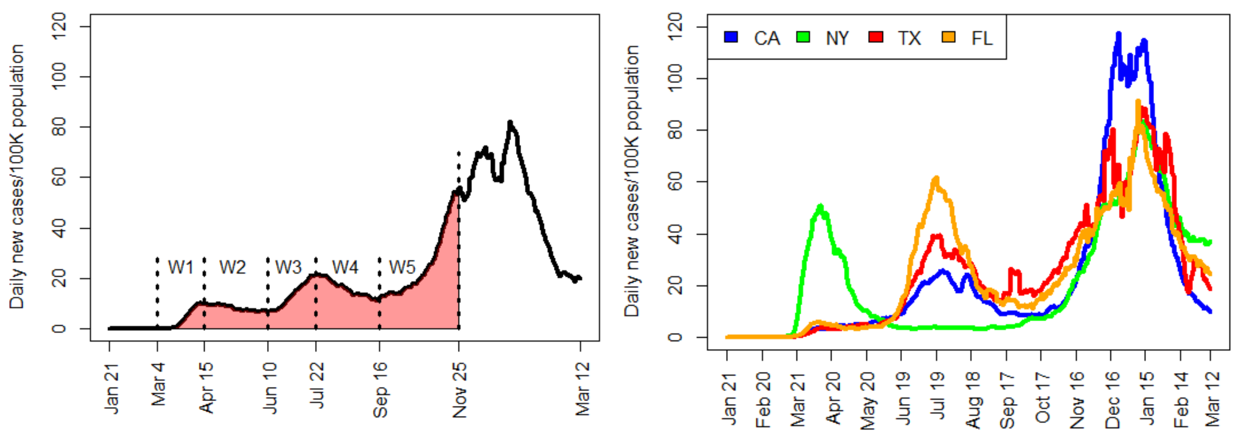
1. Overview

The COVID-19 pandemic has created extreme disruption in our regular day-to-day schedules and triggered massive changes in activity-travel behavior. Due to social distance practices and activity-travel restrictions imposed by the pandemic, telecommuting — also known as working from home or telework — has become a widespread reaction, with significant increases during 2020 compared to prior years (Beck and Hensher, 2020a, 2020b; Conway, 2020). A recent survey estimates that between February and May 2020, over one-third of the American labor force replaced in-person work with telework, which resulted in the share of remote workers nearing 50 percent of the nation's workforce (Brynjolfsson et al., 2020). In addition to work, other daily routines also changed: in-person grocery/restaurant visits were impacted by increased takeout/delivery, in-store visits were largely replaced by online shopping, and in-person social interactions often became virtual social visits. These changes in activity participation contributed to changes in travel behavior during the pandemic. This chapter reports on observed changes in telecommuting and travel, with a particular focus on California (CA). To understand the breadth and depth of change, a geographical analysis was taken. First, a disaggregate approach involved "zooming in" to major regions and counties in California and, second, an aggregate approach of "zooming out" to comparable states[4] including New York (NY), Texas (TX), and Florida (FL).

Figure 1 depicts daily new COVID-19 cases per 100K population from January 2020 to March 2021 in the U.S. and the selected states. The ebb and flow in daily new infection cases suggest that the pandemic passed through a series of waves over this period.



a. Selected time windows for U.S. **b. Infection rates for selected states**

Data source: The New York Times (2020)

Figure 1. Daily new COVID cases per 100K population from January 2020 to March 2021

We analyzed nine months of pandemic data from March 4, 2020 through November 25, 2020. To observe changes in behavior, including changes in telecommuting, visits to work and

[4] These states are the four most populous in the United States and have received significant media focus throughout the pandemic due in part to disparate policy orientations. Two states are blue (CA and NY) and two are red (TX and FL) based on the 2020 U.S. presidential election.

nonwork places, and average distance traveled during this period, we defined five *time windows*. The shaded area in Figure 1a defines the selected windows and their respective start and end dates. The overall national pattern of new COVID cases between the start of the pandemic to just before the start of the November holiday season was defined by three periods of significant increase and two periods of decrease in daily new cases. This national pattern did not necessarily reflect regional trends. Furthermore, given the time lag between COVID-19 exposure and the appearance of symptoms, the endpoints for each window were not precisely defined. Nevertheless, these windows appear quite suitable for the aggregate analyses proposed.

This exploratory study provides a descriptive analysis of the impacts of telecommuting during the pandemic using data from multiple sources (i.e., big data). We believe that such an examination using big data is essential to understanding the changes in telecommuting and the associated changes in activity-travel behavior, and consequently for informed policy analysis. After describing the data sources, three interrelated analyses are presented. First, in section 3, an assessment of the level of telecommuting in California before the pandemic provides a baseline for analysis. Second, in section 4, changes in telecommuting during the pandemic are presented. Third, in section 5, the changes are presented in activity visits and travel distance in California with reference to the selected states. Finally, the findings and policy discussion are provided.

3. Data Source and Timeframe

The datasets used for this study are drawn from the following heterogeneous sources:

- The New York Times COVID-19 data repository (The New York Times, 2020)
- MTI COVID-19 Impact Analysis Platform (Maryland Transportation Institute, 2020)
- Google COVID-19 Community Mobility reports (Google LLC, 2020)
- US Census Bureau 2018
- Bureau of Transportation Statistics 2020
- 2017 National Household Travel Survey (Federal Highway Administration, 2017)
- Household Pulse Survey 2020-2021 (US Census Bureau, 2020)

The New York Times dataset contains the US state and county-level COVID data (cumulative cases and deaths) since the first case (January 22, 2020) in the US. For the MTI dataset, we extracted data from their publicly available web platform. The MTI platform provides data on four major categories at the US state and county-level for each day from January 1, 2020 to till now. These four categories include mobility and social distancing, COVID and health, economic impact, and vulnerable population. MTI utilized privacy-protected mobile device location data that are collected from multiple sources representing person and vehicle movements. After a rigorous multi-level weighing and validation of the imputed data, data are made available to the COVID-19 impact analysis online platform (Zhang et al., 2020). For details, readers are referred to MTI's web portal (https://data.covid.umd.edu/).

Google COVID-19 Community Mobility report contains percentage change in visitor locations from a baseline in different geographic areas of the world including the US. The report categorizes activity places into a set of commonly referred types, such as retail and recreation (e.g., restaurants, cafes, shopping centers, museums, movie theaters), groceries and pharmacies (e.g., grocery markets, food warehouses, farmers markets, drug stores), parks (e.g., public gardens, castles, national forest, camp-ground), transit stations, workplaces, and residential. The data shows the relative changes in visitors to categorized places compared to baseline days. A baseline day represents a *normal* value for a specified day of the week. It is the median value from the 5-week period from January 3 to February 6, 2020. For each region-category, the baseline does not represent a single value instead, it represents seven individual values for seven different days of a week (Google LLC, 2020).

The socio-economic and location attributes of counties are obtained from the US Census Bureau 2018 and EPA Smart Location database 2014. Travel data is obtained from the Bureau of Transportation Statistics (BTS) 2020. It provides trips by distance categorical data and number of people staying at home and not staying home at the aggregate national, state, and county levels from January 2019 to March 2021. The travel statistics are estimated by the Maryland Transportation Institute and Center for Advanced Transportation Technology Laboratory at the University of Maryland based on the anonymized national panel of mobile device data. Here trips are defined as movements that stay longer than 10 minutes at an anonymized location away from home. These trips include travel by all modes, such as driving, rail, transit, and air (Bureau of Transportation Statistics, 2020a).

To identify the socio-demographic characteristics of workers who worked from home or who had options to work from home before the pandemic, the 2017 National Household Travel Survey (NHTS) is used. This dataset provides socio-demographics and travel information for US residents in all 50 states and the District of Columbia. It contains detailed trip data for a pre-assigned 24-hour period for all individuals in each household. The Census Pulse Survey 2020-2021 (US Census Bureau, 2020) is also used to observe telework behavior in the US during COVID. This is a household survey that measures the effects of COVID on people's lives. This survey collected data on travel behavior during phase 2 (August 13 – October 26) and phase 3 (October 28 – March 29, 2021) of the survey over two-week periods. Multiple datasets in this study are joined using state/county FIPS (Federal Information Processing Standard) codes. This preprocessing of data from multiple heterogeneous sources falls into the realm of *Big Data* analysis since we merge data from various sources that have a mixture of structured and unstructured data equivalent to the "variety" attribute of Big data processing (IBM Infographics, 2020).

