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The relationship between mobility and COVID-19 pandemic: Daily evidence from an emerging country by causality analysis

Mustafa Tevfik KARTAL[a,*], Özer DEPREN[b], Serpil KILIÇ DEPREN[c]

[a] Financial Reporting and Subsidiaries Directorate in Borsa İstanbul, İstanbul/Turkey
[b] Customer Experience Researches Directorate in Yapı Kredi Bank, İstanbul/Turkey
[c] Yıldız Technical University, Department of Statistics, İstanbul/Turkey

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ABSTRACT

This study examines the relationship between mobility (a proxy for transport) and the COVID-19 pandemic by focusing on Turkey as an example of an emerging country. In this context, eight types of mobility and two indicators of COVID-19 were analyzed using daily data from March 11, 2020 to December 7, 2020 by applying Toda-Yamamoto causality test. The findings revealed that (i) there is cointegration between the variables in the long term; (ii) there is an econometric causality between mobility indicators (mobility of grocery, park, residential, retail, and workplace) and pandemic indicators; (iii) various mobility indicators have an econometric causality with different pandemic indicators; (iv) neither driving mobility nor walking mobility has an econometric causality with the pandemic indicators whereas some of the other types of mobility, such as grocery, park, and retail do. These results generally show the effects of mobility and highlight the importance of appropriate mobility restrictions in terms of the pandemic.

1. Introduction

Common diseases rarely occur in all countries at the same time. In the near past, some common diseases, such as SARS (Severe Acute Respiratory Syndrome) and MERS (Middle East Respiratory Syndrome) outbreaks were observed before the coronavirus disease 2019 (COVID-19) outbreak (Chen et al., 2007; Ezhilan et al., 2021). SARS spread to 37 countries and MERS spread to 27 countries (Wu et al., 2020). Currently, the world is facing a new common disease crisis (AlAli, 2020). The COVID-19 has spread quickly from China since mid-December 2019 and was defined as a pandemic in March 2020 (World Health Organization, 2020a). Such common diseases are generally evaluated as black swan (Gherghina et al., 2020).

The COVID-19 pandemic has caused 123 million confirmed cases and 2.7 million deaths since the beginning of the pandemic. To be precise, the United States, Brazil, India, Russia, United Kingdom, France, Italy, Spain, and Turkey are the leading countries that are mostly affected by the pandemic in terms of the confirmed cases (World Health Organization, 2020b). Similarly, the COVID-19 pandemic, which was first defined on March 11, 2020, caused a total of 2.8 million cases and 30 thousand deaths in Turkey (Ministry of Health of Turkey, 2020).

While the pandemic spread, most economic and financial indicators, such as foreign exchange rates and interest rates deteriorated (Kartal, 2020a; Kartal et al., 2020). Since negative developments have been seen through such indicators due to the pandemic effect, the COVID-19 pandemic is assessed as the most influential global phenomenon that the world has ever faced (Bloomberg, 2020; Shehzad et al., 2020).

The increasing number of the new cases, new patients, and deaths from the pandemic has become a significant threat to public health. By considering this threat, countries including Turkey have been taking precautions to contain contagion and decrease the negative effects of the COVID-19 pandemic on economies and public health (Gherghina et al., 2020; Narayan et al., 2020a, 2020b).

As mentioned above, the COVID-19 pandemic has unprecedented, destructive, negative effects on countries, economies, and economic actors (Goodell, 2020; Rizwan et al., 2020). Therefore, the COVID-19 pandemic should be taken into consideration while conducting an analysis concerning public health and economies.

* Corresponding author at: Financial Reporting and Subsidiaries Directorate in Borsa İstanbul, İstanbul/Turkey.
E-mail addresses: mustafatevfikkartal@gmail.com (M.T. KARTAL), ozerdepren@gmail.com (Ö. DEPREN), serkilic@yildiz.edu.tr (S. KILIÇ DEPREN).

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In summary, the first case of the COVID-19 was recorded in Turkey on March 11, 2020 and there is now a high number of patients and deaths caused by the pandemic. In addition, some precautions like mobility and transport restrictions have been applied to keep the pandemic under control so that public health can be preserved. Therefore, it will be helpful to understand the effects of mobility as a proxy of transport activities of citizens on the spread of the COVID-19 (proxied by the number of patients and deaths) in Turkey. Such an analysis can contribute to the regulatory bodies while making decisions to sustain, decrease or stop mobility restrictions. This is important because such limitations have a negative impact on the economic development, especially in terms of employment and welfare (Yılmazkuday, 2020a).

This study examines the relationship between mobility and the pandemic by applying the Toda-Yamamoto causality test and focusing on an econometric view rather than real-life mechanistic causality. Daily data from March 11, 2020 to December 7, 2020 were considered and eight different types of mobility and two pandemic indicators were used. Including different types of mobility in analyses is important because they are subject to different administrative precautionary measures. Moreover, the study focuses mainly on Turkey as a pioneering, leading country, which has been highly affected by the pandemic with a high total number of confirmed cases. Another motivation of this study is to confirm whether the restrictions, which are to limit mobility, are influential in spreading the pandemic.

