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Does COVID-19 affect metro use in Taipei?

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ABSTRACT

This paper provides the first evidence of the causal effect of COVID-19 on metro use using real-time data from the Taipei Metro System in Taiwan. In contrast to other cities or countries, Taiwan did not enforce strict social lockdowns or mandatory stay-at-home orders to combat COVID-19. The major prevention strategies to the pandemic in Taiwan include promoting social distancing, mandating the wearing of face masks in public areas, and requiring all international arrivals to quarantine for 14 days. Using administrative data on confirmed cases of COVID-19 and ridership from metro stations with the difference-in-differences model, we find that an additional new confirmed case of COVID-19 reduces metro use by 1.43% after controlling for local socio-demographic variables associated with ridership and the number of international arrivals to Taiwan. This result implies that the reduction in metro trips is attributable to decreases in residents’ use of public transportation due to perceived health risks. Furthermore, the effect of COVID-19 on metro use disproportionally impacts stations with different characteristics. The effect is more pronounced for metro stations connected to night markets, shopping centers, or colleges. Although decreases in metro ridership lower the revenue of the Taipei Metro System, our results indicate a tradeoff between increased financial burdens of public transportation systems and reducing medical expenses associated with COVID-19.

1. Introduction

The coronavirus disease 2019 (COVID-19) outbreak has posed serious health risks to the world's population, with more than 75 million confirmed cases and 1.5 million deaths in more than 200 countries and territories by the end of December 2020 (WHO, 2020). In response to this serious threat, many cities or countries have implemented border controls, lockdowns, social distancing, and quarantines to contain the spread of COVID-19 (Cheng et al., 2020a, 2020b). While these public health measures are effective in reducing the prevalence of COVID-19 (Jarvis et al., 2020; Qiu et al., 2020; Saijan et al., 2020), they have changed many aspects of our lives. Public transportation has been especially impacted, with drastic drops in ridership across many cities worldwide (Comfort, 2020). For example, subway ridership has decreased by 93% in New York City (Hughes, 2020). Other cities such as Milan and Lombardy in Italy have also reported that the number of trips taken on public transportation was down by nearly 90% (Griswold, 2020).

Public transportation can be affected by COVID-19 in many ways. First, strict social lockdowns or mandatory stay-at-home orders directly limit the operability of public transportation. For example, public transportation in many cities such as New York City and Wuhan have stopped all passenger services or reduced non-essential services during lockdowns. Moreover, even as passenger services resume, commuters might choose to use other modes of private transportation (e.g., bicycles or personal vehicles) due to perceived health risks. Second, the demand for public transit is likely to fall because consumers will reduce leisure and recreational activities (e.g., dining out, shopping, and watching movies). Overall, it is expected that COVID-19 will decrease public transportation use and that ridership is unlikely to return to pre-COVID-19 levels in the short-run (Donaldson, 2020).

This study aims to bridge the research gap between COVID-19 and public transportation by investigating the causal effect of the outbreak on metro use in Taipei City and New Taipei City, which are the largest two urban cities in Taiwan. This study on Taipei City and New Taipei City presents a unique opportunity to examine this relationship since...
Taiwan has successfully avoided exacting prevention measures such as social lockdowns where authorities force businesses and public facilities to shut down or mandatory stay-at-home orders. The government’s major prevention strategies to combat COVID-19 include promoting social distancing, mandating the wearing of face masks in public areas, and border controls requiring all international arrivals to quarantine for 14 days. Compared to mandatory social lockdowns implemented in other countries, Taiwan’s policy allows for the mobility of its residents. Thus, the effect of COVID-19 on metro use in Taiwan is directly attributable to the perceived health risks from its residents rather than government regulations. Additionally, more than two million people rely on the metro to commute between Taipei City and New Taipei City, which are the island’s political, economic, and cultural centers (Chen and Huang, 2016). Studying the causal effect of COVID-19 on metro use in these two cities provides insight into how the virus impacts an essential form of public transportation that facilitates domestic and international activities.

To conduct our empirical analysis, we use administrative data from the Taipei Metro System on daily ridership from January 1 to March 31 in 2017, 2018, 2019, and 2020 among 108 metro stations. This data covers the major residential and commercial areas of Taipei City and New Taipei City. We estimate the effect of COVID-19 on metro use by applying the difference-in-differences model. We use the period between January 1 and March 31, 2020, as the treatment group and the same days and months from 2017 to 2019 as the control group. This empirical strategy allows us to compare changes in the number of metro trips during the COVID-19 period (2020) to the same date during the pre-COVID-19 period (2017–2019). We find that an additional new confirmed case of COVID-19 reduces the number of metro trips taken by 2.72%, ceteris paribus. The effect of COVID-19 on metro use falls to 1.43% after further controlling for the number of international arrivals to Taiwan. We also conduct heterogeneity analyses based on the day of metro trip (e.g., weekdays and weekends) and the type of metro station (e.g., stations nearby night markets, shopping centers, and schools) to determine whether certain types of domestic activities are disproportionately affected by the outbreak.

This study contributes to the emerging literature on COVID-19 in several ways. First, although a few recent studies examine the effect of COVID-19 on transportation such as traffic injuries and trends (e.g., Oguzoglu, 2020; Lee et al., 2020), we are the first (to the best of our knowledge) to provide causal estimates of COVID-19 on metro use. Given that metro systems are an essential form of public transportation used by more than 168 million passengers in 178 cities across 56 countries (IAPT, 2018), a timely analysis of how COVID-19 affects metro use is important to public health and transportation policy.

Second, we identify the causal effect of COVID-19 on metro use by employing the difference-in-differences model. To do this, we compare the number of trips to each metro station during and before the COVID-19 outbreak using treatment and control groups. Specifically, we exploit the variation in the number of COVID-19 cases across districts and time in the two major cities of Taiwan which did not enforce social lockdowns or mandatory stay-at-home orders. Therefore, an advantage of our empirical strategy is that it is similar to a quasi-natural experiment and allows us to derive causal estimates.