For this current study, we consider nine months of pandemic data from March 4, 2020 to November 25, 2020. Figure 1 shows the daily new COVID cases reported in the US during the full year of the pandemic from January 2020 to March 2021. As it is observed, there have been a series of rise and fall in the daily infection cases suggesting that the pandemic passed through a series of *waves* over time. This figure demonstrates the presence of three waves in the US within the one-year timeframe. The pandemic imposed substantial changes in the daily lives of a large portion of the population, creating tremendous changes to typical day-to-day business. To observe the changes in human behavioral traits, for example, changes in work from home practice, average distance travel, visiting work and nonwork places, we selected five *time-windows*. The windows are selected in such a way so that each window represents either an increasing trend or a decreasing trend of the daily infection cases. Thus, the overall national pattern of new COVID-19 cases between the start of the pandemic to just before the start of the November holiday season is defined by three periods of significant increase and two periods of decrease in daily new COVID cases.

The first, Window 1 from March 4 through April 15 (6-weeks) corresponds to the first wave of increased cases. This period of increasing cases repeats in Windows 3 and 5, defined as June 10 to July 22 (6-weeks) and September 16 to November 25 (10-weeks) respectively. On the other hand, Windows 2 from April 15 to June 10 (8-weeks) and Window 4 from July 22 to September 16 (8-weeks) correspond to a "flattening of the curve". This national pattern does not necessarily reflect regional trends. Furthermore, given the time lag between COVID-19 exposure and the appearance of symptoms, the endpoints of each window are not well defined. The shaded area in Figure 1 denotes the five selected windows and their respective time-periods.

This study analyzes the impacts of the COVID-19 pandemic on telecommuting practice and travel behavior in California. In appropriate cases, telecommuting and travel behavior in other three populous states with similar economic growth are also studied to observe their differences with California. Figure 1 also shows how the pandemic spread over one year (January 2020 to March 2021) in California and other three states in the US namely, New York, Texas, and Florida. It is observed that New York experienced a severe early hit of the pandemic compared to the other three states. The infection curve of New York got flatten during the middle of the year (summer quarter) where the other states reached a higher spike of daily infection cases. During the latter period of the year, California reached the highest peak among the four states.

The first case of COVID-19 pandemic was confirmed on January 25, 2020 in California. Ten of the first twenty confirmed cases in the US occurred in California (Worldometer, 2020). As of March 12, the cumulative confirmed COVID-19 cases in California were 3,616,872, which resulted in a total of 55,336 deaths (The New York Times, 2020). Table 1 shows the progress of COVID-19 cases over time in California and other three states. It is observed that compared to the other three states, the first 10K confirmed cases appeared later in California (after 68 days). In contrast, New York reached the first 10K and 100K cases very rapidly (after 20 and 33 days respectively). After that, the first 1M cases appeared later in New York than in the other states due to the restrictive measures. California is the first state to impose a stay-at-home order that mandates all residents to stay at home except for essential jobs and needs. This order also instructs health care facilities to prioritize service to those people who are the sickest (The American Journal of Managed Care, 2021). The first stay-at-home order activation period was longer in California and New York compared to Texas and Florida (Table 3).

Table 1: COVID-19 cases in California and other three states in the US

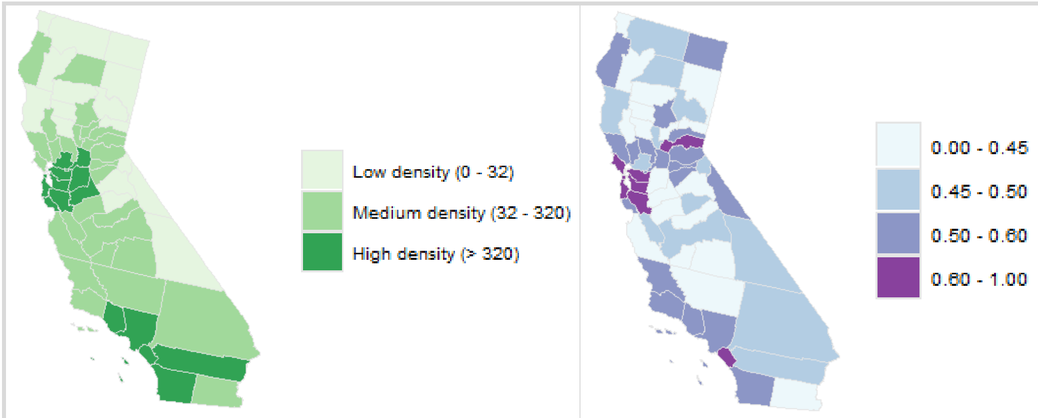
COVID-19 cases	California	New York	Texas	Florida
First confirmed case	25-Jan-20	01-Mar-20	12-Feb-20	01-Mar-20
First confirmed death	04-Mar-20	14-Mar-20	16-Mar-20	06-Mar-20
First 10 case after 1st case	30	3	12	6
First 100 cases after 1st case	42	7	34	14
First 1K cases after 1st case	54	16	42	21
First 10K cases after 1st case	**68**	**20**	57	33
First 100K cases after 1st case	123	**33**	127	113
First 1M cases after 1st case	292	**307**	268	275
Cumulative cases till Mar 12, 2021	3,616,872	1,728,900	2,722,037	1,967,857
Cumulative deaths till Mar 12, 2021	55,336	48,277	46,391	32,144
First stay-at-home activation period	Mar19 – May8	Mar22 – May15	Apr2 – Apr30	Apr3 – May4

Data source: The New York Times (2020) and the Economic Tracker (2020)

Note: In the table, data from 3rd row to 8th row show number of days.

4. Overview of Telecommuting in California

California is located on the west coast of the United States. It is the most populous state and the third-largest state by area with a population of over 39.3 million living in the area of about 163,696 square miles. The state is divided into 58 counties. The distribution of population density (number of persons per square mile) in each county is shown in Figure 2(a). High-density metropolitan areas are mostly observed near bay areas, central, and the southern portions of the state (darker green color). The low-density non-metropolitan areas are mostly located in the northern and eastern portions of California. Based on the regional regimes of the 18 Metropolitan Planning Organizations of California, the metropolitan areas can be divided into three broad groups: Bay area, Central valley, and Southern California. The Bay area is familiar with its large concentration of many high-tech companies. The tech-hub of the Bay area is called Silicon Valley, which serves as the global center for high technology and innovation. The socio-demographic and location characteristics of California metro and non-metro areas are shown briefly in Table 2.



(a) **(b)**

Data source: US Census Bureau (2018)

Figure 2: Distribution of California counties by (a) population density (number of persons per square mile) and (b) fraction of workers in telecommutable jobs

Table 2 shows that the median annual income is considerably higher in California than the national average, particularly in the Bay area (89.8K USD). On the other hand, the fraction of people in full-time jobs in California is lower than the US fraction (52.4 versus 57.6). A higher fraction of households has internet access and computing device in California than the overall US fraction. Rural CA households comparatively have less internet access than metro households, yet the fraction is higher than the national-level fraction.

Table 2: Socio-demographics of people living in CA metro and non-metro areas

Sociodemographic and location characteristics	United States	California	California			
			Bay area	Southern CA	Central valley	Non-MPO areas
Median annual income (in 1000 USD)	**51.6**	**64.4**	**89.8**	67.0	58.5	51.7
Low household income: below $35K (%)	35.5	29.2	19.6	27.3	30.9	34.7
Medium household income: $35K - $100K (%)	44.9	41.7	36.3	40.9	43.0	44.5
High household income: above $100K (%)	19.6	29.1	44.1	31.8	26.0	20.8
Full-time job: weekly work hour above 35 (%)	**57.6**	**52.4**	58.1	53.4	51.7	**49.0**
Workers in telecommutable jobs (%)	**46.6**	**50.0**	**57.3**	**51.0**	48.0	**46.5**
Households having computing device (%)	**83.4**	**89.2**	92.9	90.5	89.7	85.9
Households having internet access (%)	**77.3**	**84.7**	90.3	86.5	84.5	**80.6**
Population density (people per sq. mile)	224.4	402.6	893.9	808.2	265.6	22.5
Employment density (jobs per sq. mile)	125.6	212.6	543.2	383.9	102.7	13.1

Data source: US Census Bureau (2018)

Again, a higher fraction of workers in California is in telecommutable jobs, particularly in the Bay area and Southern CA areas. Note that, telecommutable jobs are defined as jobs in "management, business, science, arts" and "sales and offices" based on the US Census Bureau 2018 occupation codes. The distribution of workers in telecommutable jobs is shown in Figure 2(b), which affirms that the Bay area (dark purple) indeed accommodates a higher number of these jobs since many of the tech giant companies are located there.

Table 3 shows the distribution of population across different socio-demographic characteristics (e.g., household income, household size, age, race, education, and occupation), based on the 2017 NHTS data, for three groups of people: (a) overall population in California, (b) people working from home in California, and (c) people have the option of working from home. As observed from the table, the socio-demographic characteristics of individuals who work from home or who can work from home slightly differ from the general population distribution. Apparently, household income, education, and occupation are the key enablers of people working from home (or providing options to do so). For example, among the people who work from home, 48 percent have household income higher than 100K USD (the last three rows under "household income") and among the people who have options for working from home, this fraction is 65 percent (in CA, around 38 percent population has an annual household income higher than 100K USD in general).