The study hypothesized that a relationship between mobility and the pandemic is expected, but this relationship may not be observed for all types of mobility. In other words, not all types of mobility may be related to the pandemic. To test this hypothesis, daily time-series data were used and the Toda-Yamamoto causality test was performed. The results showed that there are causalities between some types of mobility (grocery, park, residential, retail, and workplace) and the pandemic while driving and walking mobilities are not related to the pandemic.

The contribution of this study to the evolving literature regarding the COVID-19 pandemic is that the study (i) is the first to examine the relationship between mobility and the pandemic in Turkey's case as an example for an emerging market. Although there are some studies dealing with mobility data and the pandemic in the literature, to the best of our knowledge, no study has examined the Turkish case; (ii) focuses on the relationship between different types of mobility and the pandemic; (iii) performs the Toda-Yamamoto causality test to understand whether the relationship between the variables is at the causality level; (iv) simultaneously considers the mobility data of Apple and Google, calculated according to different approaches for the first time, which increases the originality of the study.

The study is organized as follows. Section 1 introduces the subject of the study. Section 2 presents the progress of the pandemic and mobility in Turkey. Section 3 explains the variables and data. Section 4 describes the methodology. Section 5 presents the empirical results, discussion, and policy implications. Finally, Section 6 concludes.

2. The progress of mobility and the pandemic in Turkey

With the rapid spread of the COVID-19 pandemic, new data collection efforts have increased. Hence, international sources have begun to publish mobility data because of the importance of mobility. Hence, Apple and Google began to publish mobility data and the usage of these data has been increasing each day. Fig. 1 shows the mobility of Apple users in Turkey since the beginning of the pandemic.

The mobility of Apple users decreased drastically at the beginning of the pandemic. Although a gradual increase in the mobility was seen later, it decreased again with an increasing number of the cases.

Also, Fig. 2 shows the mobility of Google users in Turkey since the beginning of the pandemic.

The types of mobility of Google users had increasing and decreasing trends over time. Moreover, mobility changed over time due to the precautions which affected the mobility capabilities of citizens.

Besides, Fig. 3 shows the development of the main pandemic indicators in Turkey since the beginning of the pandemic.

The first case of coronavirus was confirmed in Turkey on March 11, 2020. The number of patients (whose COVID-19 tests were positive and needed treatment in the health sector) and deaths (caused by the pandemic) increased until April 20, 2020. With the effect of the precautionary measures that were applied, the figures began to decrease. The figures showed a horizontal trend for a while; however, they began to increase again with the effect of the gradual normalization steps in Turkey.

At the beginning of the pandemic, countries naturally applied various precautionary measures that affected mobility. Some of these precautions, which affect transportation both directly and indirectly via limiting mobility, can be summarized as mobility restrictions, local lockdowns, and weekend lockdowns, quarantines in residential areas, ban on flights, isolation rules, and social distancing (Morgan Stanley, 2020). Such precautionary measures aim to decrease mobility including transport so as to control the spread of the pandemic. Some of the precautionary measures that Turkey apply can be exampled in Table 1.

The role of mobility has frequently been debated by policymakers during the fight against the COVID-19 pandemic. However, it is not certain that there is a relationship between mobility and the pandemic for all types of mobility in all countries. Hence, this study explores the answer to this question by studying Turkey's case as an emerging market case and as one of the most affected countries.

3. Data

The literature concerning the COVID-19 pandemic has been developing each day (Akhtaruzzaman et al., 2020; Kartal et al., 2020; Loske, 2020; Phan and Narayan, 2020; Sobieralski, 2020) because the pandemic is a very recent significant phenomenon that all countries have been faced with. Therefore, studies have been done to examine different aspects of the pandemic day by day. In this context, this study focuses on examining the relationship between different types of mobility and the COVID-19 pandemic indicators.

Various indicators of the COVID-19 pandemic have been used in the existing literature. Some studies consider the number of new cases of the pandemic (Chen et al., 2020; Kartal, 2020a; Taquet et al., 2020) while some others prefer to use the number of deaths from the pandemic (Kartal, 2020a; Roy et al., 2020; Woolf et al., 2020). Besides, the number of patients and the presence of the COVID-19 pandemic have been used as pandemic indicators (Kartal et al., 2020; Kronbichler, et al., 2020; Liotta et al., 2020). Moreover, daily and/or cumulative figures have been considered. After evaluating all these alternatives, we preferred to use the daily number of patients and deaths.

In addition, we evaluated the mobility data in line with the aims of this study. Apple and Google publish daily mobility data for almost all countries by collecting data from the users of Apple or Google devices and applications. Apple publishes mobility data for driving and walking sub-details (Apple, 2020). Apple collects this data from the users of Apple devices. As is known, Apple is one of the largest companies in the world whose devices are used worldwide and there are over 1.4 billion Apple devices in the world (Google, 2021). Apple publishes mobility data in which the mobility measures for every country or city are indexed to 100 at the beginning of the series, so trends are relative to that baseline (Apple, 2020). For example, driving mobility was 106.5 and walking mobility was 108.5, on March 11, 2020, in Turkey when the pandemic was first declared.