Finally, our results have implications for relief assistance funds and programs related to COVID-19. Many countries are passing economic stimulus policies to assist businesses that have been hurt by the virus, including the food, transportation, travel, and retail industries. We conduct heterogeneity analyses to provide further insight on which types of metro trips are impacted by COVID-19. The justification is that metro trips taken to certain stations such as those nearby night markets and shopping centers are intended for leisure and recreation. Since individuals and families rely on the metro to travel to these destinations, these findings provide suggestive evidence on which industries have been particularly impacted by COVID-19 in Taiwan.

2. Background on the Taipei City Metro System

The Taipei Metro System, also known as the Mass Rapid Transportation (MRT), is operated by the government-owned Taipei Rapid Transit Corporation. The first metro station was built in 1996, and the system now has six routes, including the Wenhu Line, Tamsui-Xinyi Line, Songshan-Xindian Line, Zhonghe-Xinlu Line, Bannan Line, and the Circular Line (see Fig. A.1 in the appendix).

Before the construction of the metro system, Taipei had severe problems with air pollution and traffic congestion. Initially, the Taipei Metro System took nearly ten years to build and was plagued with severe safety concerns (Chen and Whalley, 2012). However, the metro system is now praised for facilitating the economic development and urban renewal of Taipei City and New Taipei City. Many people consider the Taipei Metro System to be an indispensable part of the city, and it is also ranked as one of the most reliable metros in the world (Taiwan News, 2016).

The Taipei Metro System continues to be an essential form of public transportation as it covers the major areas of Taipei City and New Taipei City which are also significant business, leisure, and recreational areas in Taiwan. There are 12 and 29 administrative districts in Taipei City and New Taipei City, respectively. All administrative districts in Taipei City have at least one metro station within the district, while 9 out of the 29 districts in New Taipei City have metro stations. To encourage the use of public transit, the governments in Taipei City and New Taipei City offer a price discount on passengers’ metro or bus fare when transferring between these two forms of transit within one hour.

In addition to serving residents, the metro system is also convenient for foreign tourists. Metro stations are also located near famous tourist destinations, including city museums, major shopping malls, and traditional night markets. The city government also offers daily and weekly travel passes to foreign tourists and sold more than 290,000 related tickets for these passes in 2018 (TRTC, 2018). Furthermore, the system is connected to the Taipei-Taoyuan and Songshan Airports (Chang and Lai, 2009). Fares for the metro range from NT $20 to 65 (US $0.66 to 2.16) per trip as of 2020.

3. Data

3.1. Data on the Taipei Metro System

The primary dataset contains information on the number of trips/daily ridership taken on the Taipei Metro System. This dataset was drawn from the administrative records provided by the Taipei Rapid Transit Corporation. In total, there are 119 metro stations in the Taipei Metro System located in Taipei City and New Taipei City. We exclude 11 metro stations newly operational as of January 2020 to have the same stations for comparing the number of passengers between 2017 and 2020.
3.2. Background and data on COVID-19 in Taiwan

2020. For each station, we collect the total number of tap-ins and tap-outs of metro cards per station per day between January 1 and March 31 from 2017 to 2020.\footnote{The regular operating hours of the metro system is from 6 AM to midnight every day. We measure total metro ridership during the operating hours of each station for each day.} We then aggregate this data at the station-day level, resulting in a balanced panel dataset. Since the COVID-19 outbreak first appeared in Taiwan on January 22, 2020, we use daily ridership between January 1 and March 31, 2020, as the treatment group. The control group is the same days and months from 2017 to 2019. Our final sample contains 108 metro stations and 90 days annually from 2017 to 2020, totaling 38,880 station-day specific observations. Of these, 9720 observations are from 2020.

Other information included in these administrative records is the characteristics of each metro station. We define several variables to indicate if the metro station is connected to an airport, other metro lines (i.e., transfer stations), or located nearby a school (separately for colleges, senior high schools, junior high schools, and elementary schools, respectively),\footnote{The dummy variables that indicate the different type of schools are not mutually exclusive.} major shopping malls, night markets, government agencies, or business centers.\footnote{We categorize the type of metro station based on whether the specific facility is within 10 min of walking distance.} Additionally, we specify whether the metro station is a terminal station or connects to a high-speed rail station. Since ridership is assumed to vary between working and non-working days, we define a dummy variable for the weekend or holidays.

Since passenger use is also determined by the supply of metro rides, we collect information on the frequency of trains/shifts in each day for all metro lines to control for the effect of metro system operations on the number of passengers. This information is not publicly available but was provided by the Taipei Metro System.\footnote{Statistics on train frequency for each station is not available. The Taipei Metro System only maintains statistics on the total number of metro trains for each day.}

3.3. Socio-demographic characteristics and other variables

In addition to the geographic locations of metro stations, the number of trips is associated with socio-demographic characteristics in the local area (Deka and Fel, 2019). There are 12 and 29 administrative districts in Taipei and New Taipei City, respectively. The average size of each district in these two cities is 57 km², ranging from 5.7 km² to 321 km². The average population density of each district is 9252 persons/km² and ranges from 20 persons/km² to 38,404 persons/km². In addition, each district has an average of 2.9 metro stations, ranging from a minimum of 0 to a maximum of 10. To control for the differences in the socio-demographic characteristics of the districts, we collect monthly data on the number of registered households and the population density in each district of Taipei City and New Taipei City. We also include the ratio of residents that are male, younger or equal to the age of 14, between the ages of 15 and 64, and older or equal to the age of 65 in each district. Finally, we include the average personal income to account for the economic composition of each district. These variables are merged to our station-day specific data based on the day of the trip and the district where each station is located as controlled variables in the empirical analysis.

