Electronic Research Archive

http://www.aimspress.com/journal/ERA

ERA, 30(12): 4447–4468.
DOI: 10.3934/era.2022226
Received: 18 September 2022
Revised: 29 September 2022
Accepted: 08 October 2022
Published: 14 October 2022

Research article

Airport passenger flow, urban development and nearby airport capacity dynamic correlation: 2006-2019 time-series data analysis for Tianjin city, China

Ming Wei[1,2], Shaopeng Zhang[1] and Bo Sun[1,3,*]

1 School of Air traffic Management, Civil Aviation University of China, Tianjin 300300, China
2 Beijing Civil Aviation Design And Research Institute Of China Design Group, Beijing 100000, China
3 School of Transportation, Nantong University, Nantong 226019, China

* **Correspondence:** Email: bosun@cauc.edu.cn; Tel: +15022309627.

Abstract: Airports, as integral components of the global aviation industry, experience dynamic changes in air passenger traffic load, which are also related to the trends of local urban development and airspace restrictions of nearby airports. Using time-series data from 2006 to 2019, this study comprehensively applied the autoregressive distributed lag and vector auto-regression mode approaches to identify causal relationships between the urban development factors, including GDP, population, tourism industry, industrial structure, etc., of Tianjin city (China); the Tianjin airport passenger flow; and the Beijing Capital airport's airspace restriction factor, namely, airport aircraft sorties. The results show that the growth of Tianjin city's GDP, primary industry and disposable income per capita was accompanied by a long-term decline in the passenger flow at the Tianjin airport. In addition, increased aircraft sorties of Tianjin airport, as well as the growth of primary, secondary and tertiary industries in Tianjin city, led to a short-term decline in passenger flow at the Tianjin airport. In general, there is variability in the long- and short-term impacts of urban economic structure on airport passenger flow, and this variability applies to other airports. The increased aircraft sorties at the Beijing Capital airport had a short-term positive impact on passenger flow at the Tianjin airport but resulted in a long-term decline of the latter's aircraft sorties. This phenomenon indicates that there is interaction between airports and that this influence varies depending on the competition and cooperation mechanisms between airports. The findings of this study are considered instrumental in guiding the competitive and cooperative strategies of nearby airports and predicting the coupled trends of the airport and urban development.

Keywords: airport passenger flow; airspace restriction factor; urban development; ARDL; VAR; dynamic correlation

1. Introduction

The steady growth of the global economy and rapid development of the air transport industry increase passenger turnover and airport daily loads, while the negative effects of Covid-19 drastically change the long-established airport passenger flow (APF) trends. The analysis of APF statistics is vital for airlines' route planning, shipping dynamics adjustment, operational decisions and optimization of limited resources. Moreover, it is necessary to clarify influencing factors, dynamic mechanisms and APF improvement strategies to meet the latest development trends and challenges.

The research efforts on factors influencing the APF have been mainly focused on the econometric parameters of nearby cities and regions (Dobruszkes and Van Hamme [1]; Kasarda and Green [2]; Juan-Gabriel et al. [3]). Several scholars also explored the correlation of other factors with the APF. Thus, Kasarda and Green [2] considered such factors as aviation liberalization, quality of customs and degree of corruption. John-Button et al. [4,5] expanded the study of APF by addressing the problem of employment and per capita income. Van-De-Vijver et al. [6] analyzed the relationship between trade and APF, while Baltaci et al. [7] reported that airport geography, education level and surrounding airports were the additional factors influencing the APF. The above studies involved city-related factors but failed to provide a systematical analysis of the urban development effect on the passenger flow at the city airport. In addition, to the best of the authors' knowledge, the impact of surrounding airports has not been considered in combination with urban development-related factors.

Multiple scholars attempted to derive the short- and long-term causal relationships between APF, city economic growth and other related factors. Some of them used statistical methods, such as regression analysis (Green [8]). Several econometric models have also been developed: the bivariate vector auto-regression (VAR) model (Marazoo et al. [9]), the dynamic ordinary regression equation (Alexander-Anfofum et al. [10]), the co-integration model (Higgoda and Madurapperuma [11]), the error correction model (Alexander-Anfofum et al. [10]), the Johansen co-integration analysis (Bride et al. [12]), the Granger causality test (Y. H. Chang and Y. W. Chang [13]), the modified ordinary least squares (OLS) method and dynamic OLS (Mehmood and Kiani [14]), parametric linear and non-parametric regression tree models (Li-Yen [15]) and Granger causality techniques (Alexander-Anfofum et al. [10]). The related approaches can be classified into three categories, as shown in Table 1.