Similar to Apple, Google also publishes mobility data but has different details from Apple. Google provides more sub-details of mobility

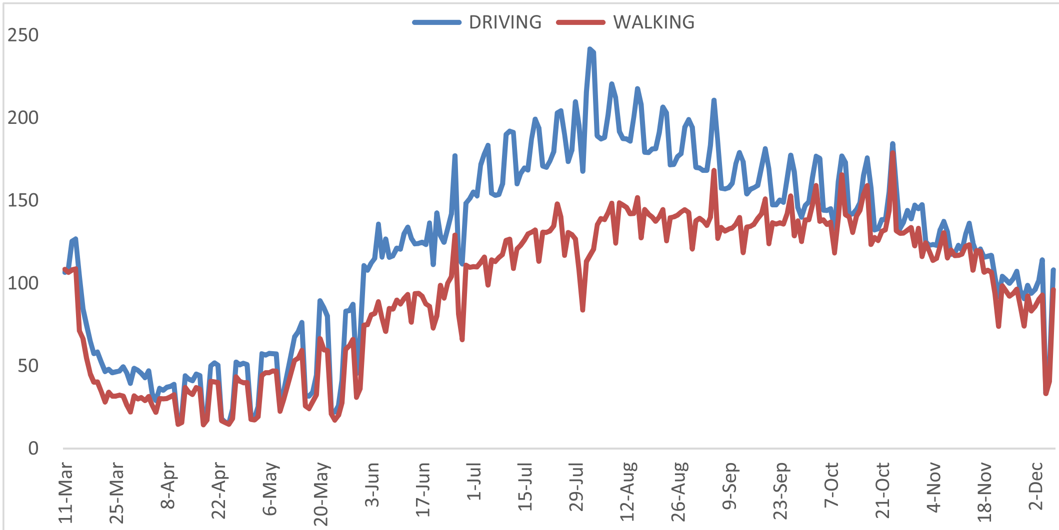

Fig. 1. Mobility of Apple Users in Turkey. Source: Apple (2020).

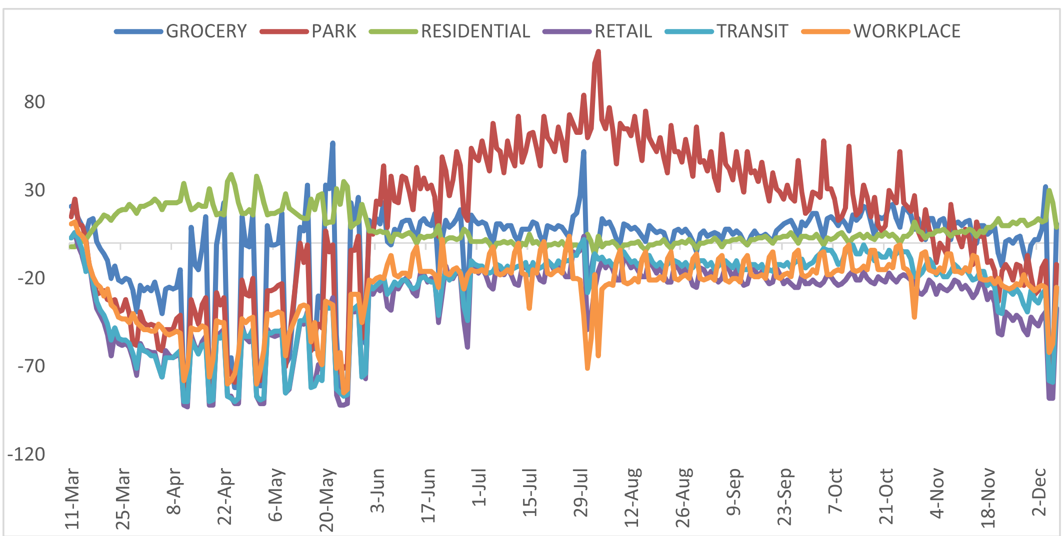

Fig. 2. Mobility of Google Users in Turkey. Source: Google (2020).

data. Google mobility data includes grocery, pharmacy, park, residential, retail, recreation, transit stations, and workplace sub-details (Google, 2020). As is also known, Google is one of the largest companies in the world whose applications are used worldwide and there are over 2.5 billion Google devices in the world (Google, 2021). Google uses a different approach for measuring mobility from Apple. Google prefers to use a percentage change in relation to previous values (Google, 2020). Specifically, grocery mobility increased by 21%, park mobility increased by 15%, workplace mobility increased by 11%, retail and transit mobilities increased by 3%, and residential mobility decreased by 2% on March 11, 2020 in Turkey compared to the previous day (e.g., March 10, 2020).