Since the metro is used not only by residents but also by foreign tourists, we collect data on the number of international arrivals to Taiwan for each day during our study period. This information was provided by the National Immigration Agency of the Ministry of Interior in Taiwan. Because the primary focus of this study is to examine the change in metro use by residents due to COVID-19, we use this measure to control for the intensity of the border control policies on metro use. Although no measure precisely captures the effect of border controls, it is likely that border control policies implemented domestically and internationally will reduce the number of arrivals to Taiwan.

4. Analytical framework

The main task in the empirical analysis is to estimate the metro ridership equation. We apply the difference-in-differences (DiD) model to the panel data structure.\footnote{The standard DiD model is applied to a cross-sectional dataset with two time periods and two groups. When the DiD model is applied to a panel dataset, this is seen as the generalized version of the difference-in-differences model (Wooldridge, 2010).} The estimation equation is specified as follows:

\[ M_{ijt} = \alpha + \gamma \times COVID + \beta' X_{ijt} + v_j + v_m + \epsilon_{ijt} \]  

where \( M_{ijt} \) indicates metro ridership for the \( i \)th station in district \( j \) at time \( t \). Variable \( COVID\) represents the cross-sectional and temporal variation in the number of COVID-19 cases in district \( j \) at time \( t \) (with values equal to zero before January 22, 2020). \( X_{ijt} \) is the vector of the explanatory variables that are associated with metro ridership, including the characteristics of the station and socio-demographic characteristics of the local district (see Table 2 for the full list of the variables). The model also controls for district \( (v_j) \), month \( (v_m) \), and year \( (v_y) \) fixed effects. \( \epsilon_{ijt} \) is the random error. In Eq. (1), \( \gamma \) is the coefficient of primary interest and captures the change in the number of COVID-19 cases on the change in metro ridership, ceteris paribus. We use the two-way-cluster-robust variance approach proposed by Cameron et al. (2015) to cluster the standard errors of the coefficients in Eq. (1) at both the district and day level.

The identification of the model relies on the variation of COVID-19 cases across districts and time. Thus, the causal effect of COVID-19 on metro use is identified by comparing the differences in ridership in districts that have COVID-19 cases during and before the outbreak. Unlike the conventional DiD model that uses cross-sectional data, we use a panel dataset with district-level fixed effects to control for the endogeneity bias associated with time-invariant unobserved factors related to COVID-19 in different districts. Furthermore, we include year and month fixed effects to control for unobserved citywide trends in metro use (Wooldridge, 2010).

5. Results

5.1. Descriptive statistics

To provide snapshot evidence on the effect of COVID-19 on metro use, we depict a line graph to show the daily number of metro trips taken from January 1 to March 31, 2020 and the pre-COVID-19 period (average values between 2017 and 2019) for the 108 metro stations in Fig. 1. Visually, the number of metro trips immediately falls after the first case of COVID-19 was identified in Taiwan on January 22, 2020. After an initial rebound, the number of trips taken in 2020 has been...
consistently lower compared to ridership during the same time from 2017 to 2019.

Note: Daily ridership for all metro stations is reported. The solid line represents daily ridership in 2020. The dotted line reports the three-year average of daily ridership between 2017 and 2019. The vertical line indicates the day of the first confirmed case of COVID-19 in Taiwan on January 22, 2020.

Table 1 presents the descriptive statistics on metro ridership and the number of confirmed cases during and before the COVID-19 period.

| Date   | Metro ridership for all stations in 2020 (10,000/day) | Metro ridership for all stations in 2017-2019 (10,000/day) | Difference (%) | # of cumulative cases of COVID-19 | # of cumulative cases of COVID-19 |
|--------|--------------------------------------------------------|-------------------------------------------------------------|----------------|-----------------------------------|-----------------------------------|
|        | (A)                                                    | (B)                                                         | (A)-(B)/ (B)   | Taipei City                       | New Taipei City                   |
| Jan. 1 | 177                                                    | 174                                                         | 1.4%           | 0                                 | 0                                 |
| Jan. 15| 237                                                    | 199                                                         | 18.8%          | 0                                 | 0                                 |
| Feb. 1 | 164                                                    | 201                                                         | −18.2%         | 2                                 | 0                                 |
| Feb. 15| 128                                                    | 182                                                         | −29.6%         | 7                                 | 0                                 |
| Mar. 1 | 113                                                    | 211                                                         | −46.7%         | 9                                 | 9                                 |
| Mar. 15| 128                                                    | 232                                                         | −44.9%         | 15                                | 13                                |
| Mar. 31| 107                                                    | 208                                                         | −48.6%         | 91                                | 75                                |
| All    | 1053                                                   | 1408                                                        | −25.2%         | 91                                | 75                                |

Note: Samples were collected between January 1 and March 31 in 2017, 2018, 2019, and 2020. The number of metro trips in Columns (A) and (B) were summarized for the 108 metro stations.

Table 1 presents the descriptive statistics on metro ridership and COVID-19 cases in Taiwan.

5.2. The effects of COVID-19 on metro use

One interesting question is related to how metro use is affected by implementing prevention strategies against COVID-19. While effective in reducing the spread of infection, these policies can negatively impact metro use by reducing unnecessary domestic activities and international tourist visits. In this study, we use the number of international arrivals to Taiwan to control for the intensity of border controls on metro use. We then estimate the models with and without controlling for the number of international arrivals. The full model is the specification of all explanatory variables (the number of COVID-19 cases, metro station characteristics, frequency of trains/shifts, non-working days, local sociodemographic characteristics, the number of international arrivals with district, month, and year fixed effects). The restricted model excludes the variable for the number of international arrivals.