Again, with respect to educational qualification, among the people working from home 32 percent has a Bachelor degree (which is the largest education bracket for this group) and for people who can work from home, this bracket is a Graduate degree. That means people with higher education are prone to do work from home than people who have a college degree or less (out of people who work or can work from home, only 10 percent and 5 percent have high school degrees). Under the hood, this all depends on which occupations individuals are in. In California, 55 percent of jobs belong to the "professional/managerial/technical" category followed by "sales/service" (23 percent). And, these are very two categories where most people who work or can work from home belong. Interestingly, Hispanic and Black people do less work from home than their White counterparts (with respect to their usual demographic distribution). Not surprisingly, metro areas host most of the work-from-home opportunities compared to non-metro areas (92 percent vs. 8 percent).

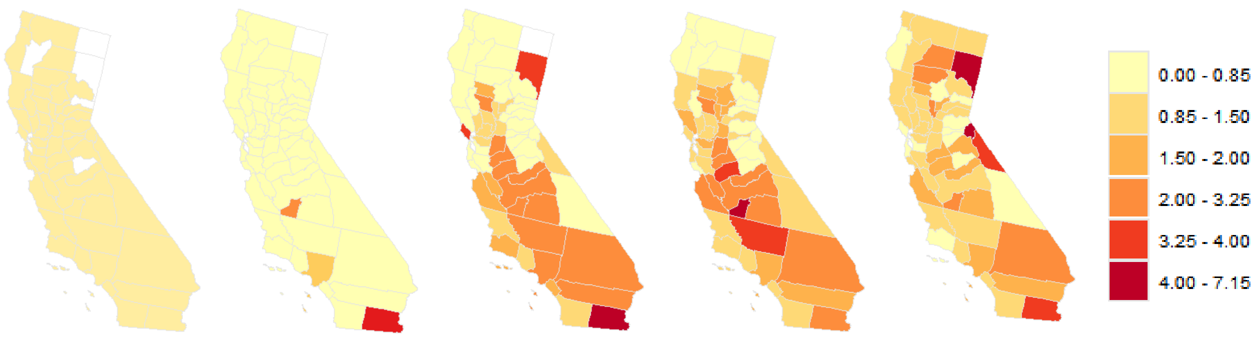
Table 3: Socio-demographics of workers who worked from home during pre-COVID

Household and personal characteristics	**NHTS CA samples (%)** N = 53,603	**Work from home (%)** N = 4,176	**Option of working from home (%)** N = 3,706
Household income			
<$25K	13.90	10.91	3.83
$25K — $35K	7.71	6.34	2.53
$35K — $50K	9.79	6.98	5.39
$50K — $75K	15.88	13.83	9.74
$75K — $100K	13.97	12.95	12.80
$100K — $150K	**19.83**	**22.30**	**25.05**
$150K — $200K	8.59	10.32	15.47
>$200K	10.32	16.38	25.19
Household size			
1	15.77	15.97	16.54
2	**40.66**	**46.55**	**42.85**
3	16.94	17.72	18.62
4	15.66	13.77	15.89
5	6.58	3.35	4.26
Above 5	4.39	2.63	1.83
Age			
<18	11.98	11.77	11.82
18 — 38	20.43	20.54	20.21
39 — 58	**27.18**	**28.02**	**28.13**
59 — 68	20.03	19.63	19.94
>68	20.37	20.04	19.91
Gender:			
Male	47.39	49.97	**58.85**
Female	**52.61**	**50.03**	41.15
Educational qualification			
High school or less	22.30	10.25	5.00
Some college degree	**30.65**	26.30	16.64
Bachelor degree	24.09	**32.05**	36.54
Graduate degree	22.97	31.40	**41.83**
Hispanic/Race status			
Hispanic	14.60	9.75	9.90
White	**74.85**	**78.38**	**75.50**
Black	3.08	2.25	2.48
Asian	9.70	9.32	13.65
Others	11.39	9.12	7.69
Occupation			
Sales/service	22.96	28.09	13.90
Clerical/administrative	10.48	6.49	4.96
Farming/manufacturing	10.70	9.15	5.21
Prefessional/managerial/technical	**55.69**	**55.89**	**75.77**
Others	0.17	0.29	0.13
Residence type			
Metro area	**87.80**	**86.66**	**92.09**
Nonmetro area	12.20	13.34	7.91

Data source: 2017 National Household Travel Survey, Federal Highway Administration (2017)

5. Impact of COVID on Telecommuting in California

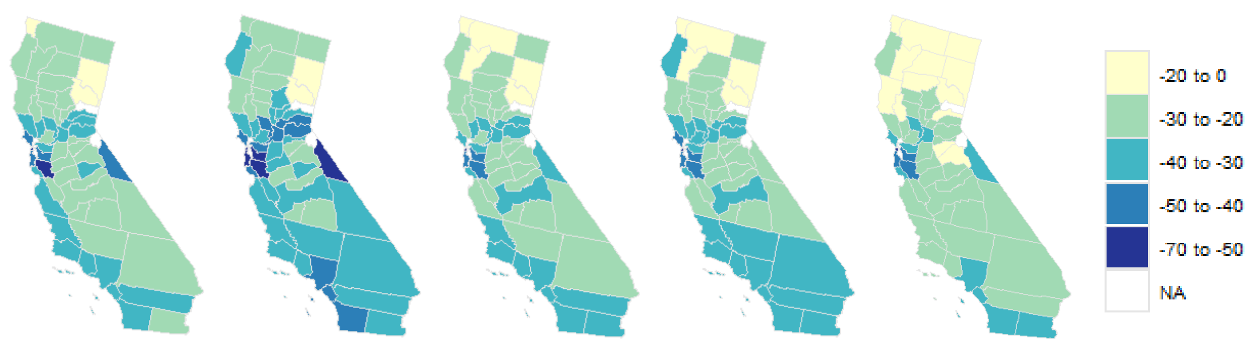
In this section, the changes in workplace visits and the adoption of telecommuting practice due to the COVID-19 pandemic are discussed. The spread of COVID-19 cases over the five selected time windows and the respective changes in visits in workplaces across California counties are shown in Figure 3 and Figure 4 respectively. Apparently, the cases started appearing in the south and progressively moved toward the north (more rural counties) and then all over California (the map becomes darker from one window to the other as time progressed). The cases grew to a high number during Window 3 onward when the majority of the counties had recorded infection higher than 2 confirmed cases per day per 10K people.



Window 1 Window 2 Window 3 Window 4 Window 5

Data source: The New York Times (2020)

Figure 3: Daily new infection cases per 10K population for all counties in California in five time-windows (darker shade indicates higher rates)



Window 1 Window 2 Window 3 Window 4 Window 5

Data source: Google LLC (2020)

Figure 4: Changes in workplace visits from the baseline in five time-windows (darker shade indicates higher changes)

The maps in Figure 4 depicts the percentage changes in workspace visits across all California counties from their respective baselines (five-week span of Jan 3 – Feb 6, 2020) from

Window 1 to Window 5. Note that the changes are actually a *reduction* from the baseline due to COVID and hence are expressed in negative numbers. That means, a higher absolute value indicates higher changes and has a darker shade in color whereas a lighter shade indicates lower changes in workplace visits that are close to the baseline values. It can be observed from the figure that during Window 2 (8 weeks from April 15 – June 10, 2020), most counties had higher changes in workplace visits with respect to their baselines (reduction was more than 30 percent) compared to other windows. In later windows, however, the changes in workplace visits reduced and the overall workplace visits became close to the baselines (reduction from the baseline is less than 30 percent) as more and more counties take lighter in shade in color in the maps. Some rural counties (located in northern CA) even catch up the baseline visits and obtained the lightest shade in the map.

The higher change in workplace visits from the baseline (higher absolute reduction in workplace visits) during COVID implies two situations: (1) workers are no longer commuting but working the same amount of hour at home and/or (2) unemployment rate increases and thus, no commute involves. Table 4 shows the percentage of workforce working from home and unemployment rate in five study windows in California. It is observed that during COVID both work from home fraction increased drastically compared to the pre-COVID period (25 percent vs. 5.7 percent) and it kept increasing in the successive windows till Window 3 (39.8 percent). After that in Window 4 and 5, the fraction slightly reduced. Similar trend is observed for unemployment rate: it was nearly 10 percent in Window 1 (almost 2.5 times from the pre-COVID baseline, 3.9 percent), it increased in Window 2 and then successively declined in rest of the window reaching 9.2 percent in Window 5.