Apple and Google consider only the data of the devices whose users allow their location and moving information to be used anonymously. Hence, Apple and Google can include those people's mobility data in the published mobility data. We know that Apple and Google mobility data do not reflect all mobilities. Moreover, these data do not show why (for which purpose) people move. It is known that people move for a variety of aims, such as for a trip, on business, etc. Therefore, we acknowledge that Apple and Google mobility data have some shortcomings. However, we think that Apple and Google mobility data can be considered in understanding how mobile people are in a community. Hence, we believe that these data can be used in the analysis of mobility and transport as reliable and accurate.

The use of mobility data has been increasing in the literature to examine pandemic-related issues each day (see Wang and Yamamoto, 2020; Yılmazkuday, 2020a, 2020b, 2020c; Zhu et al., 2020; Nouvellet et al., 2021). We used Apple and Google mobility data based on these studies and considering the probable role of mobility in spreading the pandemic. Hence, mobility could be used as a proxy to reflect the effects of various precautionary measures on transport (Eichenbaum et al., 2020; Elgin et al., 2020; Wielechowski et al., 2020; Kartal et al., 2021). In addition, the data of mobility sub-types were included in this study because not all types of mobility may be related to the COVID-19 pandemic. That is why, there are different administrative precautionary measures, which have been applied in various parts of daily life and these may be effective on different types of mobility in turn. For example, citizens aged 65 and over have been restricted from going outdoors, which was expected to influence walking mobility. In addition, some places, such as schools and restaurants

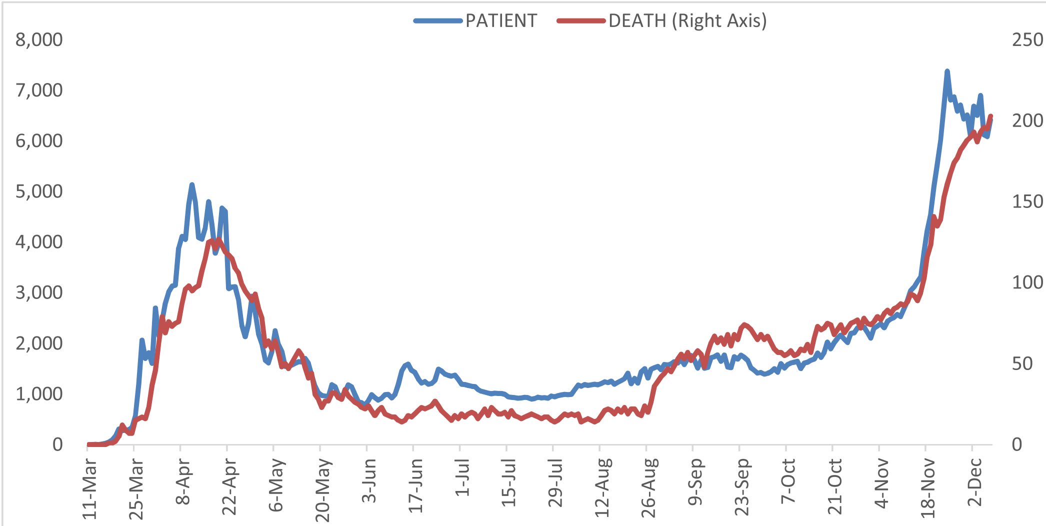

Fig. 3. The Progress of the COVID-19 pandemic in Turkey. Source: Ministry of Health of Turkey (2020).

Table 1
Some Precautionary Measures in Turkey.

Dates	Precautionary Measures
Mar 16	Schools went on spring break one week early.
Mar 17	Flights to 20 countries were canceled. Social areas excluding restaurants and shopping centers were closed.
Mar 19	All levels of education were suspended.
Mar 21	The flight ban to 46 countries was extended. All restaurants were closed except for takeaway services.
Mar 22	Curfews were imposed on citizens with chronic diseases and those aged 65 and over. Public employees were directed to work from home.
Mar 28	A partial curfew was declared in 12 districts. This was the first partial ban.
Apr 03	Travel restrictions were imposed in 31 cities and this restriction was extended for some time.
Apr 10	Curfews were declared in 31 cities between April 11 and 12. Later, curfews were applied for various periods (in April, May, and June), in various scopes (local and national), and are still in effect on weekends in all cities in Turkey.
May 04	Some exams at the national level were postponed.
Sep 04	Wedding ceremonies were banned.
Sep 12	Going outdoors was banned for those aged 65 and over.
Sep 20	Shift work was implemented.

Source: Morgan Stanley (2020), Official Gazette (2020).

were closed for a certain period of time, which was expected to have an effect on driving mobility, mobility in parks, and residential areas. Quarantines and local lockdowns were applied at different time periods; hence, they had a significant effect on mobility at workplaces, parks, grocery, etc. Also, other precautionary measures were applied in many countries that affect different types of mobility (Morgan Stanley, 2020).

Table 2
Summary of Variables.

Symbol	Description	Data Source
PATIENT	Daily number of patients with the COVID-19	Ministry of Health of Turkey[1]
DEATH	Daily number of deaths from the COVID-19	
DRIVING	Driving mobility of Apple users	Apple[2]
WALKING	Walking mobility of Apple users	
GROCERY	Mobility of Google users in grocery and pharmacy	Google[3]
PARK	Mobility of Google users in park	
RESIDENTIAL	Mobility of Google users in residential	
RETAIL	Mobility of Google users in retail and recreation	
TRANSIT	Mobility of Google users in transit stations	
WORKPLACE	Mobility of Google users in workplaces	

[1] https://COVID19.saglik.gov.tr.
[2] https://covid19.apple.com/mobility.
[3] https://www.google.com/covid19/mobility.