Table 3 presents the estimation results of the metro ridership equation specified in Eq. (1) using the full sample. Panels A and B report the results of the full and restricted model, respectively. In each panel, we also use two different specifications measuring the COVID-19 variable. The first specification considers the effect of an additional new confirmed case of COVID-19. The second specification uses the number...
Table 2
Sample statistics and definition of the selected variables.

| Year          | Definition                                           | 2017–2020 | 2020 | 2017–2019 | 2020 |
|---------------|-----------------------------------------------------|-----------|------|-----------|------|
| Trips         | # of trips per station per day (in 10,000).         | 1.866     | 1.820| 1.698     | 1.584|
| COVID19       | # of new COVID-19 cases per day.                    | 0.226     | 1.065| 0.946     | 1.966|
| COVID19_cum   | # of cumulative COVID-19 cases per day.             | 3.115     | 11.863| 12.461   | 21.130|
| Metro frequency| # of metro trips supplied in each day (1000 trains). | 2.603     | 0.216| 2.595     | 0.210|
| Arrival       | # of international arrivals (10,000 persons/day)    | 4.172     | 1.600| 2.213     | 1.814|
| S_terminal    | If the station is a terminal station (1=).          | 0.120     | 0.325| 0.120     | 0.325|
| S_rail        | If the station connects to other metro lines (1=).   | 0.128     | 0.334| 0.150     | 0.357|
| S_college     | If a university is nearby the station (1=).         | 0.315     | 0.464| 0.315     | 0.464|
| S_senior      | If a senior high school is nearby the station (1=). | 0.361     | 0.480| 0.361     | 0.480|
| S_junior      | If a junior high school is nearby the station (1=). | 0.324     | 0.468| 0.324     | 0.468|
| S_elementary  | If an elementary school is nearby the station (1=).  | 0.231     | 0.422| 0.231     | 0.422|
| S_business    | If a business center is nearby the station (1=).     | 0.056     | 0.229| 0.056     | 0.229|
| Weekend       | If a holiday or weekend (1=).                       | 0.350     | 0.477| 0.356     | 0.479|
| New Year      | If Chinese New Year holiday period (1=).            | 0.078     | 0.268| 0.078     | 0.268|
| Household     | Number of household in the district (10,000/month). | 1.057     | 0.374| 1.069     | 0.382|
| Pop. density  | Population density in the district (10,000/month).  | 1.599     | 0.873| 1.590     | 0.869|
| Ave_income    | Average personal income in the district (NT$100,000/month). | 4.249    | 0.397| 4.363     | 0.403|
| R_male        | Ratio of male residents in the district.            | 0.479     | 0.008| 0.479     | 0.008|
| R_kid         | Ratio of residents aged ≤14 years old in the district.| 1.668     | 0.551| 1.644     | 0.540|
| R_elderly     | Ratio of residents aged ≥65 years old in the district.| 2.046     | 0.698| 2.158     | 0.724|
| R_adult       | Ratio of residents aged 15–64 years old in the district.| 0.711     | 0.025| 0.700     | 0.024|
| N*T           |                                                      | 38,880    | 9720 | 38,880    | 9720 |

Note: The dataset includes information on 108 metro stations. The sample time period is January 1 to March 31 from 2017 to 2020. The station-date specific sample includes 38,880 observations.

Table 3
Estimation results of the metro trips equation.

| Variable     | Panel A. The full model (control for international arrivals) | Panel B. The restricted model (no control for international arrivals) |
|--------------|--------------------------------------------------------------|---------------------------------------------------------------|
|              | Coefficient  | S.E     | Coefficient | S.E     | Coefficient | S.E |
| COVID19      | 0.027        | 0.003   | 0.004       | 0.001   | 0.004       | 0.001 |
| Magnitude††  | -1.43%       |         | -2.72%      |         | -0.33%      |      |
| COVID19_cum  |              |         |             |         |             |      |
| Magnitude††  |              |         |             |         |             |      |
| Arrival      | -0.060       | 0.015   | 0.014       |         | -0.128      | 0.026|
| Metro frequency| 1.081      | 0.128   | 0.128       |         | 1.082       | 0.128|
| S_terminal   | 0.039        | 0.035   | 0.035       |         | 0.039       | 0.039|
| S_rail       | 1.561        | 0.398   | 0.398       |         | 1.559       | 0.399|
| S_college    | 0.634 ± 0.034| 0.634   | 0.633       |         | 0.634 ± 0.034| 0.634 |
| S_senior     | -0.145       | 0.174   | -0.145      |         | -0.145      | -0.145|
| S_junior     | 0.462        | 0.461   | 0.461       |         | 0.462       | 0.462|
| S_elementary | 0.207        | 0.207   | 0.208       |         | 0.208       | 0.208|
| S_mall       | 4.079        | 4.079   | 4.079       |         | 4.079       | 4.079|
| S_airport    | 0.897        | 0.897   | 0.897       |         | 0.897       | 0.897|
| S_market     | 0.469        | 0.469   | 0.469       |         | 0.469       | 0.469|
| S_business   | 0.904        | 0.904   | 0.904       |         | 0.904       | 0.904|
| S_government| -1.280       | -1.280  | -1.281      |         | -1.281      | -1.281|
| S_business   | 0.824        | 0.824   | 0.824       |         | 0.824       | 0.824|
| Weekend      | 0.015        | 0.018   | 0.016       |         | 0.016       | 0.016|
| New year     | -0.235       | -0.235  | -0.235      |         | -0.235      | -0.235|
| Household    | -4.213       | -4.202  | -4.448      |         | -3.725      | -3.815|
| Pop. density | 5.273        | 5.273   | 5.273       |         | 5.273       | 5.273|
| Ave. wage    | 0.695        | 0.754   | 0.924       |         | 0.924       | 0.924|
| R_male       | -40.753      | -38.873| -50.851     |         | -47.358     | -54.060|
| R_kid        | 17.200       | 15.390  | 27.891      |         | 18.724      | 29.306|
| R_elderly    | 6.507        | 5.859   | 17.794      |         | 18.783      | 19.492|
| Constant     | 7.099        | 6.879   | 22.485      |         | 21.128      | 24.110|
| Adjusted R²  | 0.641        | 0.641   | 0.641       |         | 0.641       | 0.641|
| N*¹²         | 38,880       | 38,880  | 38,880      |         | 38,880      | 38,880|

Note: The dependent variable is the number of metro trips (in 10,000). †: The magnitude of the effect is evaluated at the sample mean of metro trips in the pre-COVID-19 period (2017–2019). ††: Indicates statistical significance at the 1%, 5%, and 10% levels.
Panel B can be seen as the overall effect of COVID-19 on metro use due to policies against COVID-19 in Taiwan. By further comparing the estimates during the pre-COVID-19 period, respectively. The results reported in Table 3 can be interpreted as the effect of COVID-19 on metro use by residents of Taiwan.