Table 4: Percentage of workforce working from home (telecommuting) and unemployment rate in five study windows in California

	Work from home (%)				Unemployment rate (%)			
Window	Pre-COVID (Jan 3 – Feb 6)	During COVID (Mar 4 – Nov 25)	Change wrt. pre-COVID	Change wrt. prior window	Pre-COVID (Jan 3 – Feb 6)	During COVID (Mar 4 – Nov 25)	Change wrt. pre-COVID	Change wrt. prior window
Window 1 (Mar 4 - Apr 15)	5.7	25.0	338.6	----	3.9	10.1	159.0	----
Window 2 (Apr 15 - Jun 10)		35.4	521.1	41.6		16.2	315.4	98.4
Window 3 (Jun 10 - July 22)		39.8	598.2	12.4		14.0	259.0	-17.9
Window 4 (July 22 - Sept 16)		39.5	593.0	-0.8		11.5	194.9	-24.8
Window 5 (Sept 16 - Nov 25)		36.8	545.6	-6.8		9.2	135.9	-30.3

Data source: Maryland Transportation Institute (2020)

Table 5 reports various telecommuting indicators (fraction of people working from home, changes in workplace visits) across California and the United States during COVID study period and also during pre-COVID baseline period. It can be seen that around one-third of workers (35.70 percent in CA and 33 percent in the US) did work from home during-COVID, which is nearly 6 times higher than the pre-COVID period. Considering the out-of-home work and non-work participation, around 30 percent reduction in work and 29 percent in non-work are dropped in California from the pre-COVID time.

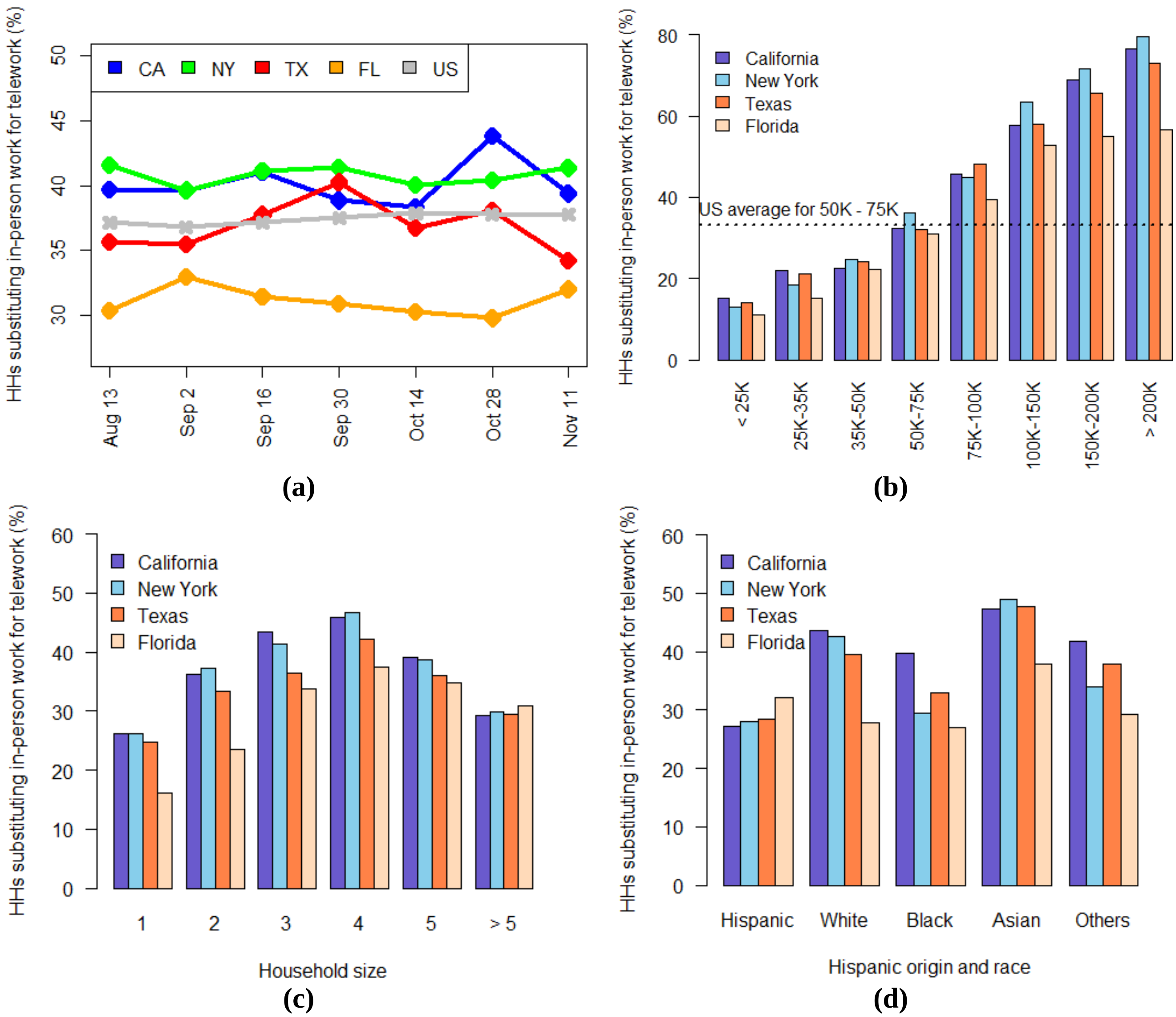
Table 5: Changes in telecommuting and activity-travel due to COVID in the US and CA

Variables	**Region**	**Pre-COVID (Jan 3 – Feb 6)**	**During-COVID (Mar 4 - Nov 25)**	**Change (%)**
Working from home (%)	CA	5.70	35.70	526.32
	US	4.68	33.14	608.70
Unemployment rate (%)	CA	3.90	12.00	207.69
	US	3.47	8.33	140.15
Change in workplace visits (%)	CA	---	---	-30.03
	US			-24.26
Change in grocery and pharmacy visits (%)	CA	---	---	-3.66
	US			1.61
Change in retail and recreation area visits (%)	CA	---	---	-25.02
	US			-10.81

Data source: Maryland Transportation Institute (2020) and Google LLC (2020).

It is imperative to observe the characteristics of the workers that affects the ability to substitute in-person work for telework due to the imposed travel restrictions and stay-at-home order situation during the pandemic. Some insights on this are drawn from the Census Pulse Survey data (2020-21) and the observations are shown in Figure 6. Figure 6(a) shows the percentage of households where at least one adult substituted in-person work for telework due to COVID-19 in the overall US as well as four of the study states. Overall, nearly 37 percent households across the US had seen at least one member replacing their in-person work with working from home. State wise, California and New York had a larger share of this substitution compared to Texas and Florida (among the four states, Florida had apparently the smallest such changes throughout the year).

Since a good fraction of households substituted in-person work with telework, it is important to observe what household characteristics attributed to these changes. Figure 6(b), (c), and (d) show the substitution rates across various socio-demographics indicators of households, namely household income, household size, and ethnicity/race. Household income serves as the proxy of the type of jobs held by adults in the households and the availability of resources in households (e.g., internet connections). As evident in Figure 6(b), households with higher income had switched to telework in more numbers than that of low-income households in all four states, notably California and New York being slightly higher than Texas and Florida. It implies that workers who are in white-collar jobs (high-income) and who have better resources in households have more ability to substitute in-person work for telework.



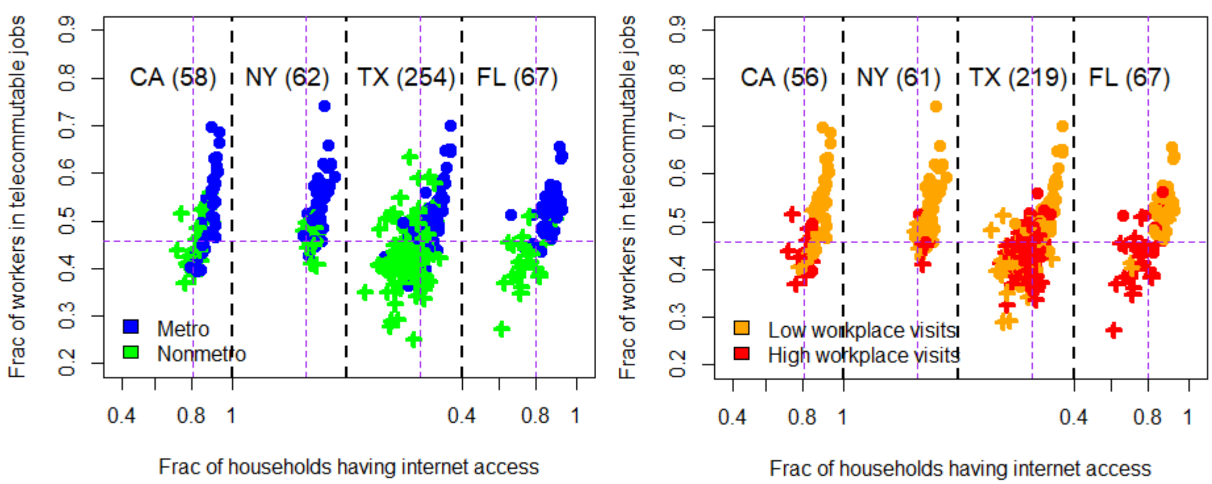
Data source: Household Pulse Survey, US Census Bureau (2020-2021)

Figure 6: Percentage of households where at least one adult substituted in-person work for telework due to COVID-19 from Aug to Nov 2020 in the US and four of the study states (a) and across different income groups (b), household size (c), and ethnicity/race (d)

Note: Only the start dates of the seven bi-weekly survey periods are shown in Figure 6(a).