Hence, two COVID-19 pandemic indicators, two types of mobility from Apple and six types of mobility from Google were included in the study. Table 2 describes these variables.

The study included the period between March 11, 2020 and December 7, 2020. Variables' data were obtained from the Apple (2020), Google (2020), and the Ministry of Health of Turkey (2020).

4. Methodology

The study performed mainly Toda-Yamamoto causality test to assess the relationship between mobility and the COVID-19 pandemic by considering the aim of the study and stationarity of the variables. Therefore, the third-step methodology was applied as follows. Firstly, the stationarity conditions of the variables were tested by using the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979). Moreover, Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test was employed for the robustness check of the unit root test (KPSS, 1992). Stationarity is the most basic and crucial issue in econometric analyses to prevent spurious and misleading results.

Secondly, Engle-Granger cointegration test was applied to examine the cointegration of the variables. Engle-Granger cointegration test focuses on long-term relationships and explores the dynamic co-movements between variables (Engle and Granger, 1987; Mukherjee and Naka, 1995).

Thirdly, Toda-Yamamoto causality test was performed to determine whether there was a relationship between the variables at the causality level (Toda and Yamamoto, 1995). The main advantage of the Toda-Yamamoto causality test is that it does not require all the variables to be stationary at the same level (Dinçer et al., 2020; Kartal, 2020b). The characteristic of the Toda-Yamamoto causality method is quite important because when the variables are non-stationary and using the first difference of variables lacks information (Tayyar, 2018).

To avoid extending the article too much and for the sake of saving space, the details of the methods used in the study (e.g. ADF test, KPSS test, Engle-Granger cointegration, Toda-Yamamoto causality) have not been discussed broadly. More detailed information related to these models can be found in the original articles by Dickey and Fuller (1979), KPSS (1992), Engle and Granger (1987), and Toda and Yamamoto (1995), and in recent studies such as Kirikkaleli and Ozun (2019), Kartal (2020b), Kirikkaleli (2021), and Kondoz et al. (2021).

5. Empirical analysis

5.1. Descriptive Statistics

Table 3 gives the descriptive statistics of the variables.

The patient figures show the number of Turkish citizens whose COVID-19 test results were positive and who needed treatment in a healthcare facility. The death figures show the number of Turkish citizens who died of COVID-19. In addition, the data for the mobility indicators show how mobility in the related areas changes over time. All the observations covered calendar days.

5.2. Unit root test

The ADF and KPSS tests were applied to examine the stationarity of the variables. The results of these tests are presented in Annex-1. The ADF test results indicate that all the variables are stationary at I(1). However, KPSS tests reveal that PATIENT and DEATH are stationary at I(0) at %1 significance level. Therefore, it is concluded that PATIENT and DEATH are I(0) whereas the other variables are I(1). Hence, we can conclude that the variables have different integrated orders.

5.3. Engle-Granger cointegration test

The Engle-Granger cointegration test was applied and the stationarity of the residuals was examined after examining the stationarity of the variables. The results of the unit root test for residuals are presented in Annex-2. According to the results, the probability values of the ADF test for the residuals are lower than 0.05, which means that there is a long-term cointegration between the variables. Hence, we conclude that the variables move together in the long run.

Table 3
Descriptive Statistics.

Variables	n	Mean	SD	Min	Max
PATIENT	270	2010.72	1519.53	0	7381
DEATH	270	55.54	44.95	0	203
DRIVING	270	122.67	56.68	15.04	241.74
WALKING	270	96.15	43.86	14.23	178.88
GROCERY	270	−1.32	25.54	−86	57
PARK	270	11.04	42.53	−81	109
RESIDENTIAL	270	8.08	9.44	−7	39
RETAIL	270	−33.59	22.97	−93	6
TRANSIT	270	−28.19	24.73	−90	6
WORKPLACE	270	−25.4	18.98	−85	12

Max: Maximum; Min: Minimum; n: Observation; SD: Standard Deviation.

Table 4
Toda-Yamamoto Causality Test Results.