The results reported in Panel B of Table 3 shows that an additional confirmed new and cumulative COVID-19 case decreases metro ridership by 520 and 60 trips respectively, other things being equal. The magnitude of these effects is approximately equal to $-0.272$ and $-0.33\%$ when they are evaluated at the average number of metro trips during the pre-COVID-19 period, respectively. The results reported in Panel B can be seen as the overall effect of COVID-19 on metro use due to the implementation of border controls and active domestic prevention policies against COVID-19 in Taiwan. By further comparing the estimates between Panel A and Panel B, the decrease in the number of international arrivals due to border control policies decrease metro use by $-1.29\%$ corresponding to an increase in every additional new confirmed case of COVID-19 in Taipei and New Taipei City.

With respect to other explanatory variables, results show that the characteristics of metro stations are also associated with the number of trips taken. For instance, considering the estimation results in the first column of Panel A, it is evident that an additional international arrival to Taiwan increases metro use by 0.06 trips per day, other things being equal. As expected, metro use is also associated with the supply of the metro rides. We find that an additional metro train shift increases metro use by 10.8 trips per day, ceteris paribus.

With respect to the characteristics of metro stations, results indicate that metro use increases by 15,610 trips per day (the coefficient is 1.561) if the metro station is a transfer station, other things being equal. A large effect of metro use is also found for the stations that have a university nearby. Compared to the stations without a university nearby, the stations with a university nearby have an additional 6340 trips. Additionally, if the metro station is located nearby a night market or business center, then metro use increases by 4690 and 8240 trips per day, respectively. We also find that metro use is less frequent during the Chinese New Year holiday period. Finally, the socio-demographic characteristics of the local district are also relevant to metro use. As expected, results show that metro use is higher for the stations in districts with a higher population density.

### 5.3. Results of the heterogeneity analysis on the effect of COVID-19

#### 5.3.1. By weekdays and the weekend

Since the Taipei Metro System is a major form of public transportation for commuters in Taipei and New Taipei City, we conduct a heterogeneity analysis to see if the effect of COVID-19 on metro use differs between weekdays and the weekend. The estimation results using the subsample for weekdays and the weekend are reported in Panels A and B of Table 4, respectively. A larger effect of COVID-19 on metro use is found during the weekend than weekdays. For example, the results reported in the first column show that one additional new confirmed COVID-19 case decreases metro use by 1.2% and 3.04% (evaluated at the average of metro ridership in the pre-COVID-19 period) during weekdays and the weekend in the full model.

| Variable | Panel A. use subsample for weekdays | Coefficient | S.E | Coefficient | S.E |
|----------|-----------------------------------|-------------|-----|-------------|-----|
| COVID19#1 | $-0.023$ *** | 0.003 |
| COVID19_cum#1 | $-1.20\%$ | |
| Other variables | Yes | Yes |
| Adjusted R² | 0.655 | 0.655 |
| N*T | 25,272 | 25,272 |
| Panel B. use subsample for weekend | |
| COVID19 | $-0.063$ *** | 0.012 |
| COVID19_cum | $-3.04\%$ | |
| Other variables | Yes | Yes |
| Adjusted R² | 0.628 | 0.628 |
| N*T | 13,608 | 13,608 |

Note: The dependent variable is the number of metro trips (in 10,000). #1: The magnitude of the effect is evaluated at the sample mean of metro trips in the pre-COVID-19 period (2017–2019). #2: All other variables can be found in Table 3. *** *, ** indicates statistical significance at the 1%, 5%, and 10% levels. 5.3.2. By type of metro station

Although we find a significant reduction in the number of trips resulting from COVID-19, ridership at metro stations with specific characteristics could be disproportionately impacted by the pandemic. For example, metro stations with schools nearby may have a smaller decrease in the number of trips since there are no lockdowns in Taiwan and students still must commute to school. On the other hand, metro stations with night markets and large shopping malls nearby may be hit harder because people will reduce non-essential activities during the COVID-19 period, especially during the weekend. To provide evidence of these hypotheses, we estimate the metro use equation based on different station characteristics. We consider metro stations that are nearby four different types of facilities: schools, workplaces, leisure and entertainment places, and airport routes, as defined in Section 3.1.

Table 5 presents these estimation results. For the ease of presentation, we only report the estimated coefficient of the variable indicating an additional new confirmed case of COVID-19. The associated magnitude of the effect is evaluated at the average value of metro rides in the pre-COVID-19 period for each subsample. Panel A reports the estimation results for metro stations that have a school nearby. Because the transportation use may differ for students in different educational levels, we estimate five subsamples for the stations that are close to a university, senior high school, junior high school, elementary school, and none of these schools. In general, results reported in Panel A echo the findings revealed in the full model for the negative effect of COVID-19 on metro use (see Table 3). However, we find a larger effect on metro stations that do not have a school nearby. Among different types of schools, a smaller effect of COVID-19 on metro use is found among stations that are close to a junior high school or an elementary school. Moreover, this result is more pronounced during the weekend than the weekdays.