Again, large households (particularly, households with 3 and 4 members) made a higher substitution to telework compared to small households having 1 or 2 members. Interestingly, households with 5 and more members considerably did less of this switching perhaps because those households might have elderly/retired individuals or young children and possibly had fewer workers compared to other households. With respect to ethnicity/race, two observations are noticeable. First, White and Asian households (in all four states except for Florida) had higher fraction of in-person to telework substitution compared to other races/ethnic backgrounds. Second, Hispanic households in Florida experienced larger adoption of telework compared to the same ethnic group in California, whereas White households in California experienced the reverse compared to Florida.

It is anticipated that counties that contain higher fraction of households with internet access and higher fraction of workers in telecommutable jobs can adjust more conveniently to the 'stay-at-home' order situation during COVID by substituting in-person work for telework. Doing more telework can ultimately results in less workplace visits, thus less movement during the pandemic. This situation indeed happened during the COVID-19 pandemic as illustrated in Figure 5. This figure shows the distribution of counties in terms of fraction of households having internet access (x-axis) and fraction of workers in telecommutable jobs (y-axis), color-coded by metropolitan and non-metropolitan areas in the left figure and by the degree of workplace visits in the right figure for four US states, namely California, New York, Texas, and Florida. The dotted lines represent the median values of the corresponding variables. Green implies non-metropolitan counties whereas blue represents metropolitan counties. Again, orange denotes workplace visits lower than the median value whereas red implies workplace visits higher than the median.



(a) (b)

Data source: US Census Bureau (2018) and Google LLC (2020)

Figure 5: Distribution of worker fraction in telecommutable jobs with respect to changes in household fraction having internet access across counties in four states, by (a) metropolitan status and (b) intensity of workplace visits during COVID

Note: The number of counties for each state is shown in parenthesis

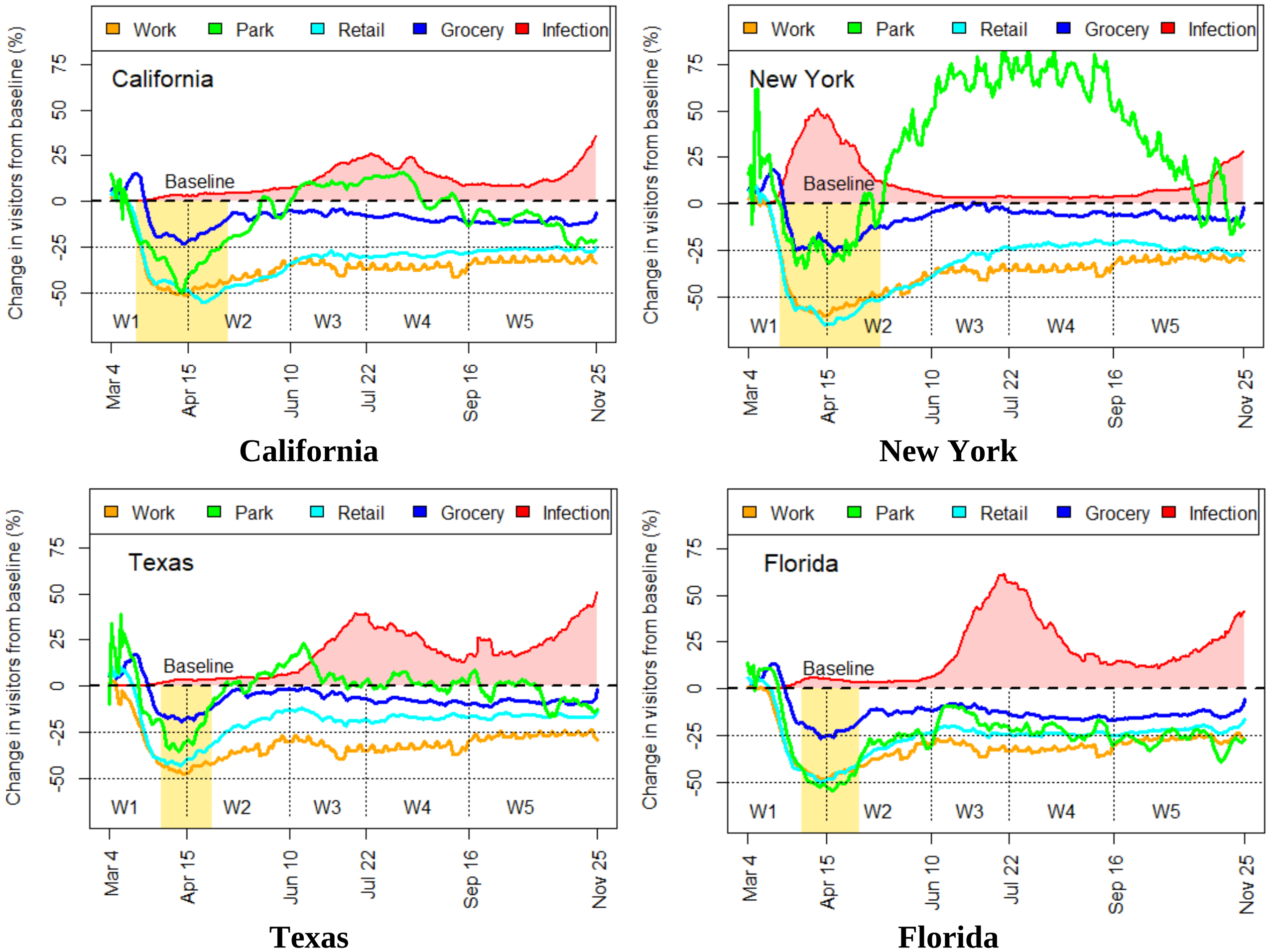
A proportional relationship is observed between internet access and workers in telecommutable jobs. Figure 5(a) depicts that in most of the non-metro counties lower fraction of workers are in telecommutable jobs where the fraction of households with internet access is also low (green ‘+’ signs in the lower left quadrant). The opposite scenario is observed for metro counties shown by blue dots in the upper right quadrant (Figure 5a). Figure 5(b) shows that orange dots are mostly reside in the upper right quadrant, which implies that the higher fraction of workers in telecommutable jobs and the higher fraction of households with internet access correspond to lower workplace visits (higher work from home) during COVID. Moreover, metro areas mostly experienced low workplace visits compared to non-metro areas during COVID as it is observed that blue dots in the left figure coincides with orange dots in the right figure. Almost identical patterns are observed for all the four states.

6. Impacts of COVID on Activity-Travel in California

This section analyzes the impacts of COVID on activity participation and travel behavior in California. Figure 6 shows the changes in visitors, with respect to the corresponding baseline values, in various activity places such as workplace, grocery and pharmacy, retail and recreation, and parks, throughout the study period (Mar 4 – Nov 25, 2020). It also shows the daily new infections for 100K population during the same time period (red shaded area). In all cases, the trend lines are drawn as a seven-day moving average. The amber shaded regions are the first stay-at-home order period for the respective states (as reported in Table 3).

The sharp decline in change in activities places in the first window (initial shock period) is due to the fact that most states had issues their first stay-at-home or shelter-in-place order (also known as “lockdowns”) during that period (shown in the amber shaded regions in the plots). In CA, visits to workplaces and to retail and recreation locations reduced much lower from the baseline in the first window and consequently remained lower than the baseline throughout the year (the percentage change in visitors from the baseline is below -25%). The grocery and pharmacy visits and visits to parks, however, started to rise right after the initial dip and almost caught the baseline later on (the park visits occasionally exceeded the baseline). Similar trend held for other three states: the activity visits declined sharply in the first window (partly due to stay-at-home order activation in the respective states) but then started to rise after the first lockdown and progressively approached toward the baseline still remaining below the baseline visits in all activities except for the park visits.