Causality Path	Estimation Degree ($k + d_{max}$)	Chi-Square Test Statistics [p-value]	Causality Relationship
DRIVING ⇒ PATIENT	9	10.89929 [0.2075]	No
WALKING ⇒PATIENT	9	7.884090 [0.4449]	No
GROCERY ⇒PATIENT	**9**	**16.39359 [0.0371]** *	**Yes**
PARK ⇒PATIENT	9	10.88384 [0.20845]	No
RESIDENTIAL ⇒PATIENT	9	8.938973 [0.3475]	No
RETAIL ⇒PATIENT	**9**	**16.92015 [0.0310]** *	**Yes**
TRANSIT ⇒PATIENT	9	7.790383 [0.4542]	No
WORKPLACE ⇒PATIENT	**9**	**14.61808 [0.0670]** **	**Yes**
DRIVING ⇒DEATH	9	10.40707 [0.2376]	No
WALKING ⇒DEATH	9	13.06792 [0.1095]	No
GROCERY ⇒DEATH	9	10.00070 [0.2650]	No
PARK ⇒DEATH	**9**	**17.27682 [0.0274]** *	**Yes**
RESIDENTIAL ⇒DEATH	**9**	**16.61616 [0.0344]** *	**Yes**
RETAIL ⇒DEATH	9	8.574832 [0.3794]	No
TRANSIT ⇒DEATH	9	6.472480 [0.5945]	No
WORKPLACE ⇒DEATH	**9**	**23.13137 [0.0032]** *	**Yes**

*: significance at 5% level; **: significance at 10% level.

5.4. Toda-Yamamoto causality test

The Toda-Yamamoto causality test was applied by considering the stationarity results of the variables. In this context, firstly lag lengths (k) and maximum cointegration degree (d_{max}) were determined and an estimation was applied by using "k + d_{max}" formula. The results of the lag lengths and maximum cointegration degree determinations are presented in Annex-3. Hence, the estimation degree was determined as 9 by considering the results. After determining lag lengths (k) and maximum cointegration degree (d_{max}), the Toda-Yamamoto causality test was performed using the VAR approach to examine the relationship between mobility and the COVID-19 pandemic. Table 4 presents the results of the Toda-Yamamoto causality test.

According to the Toda-Yamamoto causality test results, there is no causality between walking & driving mobilities and the number of patients & deaths. On the other hand, mobility in grocery, retail, and workplace has an impact on the number of patients. Besides, mobility in parks, residential areas, and workplaces has an impact on the number of deaths. The results are significant since they provide details concerning the relationship between mobility and the pandemic in terms of the spread of COVID-19 and transportation in Turkey.

5.5. Discussion and policy implications

The results of Toda-Yamamoto causality test show that there is a relationship between some types of mobility and the COVID-19 pandemic. Specifically, there is an econometric causality relationship between mobility (grocery, retail, and workplace) and the number of patients with COVID-19. There is also an econometric causality between mobility (parks, residential areas, workplaces) and the number of deaths from the COVID-19 pandemic. Moreover, it was determined that neither driving nor walking mobility has an econometric causality relationship with the number of patients and deaths from the pandemic.

The analysis results indicate that various types of mobility have an econometric causality on the COVID indicators (e.g. the number of patients and deaths). The results obtained from the test are generally consistent with the current literature (i.e. Wang and Yamamoto, 2020; Yılmazkuday, 2020a, 2020b, 2020c; Zhu et al., 2020; Nouvellet et al., 2021). However, it was found that driving and walking mobilities did not have an impact on the pandemic, which was an unexpected result. The analysis results demonstrate that although mobility generally affects the COVID-19 pandemic in Turkey, some types of mobility did not seem to have an influence on the number of patients and deaths from the pandemic.

In line with the analysis results, local or country-wide mobility restrictions may not be beneficial. Instead, re-arranging local restrictions, which affect the mobility and transport of citizens can be much more effective in controlling the number of patients and deaths without causing unnecessary economic costs. In this context, mobility in some areas, such as grocery, parks, residential, retail, and workplaces, which influences the number of patients and deaths, should be strictly managed, controlled, and followed up. However, transport restrictions in other areas, such as driving, walking, and transit, can be decreased gradually because an econometric causality relationship between these types of mobility and the number of patients and deaths cannot be determined. However, we do not suggest the removal of all the limitations on such types of mobility. That is why, the mobility data, obtained from Apple and Google, do not reflect all types of mobility because they include only data of the allowed device. Instead, maintaining mobility at low levels in such areas can be much more beneficial.

Besides, some other policies can be applied by the regulatory authorities. In this context, Turkey can re-evaluate (i) intraday mobility restrictions rather than full lockdown or night curfew; (ii) transport time intervals to go to workplaces; (iii) bans on certain types of mobility, which are defined as influential on the COVID-19 pandemic indicators; (iv) more restrictions on some types of mobility than others by considering that some types of mobility in some areas can be riskier than other types because of the contagion effect. Hence, considering the realities of the country, Turkey can develop and apply different policies from those mentioned above by using high-frequency data, which are presented by the Ministry of Health of Turkey but are not available to the public. At the time of the application of such policies, the relationship between the variables should always be considered. Therefore, possible results of the mobility policies should be foreseen before their implementation.

6. Conclusion

The relationship between mobility as a proxy for transport and the COVID-19 pandemic since the beginning of the pandemic in Turkey was examined. Turkey was selected for this purpose because it is one of the top countries that is highly affected by the pandemic. Eight different types of mobility and the number of patients and deaths as indicators of the COVID-19 pandemic were analyzed using the Toda-Yamamoto causality test and daily data from date rage between March 11, 2020 and December 7, 2020.