Panel B report the estimation results for stations that are close to different types of workplaces: government agencies, business centers, and outside these two places. The largest effect, ranging from $-1.26\%$ to $-4.27\%$, is found at metro stations that are neither close to the workplaces of government agencies or business centers. Moreover, it is evident that stations with nearby business centers are more responsive than stations nearby government agencies to the COVID-19 pandemic. Taking the results in the full sample for instance, an increase of an additional new confirmed of COVID-19 decreases metro use by $-0.94\%$ and $-1.12\%$ for stations nearby government agencies and business centers, respectively.
precise measures of the effect of a COVID-19 case on the number of

5.3.4. Back-of-the-envelope calculation on profit loss of the metro system

To test whether our results are sensitive to the specification of the COVID-19 variable, we conduct a robustness check using the total number of COVID-19 cases and control for district-level fixed effects. We estimate the total loss in ticket revenues for all COVID-19 cases and for all 108 stations between January and March 2020. Finally, by comparing these values to the profits of the Taipei Metro System in January to March 2020, we calculated the loss in the percentage of profits due to COVID-19. Since we have distinguished between the effects of the number of COVID-19 cases on metro ridership with and without the control for the number of international arrivals, we further separate how these measures impact the profits of the Taipei Metro System.

Panel C of Table 5 reports the estimation results for stations located in different leisure and entertainment places. Results point to a large negative effect of COVID-19 on metro use for stations that are close to a shopping mall. The magnitude of the negative effect is more pronounced during the weekend. We also find similar results for stations that are close to a night market. Panel D of Table 5 reports the estimation results for stations connected to airport routes, respectively. As expected, COVID-19 has larger effects on metro stations connected to airport routes. Results from the full sample analysis show that an additional new confirmed case of COVID-19 decreases the number of metro trips by 1.61% and 1.41% for metro stations connected and not connected to airport routes, respectively.

5.3.3. Robustness check of the specification of the COVID-19 variable

As noted in the main models, we define a district-day specific variable for the number of COVID-19 cases and control for district-level fixed effects. We do this because the variation in the number of COVID-19 cases is by location and time. The specification of the COVID-19 variable may seem inconsistent with the findings in the main results reported in Table 3. #2: The average ticket price is NT$ 50 per ride. #3: There are 166 cumulative COVID-19 cases in the two cities between January and March in 2020. (see Table 1), we can then calculate the total loss in ticket revenues for all COVID-19 cases and for all 108 stations between January and March in 2020. Finally, by comparing these values to the profits of the Taipei Metro System in January to March 2020, we calculated the loss in the percentage of profits due to COVID-19. Since we have distinguished between the effects of the number of COVID-19 cases on metro ridership with and without the control for the number of international arrivals, we further separate how these measures impact the profits of the Taipei Metro System.

Table 5

| Group        | Coefficient | S.E | N*T | Coefficient | S.E | N*T | Coefficient | S.E | N*T | Coefficient | S.E | N*T |
|--------------|-------------|-----|-----|-------------|-----|-----|-------------|-----|-----|-------------|-----|-----|
| College      | -0.034 ***  | 0.004 | 12,240 | -1.64%       | -0.029 *** | 0.004 | 7956 | -1.38%       | -0.084 *** | 0.015 | 4284 | -4.84% |
| Senior high  | -0.027 ***  | 0.003 | 14,040 | -1.34%       | -0.027 *** | 0.003 | 9126 | -1.21%       | -0.050 *** | 0.007 | 4914 | -3.07% |
| Junior high  | -0.026 ***  | 0.003 | 12,600 | -1.21%       | -0.024 *** | 0.003 | 8190 | -1.02%       | -0.053 *** | 0.011 | 4410 | -3.07% |
| Elementary   | -0.021 ***  | 0.003 | 9000  | -1.21%       | -0.019 *** | 0.002 | 5850 | -0.96%       | -0.044 *** | 0.008 | 2150 | -3.03% |
| No schools   | -0.020 ***  | 0.005 | 11,160 | -1.89%       | -0.019 *** | 0.003 | 7254 | -1.44%       | -0.051 *** | 0.022 | 3906 | -4.96% |
| Gov. agency  | -0.026 ***  | 0.004 | 2160  | -0.94%       | -0.024 *** | 0.002 | 1404 | -0.79%       | -0.052 *  | 0.017 | 756  | -2.16% |
| Business center | -0.034 *** | 0.006 | 7920  | -1.12%       | -0.029 *** | 0.004 | 5148 | -0.94%       | -0.083 **  | 0.031 | 2772 | -3.15% |
| Neither      | -0.020 ***  | 0.003 | 30,240 | -1.26%       | -0.017 *** | 0.002 | 19,656 | -1.25%       | -0.048 *** | 0.007 | 10,584 | -4.22% |
| Night market | -0.032 ***  | 0.004 | 9360  | -1.49%       | -0.026 *** | 0.003 | 6084 | -1.00%       | -0.093 *** | 0.016 | 3276 | -4.35% |
| Shopping mall | -0.003 ***  | 0.007 | 6480  | -1.65%       | -0.028 *** | 0.005 | 4212 | -1.12%       | -0.141 **  | 0.030 | 2268 | -4.63% |
| Neither      | -0.017 ***  | 0.003 | 23,760 | -1.28%       | -0.014 *** | 0.002 | 15,444 | -0.95%       | -0.034 *** | 0.005 | 8316 | -3.18% |
| Airport      | -0.071 *    | 0.041 | 1344  | -1.61%       | -0.029 * | 0.015 | 879  | -0.64%       | -0.137 *  | 0.071 | 465  | -3.19% |
| Non-airport  | -0.026 ***  | 0.003 | 37,536 | -1.41%       | -0.022 *** | 0.002 | 24,393 | -0.51%       | -0.057 *** | 0.008 | 13,143 | -1.25% |

Note: The dependent variable is the number of metro trips (in 10,000). #1: The magnitude of the effect is evaluated at the sample mean of the metro trips in the pre-COVID-19 period (2017–2019). The estimates were derived from the specification of the full model (see Table 3). ***, **, * indicates statistical significance at the 1%, 5%, and 10% levels.