The visits to parks generally increased compared to the baseline during the summer time (W3 plus W4). New York, for example, experienced a high surge in park visits, mostly due to the fact that NY got severe hit of COVID-19 at the beginning of the year and successively had lower daily new infections through the summer that might have caused higher movement of people, especially to park and outdoor spaces. On the contrary, Florida had seen lower than baseline park visits during the same time frame, which was perhaps due of the fact that the baseline period for Florida (Jan 3-Feb 6) might have high surge of visits recorded (peak time for beach goers in pre-pandemic times) so successive park/beach visits during the COVID time was much lower.



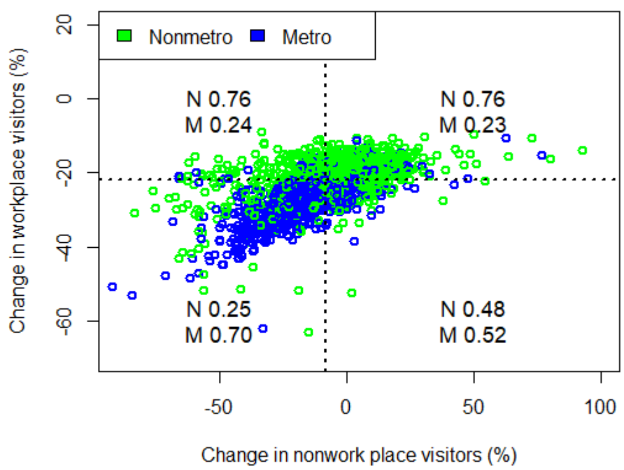
Data source: Google LLC (2020)

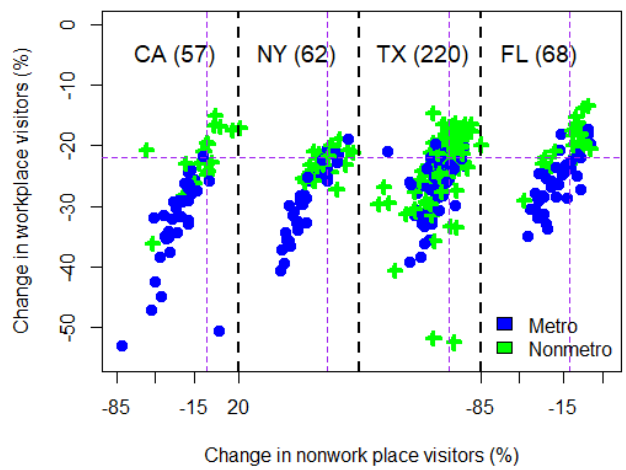
Figure 6: Change in visitors with respect to the corresponding baseline values in various activity locations and daily new cases per 100K population (red shaded area) in four study states

Note: Changes in visitors in various activity locations are shown as a seven-day moving average

Next, it is explored whether there were variations in work and non-work activity participations across urban and rural counties in the US and other study states. The observations are shown in Figure 7. Here non-work activities include grocery and pharmacy visits and retail and recreation visits. Each dot in Figure 7 indicates a county positioned with respect to its changes in non-work place visits (in x-axis) and changes in workplace visits (in y-axis) from their respective baseline values (recorded in five-week window of Jan 3 – Feb 6). The farther the dot from zero line, the higher the change is from the baseline (increase if the change in positive or decrease if the change is negative). The dots are color coded blue and green indicating metro and non-metro counties respectively. The dotted vertical and horizontal lines indicate the overall changes in workplace and non-workplace visits (median values), respectively, across the entire US within the same study period duration. In Figure, the green dots (non-metro) positioned on top of blue dots (metro) in y-axis indicates that non-metro counties experienced smaller changes in workplace visits compared to their metro counterparts.

The higher number of counties that had larger changes in both workplace and non-workplace visits—measured in terms of whether they have higher *absolute* values compared to the respective median values and whether the dots are positioned in the lower left quadrant—belong to metro areas (70 percent of them, as marked by the metro/nonmetro ratio values in the respective quadrants). Whereas, the counties that had experienced little changes from the baseline (residing in the upper right quadrant) are mostly from non-metro areas (76 percent are non-metro and the rests are metro). Figure 7(b) Shows the same scatterplot for all counties in four states: CA, NY, TX, and FL (the number of counties is shown in parenthesis). CA experienced higher changes in workplace visits (with respect to its own baseline), compared to other three states, particularly in metro areas (blue dots).





Data source: Google LLC (2020)

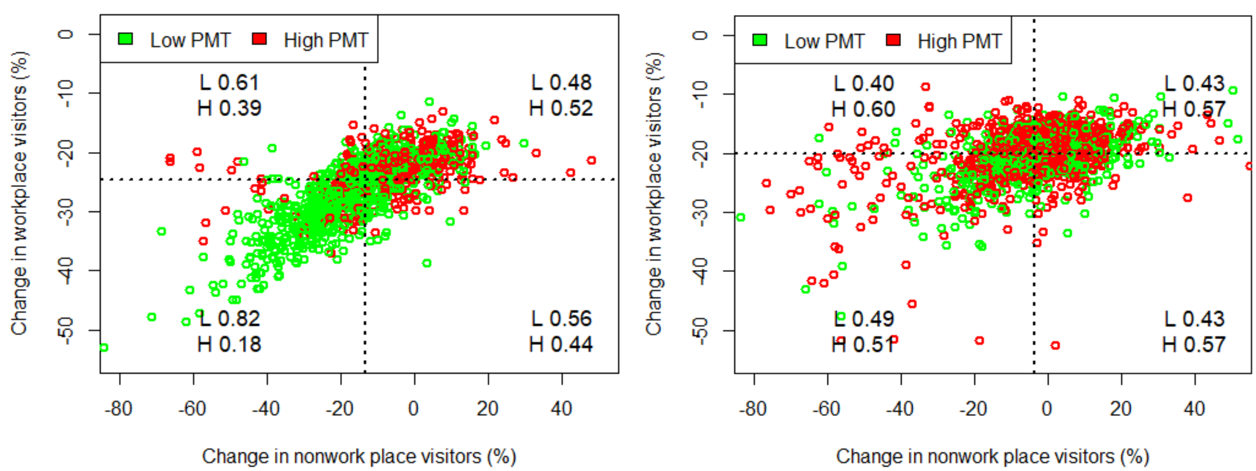
Figure 7: Distribution of counties based on changes in non-workplace and workplace visitors by metropolitan status in the US (a) and in four study states (b)

Note: N and M reports the fraction of non-metro and metro counties in the corresponding quadrant

The relationships between the number of visitors in various activity locations and the average distance traveled per person per day (person-mile traveled on all modes) varies between metro and non-metro areas during COVID. Figure 8 shows the distribution of counties in terms of changes in non-workplace (x-axis) and workplace visits (y-axis), color-coded by the degree of person-miles traveled (PMT) in both metropolitan and non-metropolitan areas. Green indicates a PMT lower than the median value whereas red denotes a PMT higher than the median. Also, for each of the figure's quadrants, the distribution of counties with high and low PMT is reported. Each of the quadrants in Figure 8b that show non-metro counties contain a higher fraction of high PMT values, which is different from the metro counties (Figure 8a). This may be due to non-metropolitan areas typically being less dense so activity locations are more spread spatially.

In contrast, in metropolitan areas, activity locations are more often located in close proximity, so fewer non-work visit results in lower miles-per person.

Counties that are considered metropolitan areas show a notably different relationship between work, non-work, and person-mile traveled than non-metropolitan areas. For example, in metro areas, the lower the work and non-work participation (lower-left quadrant in Figure 8a), the lower the person-miles traveled (82 percent of counties have a low PMT). On the contrary, in non-metro areas, a lower work and non-work participation correspond to higher PMT values (in the lower-left quadrant 51 percent of counties have a high PMT, Figure 8b). The lower non-work participation and higher work participation contributed to higher PMT values (upper-left quadrant in Figure 8b). That means, in both cases, lower non-work participation is associated with a higher PMT value. It implies that the reduction in non-workplace visits does not reduce the average distance traveled per person in a county unless the work or non-work trips that are made are associated within a shorter travel distance.