The effect of related factors on APF is more obvious and accurate in the long-term perspective, so it is necessary to study the long-term effect of relevant factors on APF. For the long-term relationships, most studies take GDP as the main research object, accompanied by other related influencing factors, such as airplane traffic, employment, education, population migration, airport geography and other factors. Among them, Marazoo et al. [9], Alexander-Anfofum et al. [10], Juan-Gabriel et al. [3] and Y. H. Chang and Y. W. Chang [13] are the main representatives of such an approach. Noteworthy are the differences in the causal relationship between GDP and APF according to different research objects. Marazoo et al. [9] used the bivariate VAR to study the relationship between Brazilian aviation demand and GDP. Alexander-Anfofum et al. [10] developed a series of econometric models, including dynamic ordinary regression equation, co-integration, error correction model and Granger causality techniques, to examine the relationship between air transport and economic growth. Juan-Gabriel et al. [3] used Johansen co-integration analysis and impulse response analysis to investigate possible causal long-term relationships between real GDP and the number of air passengers arriving and departing from Mexican airports. Y. H. Chang and Y. W. Chang [13] applied the Granger causality tests to examine the causal relationship between air cargo expansion and economic growth in Taiwan from 1974 to 2006. Baltaci et al. [7] took the Turkish airport group as an example to conduct an empirical study on the relationship between air transport and economic growth with region-fixed effects and two-stage least square (2SLS) models. They reported that GDP played an important role in long-term APF development. According to the above brief survey, although the perspective of urban development has been involved in the long-term relationship studies, no comprehensive analysis of the relevant factors' correlation has been made yet. There are few studies on population, industrial structure, tourism industry, per capita disposable income and aircraft sorties.

APF is more strongly responsive to the changes of relevant factors in the short-term perspective, so it is particularly important to study the short-term impact. The factors influencing the long-term APF trend were found to impact the short-term one as well. For example, Bride et al. [12] studied the causal short-term relationship between air transport demand, economic growth and the number of aircraft flights in Italy from 1971 to 2012. Using data from 1973 to 2012, Mehmood and Kiani [14] refined the results of Marazoo et al. [9] by applying the modified ordinary least squares (OLS) method and dynamic OLS for deriving the co-integration equation. Adetayo-Olaniyi et al. [16] took Nigeria's international aviation as an example to reveal the synergistic relationship between passenger demand and economic variables in the short run. Li-Yen [15] used parametric linear and non-parametric regression tree models to study the short-term relationship between passenger flow, market flow and various factors, including distance, population, GDP and employment rate, among the airport clusters of countries in the APEC region in 2006 and 2007. Aldonat-Beyzatlar et al. [17] investigated the Granger causality relationship between income and transportation of EU-15 countries using a panel data set covering a period from 1970 to 2008. According to the above findings, there was a bi-directional causal relationship between these factors, where a positive involvement of air travel demand in GDP was more pronounced than that of economic growth in aviation demand. The short-term relationships between APF and other factors were similar to long-term ones, according to relevant literature. However, the effects of urban development (especially per capita disposable income) and the capacity of surrounding airports (especially airspace) on APF have not been comprehensively considered.

APF permanently varies with time; whether in the short term or the long term, it is necessary to study both aspects simultaneously, which is also in line with practical significance. Several studies (Chi and Baek [18]; Baker et al. [19]; Higgoda and Madurapperuma [11]; Mahbubul-Hakim and Merkert [20]) examined the short- and long-term effects of economic growth on APF and explored some other factors, such as freight services, etc. (Chi and Baek [18]). These findings can be subdivided into three cases:

Case 1: Only the short-term correlation was revealed, but no long-term one. Higgoda and Madurapperuma [11] found no long-term relationship between them; there was a one-way causal relationship in the short term for Sri Lanka.

Case 2: Only a long-term correlation was revealed, but no short-term one. Mahbubul-Hakim and Merkert [20] found a long-term unidirectional causality between the GDP, air passenger traffic and air freight volumes. There was no short-term causal relationship between air passenger traffic, air freight volumes and GDP in the South Asian context.

Case 3: Both short- and long-term correlations were revealed. The results of Chi and Baek [18] and Baker et al. [19] showed that APF tended to increase with economic growth in the long run, and air passenger service was responsive to short-term economic growth in the USA and Australia.

Although the above studies successfully revealed the main factors influencing the APF and identified their direct and indirect interrelations, the following critical issues deserve further investigation:

1) The considered urban development factors mainly involved GDP, population, per capita disposable income, tourism industry, industrial structure, etc. Most studies have focused on the part of the factors of urban development influencing the APF but neglected all factor-specific contributions of a city's urban development to APF.