5.3.4. Back-of-the-envelope calculation on profit loss of the metro system due to COVID-19

Although the estimation results of the metro use equation provide precise measures of the effect of a COVID-19 case on the number of metro ridership, it would be interesting to estimate the economic loss on the profits of the Taipei Metro System due to the COVID-19. How much economic loss in metro use is attributable to the implementation of prevention policies against COVID-19? We conduct a back-of-the-envelope calculation to approximate the impacts of COVID-19 on the profits of the Taipei Metro System between January and March in 2020.

We conduct our calculation as follows. First, we multiply the effect of each COVID-19 case on the number of metro rides in each station (the estimates are reported in Table 3) by the average metro ticket price per ride (NT$ 50). We then evaluate the total loss in monetary terms for all 108 stations corresponding to one COVID-19 case. Given that there are 166 cumulative COVID-19 cases in the two cities between January and March in 2020 (see Table 1), we can then calculate the total loss in ticket revenues for all COVID-19 cases and for all 108 stations between January and March in 2020. Finally, by comparing these values to the profits of the Taipei Metro System in January to March 2020, we calculated the loss in the percentage of profits due to COVID-19. Since we have distinguished between the effects of the number of COVID-19 cases on metro ridership with and without the control for the number of international arrivals, we further separate how these measures impact the profits of the Taipei Metro System.

| Definition                                                                 | Overall effects | Due to domestic prevention |
|---------------------------------------------------------------------------|-----------------|-----------------------------|
| Loss in the number of trips per station per COVID-19 case.                 | 64              | 38                          |
| Loss in ticket revenues per station per COVID-19 case (NT$).              | 3201            | 1915                        |
| Loss in ticket revenues due per COVID-19 case for all stations (NT$ 10,000). | 35              | 21                          |
| Total number of the cumulative cases of COVID-19.                          | 166             | 166                         |
| Loss in ticket revenues due to all COVID-19 cases (NT$ million).          | 57              | 34                          |
| Loss in ticket revenues in January-March from 2019 to 2020 of the Taipei system (NT$ million). | 333             | 333                         |
| Percentage in profit loss due to COVID-19.                                | -17%            | -10%                        |

Note: #1: See the estimates of the COVID-19 variable in the regression model reported in Table 3. #2: The average ticket price is NT$ 50 per ride. #3: There are 108 metro stations. #4:rawn from the financial reports of the Taipei Metro System.

The results in Table 6 show that the combined effect of the prevention actions to COVID-19 accounts for approximately 17% of the profit loss of the Taipei Metro System in January-March 2020. Moreover, the
loss in the profits of Taipei Metro System due to domestic prevention policy is approximately equal to 10%, after controlling for the number of international arrivals.¹²

6. Discussion

Using real-time data on metro ridership in Taipei and the difference-in-differences model, this paper investigates the effect of COVID-19 on the use of metro systems. Some interesting findings are summarized and discussed below. First, we show that COVID-19 has a significant and negative impact on metro use in Taipei Metro System. Each additional new confirmed case of COVID-19 leads to a reduction in the number of metro trips by 1.43% after controlling for the number of international arrivals to Taiwan. The overall effect of border controls and the domestic prevention policies such as social distancing leads to a reduction in metro use by 2.72%, other things being equal. Our back-of-the-envelope calculation further indicates that the COVID-19 accounts for a 17% reduction in profit of the Taipei Metro System from January to March 2020. Of which, domestic prevention policies account for 10% of the overall reduction, respectively.

The effect of COVID-19 on metro use is substantially smaller in Taipei than in cities such as New York City and Seoul. Subway ridership in New York City decreased by 93% in March 2020 (Hughes, 2020). This drop corresponds to New York’s mandatory stay-at-home order, which prohibited non-essential activities. Park (2020) notes that the mean daily number of passengers riding the Seoul Metro decreased by up to 40% in March 2020 in association with the first reported death and cluster of COVID-19 cases in Daegu, South Korea. Although Park’s study on Seoul was based on descriptive analysis and did not specifically control for metro supply and the number of international arrivals, the author suggests that decreases in metro use in Seoul are related to residents’ risk perceptions since no lockdown policies were implemented in South Korea.

Although the Taipei Metro has suffered from losses in revenues due to reduced metro use, these financial burdens are tolerable since there will be reduced medical expenditures with fewer domestic and international activities. For example, the overall mean cost of treating a patient with COVID-19 in Shandong, China, is USD 6827 (Li et al., 2020). Similarly, the estimated cost of treating a patient with COVID-19 in Taiwan ranges from NTD 800,000 to 2.1 million or USD 28,000 to 74,600 (CNA, 2020). It is estimated that the cost of treating the 776 confirmed cases of COVID-19 in Taiwan ranges from NTD 620 million to 1.63 billion or USD 22 million to 57 million. Thus, there are tradeoffs between the financial burdens incurred by metro systems and reduced medical expenditures.

Our results suggest that the perceived health risks of using public transportation are high in Taiwan, as the island has managed to contain the spread of COVID-19 with only 166 cases in Taipei City and New Taipei City at the end of March 2020 (Table 1). Nevertheless, the undesirable effect of reduced ridership due to COVID-19 has put metro systems in financial distress. While these losses are acceptable based on the cost of treating patients with COVID-19, ensuring that metro systems remain financially solvent in the long-run should be a priority for policymakers. Special attention should be paid to how metro systems can persist through financial crises during and after the pandemic.

Second, we find that active domestic prevention policies and border controls affect metro ridership. Since the metro is an essential form of public transit for visitors, it is necessary to control for the number of international arrivals to identify the effect of COVID-19 on metro use by residents. Our results show that the full model that accounts for the number of international arrivals has smaller effects than the restricted model that does not control for these figures. Active domestic prevention policies and border controls limit non-essential activities which prevent visitors from entering and using the metro in Taipei.