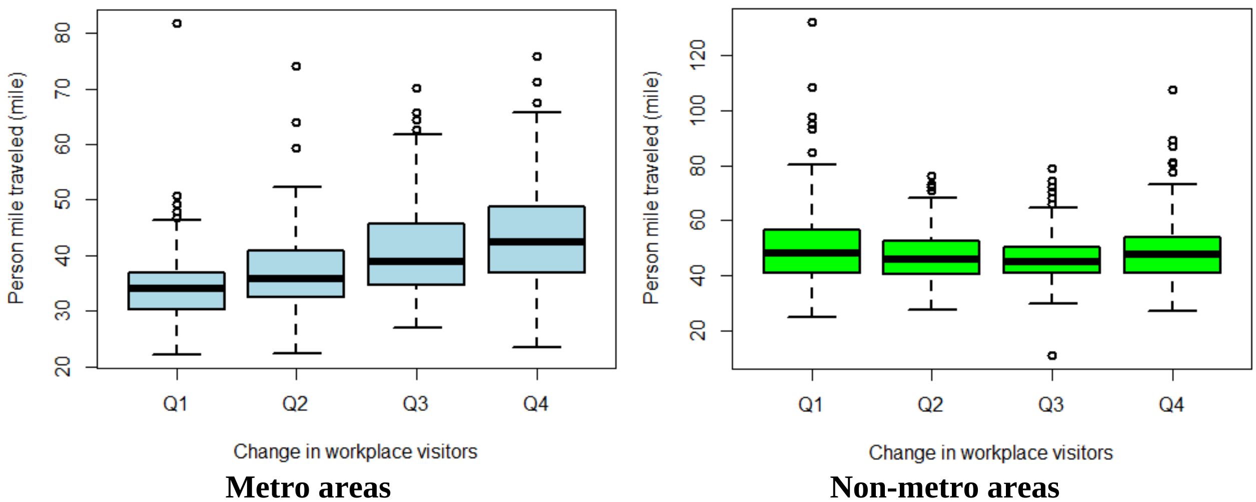


Data source: Google LLC (2020)

Figure 8: Distribution of counties based on changes in non-workplace and workplace visitors by person-mile traveled in metro (left) and non-metro areas (right) in the US

Note: L and H reports the fraction of counties with low and high PMT in the corresponding quadrant

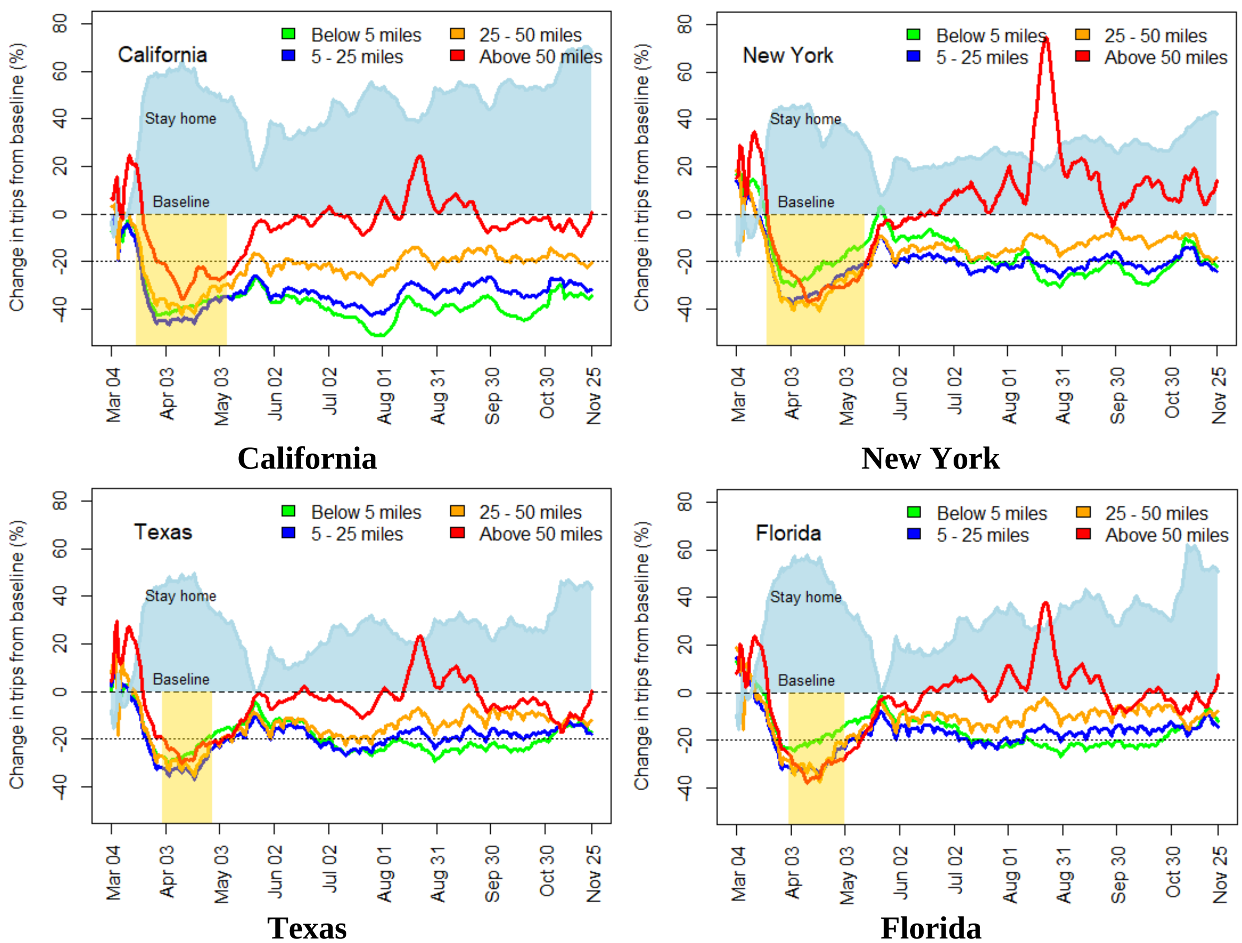
The less number of visitors in workplaces during COVID indicates more people working from home. It is anticipated that more people working from home involves less distance traveled in an area since telework practice does not involve commute. To examine this effect, quantile boxplots are constructed, as shown in Figure 9, to depict the corresponding person-mile traveled in counties within a specified range of the percentage change in visitors in workplaces. Here the counties are split into groups based on quartile values, with Q1 denoting counties having below a 25-percentile value of the percentage change in workplace visits, Q2 denoting counties above the 25-percentile but below 50-percentile, and so on. It is observed that counties with fewer workplace visits have indeed lower person-miles traveled, as the median values (the central line inside the box) increase in higher quartile boxes (Figure 9a). However, this relationship does not hold for non-metropolitan counties. In non-metropolitan areas, higher person-miles traveled is observed for lower quantile values of workplace visits. The higher non-work activity participation and longer travel distance to avail those facilities in non-metro areas might increase the person-mile traveled in those areas despite the reduction in workplace visits.



Data source: Maryland Transportation Institute (2020) and Google LLC (2020)

Figure 9: Relationship between percentage change in visitors in workplaces from the baseline and average person-mile traveled per person per day in metro (left) and non-metro (right) counties in the US

Changes in activity participation contribute to changes in the number of trips. Figure 10 shows the percentage changes in the number of trips across California and other three states during the entire study period (Mar to Nov 2020) with respect to the baseline average during the 5-week duration from Jan 3, 2020, to Feb 6, 2020 (for the sake of consistency, the same baseline time period of Google Mobility report is used here, but only a single average value is extracted instead of 7-week day medians as done in Google Mobility reports). The negative percentage change indicates that the number of trips declined from the baseline due to the pandemic. In addition, trips are categorized into four types based on their distance: (i) short distance trips (below 5 miles), (ii) average commute distance (5-25 miles), (iii) long commute distance (25 - 50 miles), and (iv) long-distance trips (above 50 miles). The figure also shows the percentage changes in people staying home compared to the baseline, which is reported to be positive as more people stayed home than the baseline period. For the same four trip distance categories, Figure 11 shows the absolute number of trips per day in the year 2019 and 2020 in California, which depicts the variation in the number of daily trips for the two years (pre-pandemic 2019 and during-pandemic 2020).



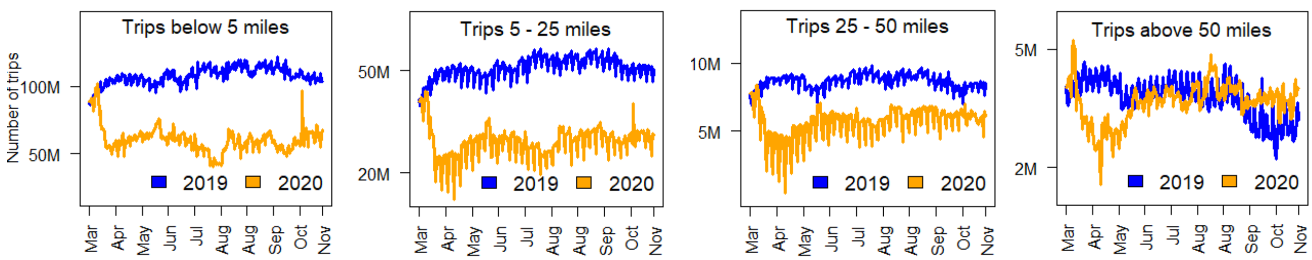
Data source: Bureau of Transportation Statistics (2020)

Figure 10: Changes in the number of trips with respect to the corresponding baseline values by four distance categories and change in the fraction of people staying at home (blue shaded area) in four study states

California had a considerably higher fraction of people staying home with respect to its baseline values compared to the other three states (Figure 10). Moreover, California had higher changes in the number of trips from the baseline (almost below -20 percent every day since March 2020), indicating a higher reduction in overall trips. In the other three states, however, the reduction in trips was not that large (within 20 percent from the baseline or less). Interestingly, Texas and Florida had considerably shorter stay-at-home order duration (only around two weeks) compared to California and New York (which are around 4-5 weeks), which might be a reason for a smaller reduction in trips from their respective baselines.