The results showed that there was a cointegration between mobility and pandemic indicators in the long term. There was also a relationship between some types of mobility, such as grocery, parks, residential, retail, workplaces and pandemic indicators (e.g. the number of patients and deaths). Whereas some types of mobility affect the pandemic, the results showed that neither driving mobility nor walking mobility affects the pandemic indicators, which was surprising. In addition, driving and walking mobilities were not significant enough to be regarded as related to the pandemic indicators. For example, social distancing can be the reason for this determination. Although we show that there is no relationship between these types of mobility and the pandemic according to the econometric causality test, we still think that these types of mobility can be important for the spread of the pandemic and aggregate-level mobility data from Apple and Google may have caused these results because of not including all mobilities. In addition, the scope of the mobility data is an important issue for such analyses because trip purposes can play a different role in spreading the pandemic. Therefore, we prefer to recommend a follow-up mechanism and gradual expansion of such types of mobility so as not to cause a new peak or wave during the pandemic rather than removing all the restrictions. New analyses can be conducted in future studies if the mobility data include trip purposes in the future.

By considering the results of the econometric causality analysis of this study, Turkey can re-arrange the policy set and manage mobility as well as transportation activities more effectively. Such an approach contributes to the controlling of the pandemic and supporting economic activities without applying excessive restrictions in unnecessary areas which cause unwanted, negative results. This is quite significant especially in the transition period of the gradual re-opening of the economies. Applying precautions in unnecessary areas can delay re-opening the economy, result in low economic activity levels and slow down economic growth, which is the last thing that policymakers and people in charge of economic management want. Similar to other countries, Turkey desires to start re-opening the economy as soon as possible. Considering all these facts, it is recommended that Turkey follow up on the effects of mobility on the pandemic in all sub-areas while gradually re-opening the economy. The results present significant implications for other emerging countries as well as countries mostly affected by the pandemic.

In addition to this study, which focuses on Turkey and some other studies, which focus on the United States generally, new studies can be prepared to work on the nexus between mobility and the pandemic in different countries like Brazil, India, Russia, United Kingdom, France, Italy, Spain, Germany, Colombia, Argentina, and Mexico, which are highly affected by the pandemic. Even county/city level analyses can be applied if the data for the indicators of mobility, the pandemic, and restrictions become available at country and city levels. In addition, comparative analyses between the most severely affected and less affected countries can provide additional insights. Such studies can provide contribution to the literature on the spread of the COVID-19 pandemic in terms of mobility and transport.

While this study focuses on the effects of mobility indicators on the COVID-19 pandemic, the effects of the COVID-19 pandemic (e.g. the number of patients and deaths in this study) on mobility can be examined in future studies. In addition, other COVID-19 pandemic indicators like the number of cases and the number of patients recovering can be included in the new analyses. Moreover, new methods in economics and areas of finance, such as the wavelet coherence approach and semi-non-parametric techniques, such as quantile regression and machine learning algorithms can be used in future studies to examine the nexus between mobility, transportation, spread of the pandemic, and pandemic indicators. Hence, new insights into the nexus between mobility, transport, and the pandemic can be obtained. The Toda-Yamamoto causality test focuses mainly on econometric causality rather than real-life mechanistic causality. For this reason, a new dataset that presents much more details for mobility, transport, and the pandemic including older, sicker residents, trip purposes, etc. can provide new contributions to the literature because this is an important limitation of this study and the current literature on the mobility data. Data from Apple, Google, and the Ministry of Health of Turkey are published at the aggregate level. We acknowledge this condition as an important limitation and hope that much more detailed datasets will be shared with the public and researchers so that more comprehensive analyses can be conducted in the future.

Disclosure statement

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethics approval and consent to participate

Not applicable.

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Data availability

The data that support the findings of this study are available in Apple Mobility Data at https://covid19.apple.com/mobility, Google Mobility Data at https://www.google.com/covid19/mobility, and Ministry of Health of Turkey at https://covid19.saglik.gov.tr.

0 Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

1 Acknowledgment

Not applicable.

2 Consent for publication

The authors are willing to permit the Journal to publish the article.

3 Author contributions

The authors have contributed equally to this work. All authors have read and agreed to the version of the manuscript.

Annexes

Annex-1. ADF and KPSS Unit Root Test

Variable	ADF Test		KPSS Test	
	Level Probability (t statistics)	First Difference Probability (t statistics)	Level LM Statistics	First Difference LM Statistics
PATIENT	0,7758 (−0.935588)	0,0025 (−3.888652)*	0.498713*	0.223571*
DEATH	0,8964 (−0.453546)	0,0012 (−4.083126)*	0.686521*	0.355181*
DRIVING	0,5742 (−1.416374)	0,0000 (−5.077401)*	1.059295	0.153023*
WALKING	0,4440 (−1.672657)	0,0003 (−4.484361)*	1.440027	0.178914*
GROCERY	0,4288	0,0001	1.535492	0.085585*

(*continued on next page*)

Annexes 1 (*continued*)

Variable	ADF Test Level Probability (t statistics)	ADF Test First Difference Probability (t statistics)	KPSS Test Level LM Statistics	KPSS Test First Difference LM Statistics
	(−1.702467)	(−4.862919)*		
PARK	0,6351	0,0016	0.779413	0.205306*
	(−1.289262)	(−4.011469)*		
RESIDENTIAL	0,7502	0,0000	0.879571	0.126811*
	(−1.010152)	(−8.918180)*		
RETAIL	0,5629	0,0005	0.926628	0.145574*
	(−1.438996)	(−4.313476)*		
TRANSIT	0,5035	0,0013	1.127002	0.140320*
	(−1.556207)	(−4.060472)*		
WORKPLACE	0,2533	0,0000	0.950480	0.467946*
	(−2.079344)	(−7.743260)*		

*: significance at 5% level.