Third, we find that the effect of COVID-19 on metro use is larger during weekends than weekdays. The larger reduction during weekends is likely driven by the fact that people reduced their recreational and leisure activities in response to the fear of infection (Cheng et al., 2020; Su and Huang, 2020). In contrast, commuters are less affected by the pandemic because schools and offices remain open in Taiwan and remote teaching and working is generally not feasible. This likely explains the smaller effect of COVID during weekdays.

Fourth, given the heterogeneous characteristics of metro stations, we find that certain metro stations are disproportionately affected by COVID-19. For example, we show that the negative effect is relatively smaller for stations connected to schools. This finding is not surprising since the schools in Taiwan operated normally without lockdowns during the COVID-19 period. Interestingly, we find that the effect of COVID-19 on metro use varies by different level of schools. The relatively large effect is found for stations that are close to a university or senior high school. This finding may reflect the fact that students at lower levels are more likely to picked up/dropped off by their parents than students at higher levels. Therefore, stations that are close to lower-level schools are less likely to be affected by the COVID-19. In contrast, senior high school and college students are more reliant on public transportation to commute to school. The perceived health risks of COVID-19 may discourage their use of the metro. Moreover, some universities have moved their courses with many students enrolling in online lectures. This may also reduce the frequency of college students using the metro system.

We find that metro stations that are close to different types of workplace suffered differently from the shock of COVID-19. We find a smaller effect of COVID-19 on metro use for the stations that are close to a government agency than a business center. These results may reflect the fact that government employees worked as normal and they did not have any option for work-from-home or rotational working schedules. In contrast, some private companies have more flexible ways to adjust the working schedules of their employees. For example, some companies rotate the employees of different sectors across branches and locations to reduce the chance of infection, and other private companies even implemented work-from-home policies during the COVID-19 period.

Finally, our results indicate that COVID-19 will reduce metro use even without the enactment of mandatory stay-at-home orders. These results are especially insightful for other countries that have also avoided the implementation of these measures, including Japan, South Korea, and Sweden. While there have been no prior studies examining the causal effect of COVID-19 on metro use, we provide evidence on how the outbreak may impact public transportation in countries that have not implemented these stringent policies.

7. Conclusion

COVID-19 has affected many sectors around the globe, with public transportation being particularly impacted. While drastic reductions in ridership has been reported in transportation systems across many cities, most of these findings are based on descriptive evidence and only a few of them examine the use of public transportation. This study fills this research gap by investigating the effect of COVID-19 on metro use of the Taipei Metro System. Our empirical strategy takes advantage of the fact that no social lockdown policies but only border controls and the promotion of social distancing and mandating the wearing of face masks have been implemented in Taiwan. We also conduct a heterogeneity analysis by type of metro stations to implicitly understand the behavior of the residents toward COVID-19.

As the COVID-19 pandemic continues, the public transportation sector is likely to face limited demand for an extended period. These

¹² The Taipei Metro Company receives a substantial amount of their profits from non-operating revenues (81.9%) and other operating revenues (14.3%). Some examples include the rents from commercial shops in metro stations, multimedia advertisements, and affiliated businesses (TRTC, 2018).
reduced revenues due to declines in ridership can affect the financial stability of transit operations. The results of this study have direct implications for the relief assistance funds allocated to the public transportation sector. Our findings on the reduced ridership resulting from COVID-19 justifies the need for metro systems to receive financial support. Additionally, our results on the differing patterns of metro use by the characteristics of metro stations may aid policymakers as they plan to increase ridership levels as the outbreak eases. Additionally, these results have implications for intervention measures in public transportation systems. For example, since a smaller reduction in ridership is found in stations with schools nearby, encouragement or enforcement of social distancing may need to be strengthened in these relatively crowded stations.

Although our results have some interesting findings, several caveats exist in this study. First, we do not have information on each journey’s specific characteristics, such as whether the trip is intended for leisure activities or commuting to work. While we can work around this by using information on the time and station of the journey, the estimates would be more precise if such data becomes available. Second, we do not have data on passengers such as age or education level. Our results could be more informative if more detailed data is available. For instance, the effect on metro use may vary between older and younger passengers because they have different health risks to COVID-19. Furthermore, if we have information on the county for international arrivals to Taiwan and the purpose of their visits, we can possibly examine the effect of the social lockdowns implemented in other countries to the metro operation in Taiwan. Finally, given the significant reduction in metro ridership, it would be interesting to study how people change the way they travel. This result could have important implications for traffic congestion and air pollution. Regardless of these potential caveats, this paper provides the first piece of evidence to examine the negative effect of COVID-19 on the use of metro systems.

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Author statement

All of the authors claim that this manuscript is not being considered for publication elsewhere, and does not infringe upon other published material protected by copyright.

Declaration of Competing Interest

None.

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Appendix A

Table A.1

| Variable              | Model A                | Model B                |
|-----------------------|------------------------|------------------------|
|                       | Coefficient | S.E | Coefficient | S.E |
| COVID19_cities       | –0.012      | *** | 0.004 \*   |     |
| COVID19_cities_cum   | 0.056       | *** | 0.050 \*   | 0.013 |
| Arrival              | 0.056       | *** | 0.016 \*   |     |
| Other variables      | Yes         |     | Yes \*     |     |
| Adjusted R²          | 0.641 \*   | 38,880     | 0.641 \*   | 38,880 |

Note: The variable “COVID19_cities” and “COVID19_cities_cum” indicate the total number of the COVID-19 cases in the two cities in each day. The estimates are derived from the specification of the full model (see Table 3). \*, ** and *** indicates statistical significance at the 1%, 5% and 10% level, respectively.
Routes are depicted schematically and do not reflect the exact location.
Fig. A.1. Distribution of all metro stations in Taipei City and New Taipei City.

Note: There are 119 stations in the Taipei Metro System operated in March 31, 2020. The figure was drawn from the Taipei Metro Company.

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