With regard to the trips of different types, California experienced the largest changes in short distance trips (below 5 miles) (Figure 10) and notably, the number of daily trips of this type dropped from 100 million in 2019 to 50 million in 2020 (Figure 11). Average and long commute distance trips are also declined considerably in California. The long-distance trips (trips longer than 50 miles) did reduce drastically but only in the first pandemic window (around April and

May) and then successively increased to catch the baseline (past May 2020's long-distance trips are almost equal to the 2019's trips). Moreover, long-distance trips occasionally exceeded the baseline. For example, there is a noticeable spike in long-distance trips around the second week of August 2020 in all four states (New York being the highest) (Figure 10), which might be due to school reopening for the Fall 2020 semester that possibly caused a large number of inter-city and inter-state movements (the same spike is observed in daily trips in Figure 11).



Data source: Bureau of Transportation Statistics (2020)

Figure 11: The number of trips per day in the year 2019 and 2020 for four travel distance categories in California

The changes in travel during-COVID in the US and California are shown in aggregate measures in Table 7. This table shows that in California, both the average number of work and non-work trips per person per day were significantly lower during COVID than those during the pre-COVID period (the difference is tested through Wilcoxon signed-ranks non-parametric test). Consequently, the average number of all trips per person per day reduced significantly during COVID. In contrast, the average person-mile traveled (PMT) in California did not show any statistically significant changes during these two periods.

On the other hand, in the US, the average number of work trips decreased but the average number of non-work trips increased significantly during COVID. As a result, the average number of all trips, as well as person-mile traveled (PMT), increased (cf. Table 7). However, according to the seasonally adjusted vehicle-mile traveled (VMT) data, the average VMT is reduced by about 13 percent in 2020 from 2019 (the average VMT were 271,619 and 235,696 in 2019 and 2020 respectively) (Federal Highway Administration, 2019-2020). There is a caveat in this regard to make a straightforward comparison between the rise in PMT and the reduction in VMT in the US during COVID. PMT is calculated from trips using all modes, such as car, train, bus, plane, bike, walk, and others, whereas VMT is computed only for motor vehicle trips in roadways. For instance, non-vehicle trips, such as "walk" contribute to PMT but not to VMT. According to Apple Mobility Trends Reports (2020), "walk" has increased by 24 percent during COVID from the baseline volume on January 13, 2020, which accounted for PMT but not for VMT. These observations need further deep exploration.

Table 7: Trips and PMT in the pre-and during-COVID period in the US and CA

	Pre Pandemic	W1	W2	W3	W4	W5	During Pandemic
	Jan 3 – Feb 6	Mar 4 – Apr 15	Apr 15 – Jun 10	Jun 10 – July 22	July 22 – Sept 16	Sept 16 – Nov 25	Mar 4 – Nov 25
United States							
No. of work trips per person/day	0.53	0.51	0.44	0.43	0.43	0.46	0.45
No. of nonwork trips per person/day	2.84	2.61	2.87	3.01	3.24	3.11	2.99
No. of total trips per person/day	3.36	3.12	3.31	3.44	3.68	3.57	3.45
Person-mile traveled (PMT)	44.52	36.72	40.00	50.11	51.26	48.68	45.70
California							
No. of work trips per person/day	0.47	0.43	0.35	0.33	0.34	0.37	0.36
No of nonwork trips per person/day	2.74	2.43	2.57	2.69	2.77	2.74	2.65
No. of total trips per person/day	3.20	2.86	2.93	3.02	3.11	**3.11**	3.01
Person-mile traveled (PMT)	40.44	30.80	33.95	45.01	47.50	43.95	**40.64**

Data source: Maryland Transportation Institute (2020)

Note: A Wilcoxon signed-ranks non-parametric test was applied to assess differences between sequential windows. Window 1 and during-pandemic values are compared with the pre-pandemic baseline. All values were significantly (at the 5% level) different except for the two values in 'bold'. All the data shown are for the year 2020.

7. Summary and Future Prospects

This exploratory study analyzed the impacts of the COVID-19 pandemic on telecommuting and travel in the U.S. with a particular focus on California. The analysis "zoomed in" to four regions of California and "zoomed out" to three comparable states including New York, Texas, Florida to better position the aggregate analysis results for California. The findings of this study are summarized by general and California-specific observations.

(a) General observations

- Nearly one-third of the U.S. workforce worked from home during the pandemic, a rate about 6 times higher than pre-pandemic.
- About 35 percent of domestic households saw at least one member replace in-person work with telework. Higher-income households and White and Asian households had higher proportions of in-person work replaced by telework.
- There were sharp declines in work and non-work visits during the initial outbreak period (March-April 2020). After the initial sharp decline, however, both grocery/pharmacy and park visits increased, approaching baseline levels during the analysis period.

- A reduction in activity participation produced a reduction in the number of trips in all distance categories throughout the year, except for long-distance trips which declined only during the initial outbreak.

(b) State-specific observations

- California and New York had higher levels of telework replacing in-person work than observed in Texas and Florida.
- California had a considerably higher fraction of people staying home with respect to its baseline compared to the selected comparison states.
- Among the four states, California experienced a higher reduction in both work and non-workplace visits. California urban counties experienced higher reductions in workplace visits than its rural counties.
- Similar to reduced activity participation, California had greater trip reductions relative to the baseline as did the comparison states.

It is unclear whether the changes in telecommuting and activity-travel behavior that were observed will continue after the pandemic ebbs. There have been numerous media reports of both employers and employees preferring telecommuting over commuting, at least some of the time. Using survey data, Conway et al. (2020) anticipated that the trend of working from home was likely to continue post-pandemic. They surveyed reasons for work productivity changes for those who started telecommuting: the top reason for increased productivity was “no commute time” whereas the top reason for decreased productivity was “distraction at home”. Based on an Australian survey, Beck and Hensher (2020a) found that for many respondents working from home was a positive experience and that these individuals expressed interest in continuing to telecommute after the pandemic. Other research suggested a potential increase in telecommuting over the next two years (Amekudzi-Kennedy et al., 2020) based on lower travel/commute costs, more time savings, and higher sustainability impacts. These studies suggest that telecommuting practice is likely to continue and, in some cases, may even grow in the post-pandemic future. A recent poll from the American Institute of Architects revealed that 56 percent of firms expected to have their employees work from the office and suggested that future workplaces may reflect a hybrid mixing of in-person and telework (Keller, 2021).

It can be anticipated that changes will occur in our work arrangements after the pandemic ebbs. If telecommuting does continue at current levels or in a hybrid manner, there will be some advantages and challenges. Working from home can improve peak hour congestion and reduce commuting time and cost. Barrero et al. (2020) estimated that total time savings in the U.S. due to telework, measured by the time saved by not commuting to workplaces, was about 10 billion hours (as of mid-September 2020). They also noted that one-third of the savings was put back into the primary job and the rest was spent in leisure and household activities.

There are some challenges in the adoption of working from home arrangements. Firms would need to provide logistics, engagement, training, and coordination of remote workforces as well as robust cybersecurity infrastructure (Keller, 2021). Workers who work remotely could live anywhere. Working from home would likely decrease spending at local service businesses near former workplaces. Consequently, these service workers may bear the economic impacts (Walsh et al., 2020). Workers may prefer to move from urban residences to outlying areas to gain space needed for dedicated workspaces at home. This may raise demand for larger homes in suburban areas and thus may impact the housing market (Giammona, 2021). Offering childcare closer to home is another challenge of telecommuting (OECD, 2020). Considering these factors, it is critical to fully consider how the post-pandemic workplace may be different than today's workplace. The nature of whatever forms of work emerge will impact activity-travel behavior and the transportation systems that accommodated pre-pandemic mobility.

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Author Contribution Statement

The authors confirm contribution to the paper as follows: study conception and design: R. Rafiq, M. G. McNally; data processing: Y.S. Uddin and R. Rafiq; analysis and interpretation of results: R. Rafiq, M. G. McNally, and Y.S. Uddin; draft manuscript preparation: R. Rafiq, M. G. McNally, and Y.S. Uddin. All authors reviewed the results and approved the final version of the manuscript.

Conflict of Interests

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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