Annex-2. Unit Root Test for Residuals

Variables	ADF Test t statistics [p-values]
PATIENT & DRIVING	−3.264590 [0.0177] *
PATIENT & WALKING	−3.970468 [0.0019] *
PATIENT & GROCERY	−3.245993 [00186] *
PATIENT & PARK	−3.916203 [0.0022] *
PATIENT & RESIDENTIAL	−3.887169 [0.0025] *
PATIENT & RETAIL	−3.259013 [0.0179] *
PATIENT & TRANSIT	−3.242534 [0.0188] *
PATIENT & WORKPLACE	−3.917047 [0.0022] *
DEATH & DRIVING	−4.081999 [0.0012) *
DEATH & WALKING	−4.075899 [0.0013] *
DEATH & GROCERY	−4.096064 [0.0012] *
DEATH & PARK	−4.080226 [0.0012] *
DEATH & RESIDENTIAL	−4.084159 [0.0012] *
DEATH & RETAIL	−4.081361 [0.0012] *
DEATH & TRANSIT	−4.081276 [0.0012] *
DEATH & WORKPLACE	−4.095225 [0.0012] *

* Significance at the 5% level.

Annex-3. Estimation Degree

Variables	Lag Lengths (k)	Maximum Cointegration (d_{max})	Estimation Degree ($k + d_{max}$)
DRIVING & PATIENT	8	1	9
WALKING & PATIENT	8	1	9
GROCERY & PATIENT	8	1	9
PARK & PATIENT	8	1	9
RESIDENTIAL & PATIENT	8	1	9
RETAIL & PATIENT	8	1	9
TRANSIT & PATIENT	8	1	9
WORKPLACE & PATIENT	8	1	9
DRIVING & DEATH	8	1	9
WALKING & DEATH	8	1	9
GROCERY & DEATH	8	1	9

Annexes 3 (*continued*)

Variables	Lag Lengths (k)	Maximum Cointegration (d_{max})	Estimation Degree (k + d_{max})
PARK & DEATH	8	1	9
RESIDENTIAL & DEATH	8	1	9
RETAIL & DEATH	8	1	9
TRANSIT & DEATH	8	1	9
WORKPLACE & DEATH	8	1	9

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Assoc. Prof. Dr. Mustafa Tevfik KARTAL is a capital market professional. He received a Ph.D. degree in banking from Marmara University, İstanbul/Turkey in 2017, and received an Associate Professor degree in banking from Inter-Universities Board, Ankara/Turkey in 2020. His research interest focuses mainly on banking, central banking, economics, finance, capital markets, financial institutions, financial markets, and financial legislations. He has authored 1 book, 2 book reviews, 20 book chapters, 59 articles, and 12 proceedings in Turkish and English, some of which are indexed in SSCI, SCOPUS, and ESCI indices. Besides, his 4 articles have been accepted for publication and 13 articles have been under review. Also, he works on various articles related to CDS spreads, commodities, FX rates, interest rates, NPL, and stock market index currently.

Moreover, he has a referee role in 53 national and international journals indexed in SSCI, SCOPUS, and ESCI as well.

Dr. Özer DEPREN has been working as an Analysis and Decision Support Manager at Yapı Kredi Bank in İstanbul/Turkey for 10 years. He received the Ph.D. degree in Statistics from Marmara University, İstanbul/Turkey, 2014. His areas of interest are the Entropy, Performance Measuring Systems, Customer Experience Analytics, Advance Statistical Models, and Machine Learning Algorithms. Dr. Depren has more than 20 national/international publications in different journals indexed in SSCI, SCOPUS, and ESCI as well, and has authored 1 book chapter.

Assoc. Prof. Dr. Serpil KILIÇ DEPREN works at Yıldız Technical University (YTU) Statistics Department, İstanbul/Turkey. She received the Ph.D. degree in Statistics from Marmara University in 2012. Her areas of interest include Hierarchical Linear Models, Generalized Estimation Equations, Mixed Models, Machine Learning Algorithms, Entropy, Data Analysis, and Multivariate Statistical Methods. Dr. Kılıç Depren has 36 international and 7 national publications in different journals indexed in SSCI, SCOPUS, and ESCI and has authored 1 book and 3 book chapter. Additionally, she has participated in 20 proceedings in international conferences and 4 proceedings in national conferences; as well, she won 7 academic awards from TUBITAK and YTU.