2) To date, only a few studies addressed the airspace interference of two adjacent airports affecting the APF change. Especially for small and medium-sized airports located near large and busy airports, their aircraft sorties cannot grow indefinitely with demand growth due to limited airspace resources. Therefore, it is urgent to reveal the APF trend of such airports and allocate airspace resources accordingly.

3) To the best of the authors' knowledge, no comprehensive historical time-series-based analysis of long- and short-term effects of an airport's passenger flow, urban development and airspace restriction of surrounding airports has been reported yet. Such analysis is necessary to adopt the best dynamic strategy at the right time and place to improve the efficiency of civil aviation management.

In addition, no studies have explored the dynamic relationships between an airport's passenger flow, its urban development and airspace restriction of surrounding airports using more than ten years of time-series data, separating long- and short-term relationships and capturing both direct and indirect effects. This study attempts to fill this gap. Using time-series data from 2006 to 2019 for the airports and cities of Tianjin and Beijing, China, this study applies the autoregressive distributed lag (ARDL) and vector auto-regression (VAR) mode approaches to examine the long-term (i.e., how the change of economic structure affects the general trend of airport passenger flow during the study period from 2006 to 2019) and short-term (i.e., how changes in urban development in each year affect trends in subsequent years) relationships between Tianjin airport's passenger flow, Tianjin urban development and airspace restriction of the Beijing Capital airport.

In other words, this study attempts to clarify whether Tianjin city's urban development and airspace restriction of Beijing Capital airport have any dynamic causal relationships with the passenger flow of the Tianjin airport.

However, there are still some limitations in this study: 1) Although representative variables in urban economic structure are selected as input conditions in this paper, they are not sufficient to fully confirm the impact of urban economic structure, and multiple perspectives need to be selected for future refinement. 2) This study ignores the airport freight situation, and future research on airport freight needs to be supplemented with comparative analysis. 3) Research on airport efficiency and coupling relationships between multiple airports is an extension direction for future research.

Table 1. Classification of available econometric models into three categories.

		Marazoo et al.	Alexander-Anfofum et al.	Juan-Gabriel et al.	Baltaci et al.	Y.-H. Chang, Y.-W. Chang	Bride. et al.	Mehmood,Kiani	Adetayo-Olaniyi et al.	Li-Yen	Aldonat-Beyzatlar et al.	Chi and Baek	Higgoda and Madurapperuma	Baker et al.	Mahbubul-Hakim and Merkert
research direction	long run relationship	√	√	√	√	√						√	√	√	√
	short run relationship						√	√	√	√	√	√	√	√	√
influence factor	GDP	√	√	√		√	√	√		√	√		√		√
	airport geography				√					√					
	high capacity				√										
	the number of aircraft movements				√		√								
	air-passenger demand											√			
	employment/unemployment				√					√					
	education				√										
	population migration				√										
	aggregate real taxable income													√	

	parallel market								√		√				
	per capita disposable income								√	√		√			
	Annual import value									√					
modle	VAR	√													
	dynamic ordinary regression equation		√												
	co-integration		√	√		√	√						√		√
	ECM		√											√	
	Granger causality techniques		√			√	√				√		√	√	√
	IRF			√											
	region-fixed effect				√										
	2SLS models				√										
	OLS method							√							
	Hypothesis testing								√						
	non-parametric regression tree models; parametric linear									√					
	ARDL											√			
	Wald short-run causality tests														√

2. Data

For brevity's sake, the Beijing Capital Airport and the Tianjin airport are further referred to as PEK and TSN, respectively, according to their common abbreviations in international airports' timetables. Time series throughout 2006–2019 were used in this study, as follows.

Table 2. Index system.

Variable	Variable interpretation	Units	Variable type
PA1	Passenger flow at TSN	Person	Interpreted variable
PL0	Airspace capacity of PEK measured by aircraft sorties	Racks	Explanatory variable
GDP	Gross domestic product	Billion Yuan	Explanatory variable
PL1	Airspace capacity of TSN measured by aircraft sorties	Racks	Explanatory variable
TO	Tourism industry	Billion Yuan	Explanatory variable
FI	Primary industry	Billion Yuan	Explanatory variable
SI	Secondary industry	Billion Yuan	Explanatory variable
TI	Tertiary industry	Billion Yuan	Explanatory variable
DI	Per capita disposable income	Yuan	Explanatory variable
POP	Population	Ten Thousand people	Explanatory variable

Drawing on the studies of experts and scholars, the above variables are representative and strongly reflect the stage of urban development, economic development and the proportion of the development structure. The above variables' data were extracted from the National Bureau of Statistics and the China Statistical Yearbook databases.

The study took TSN as an example to explore the influence of related urban development factors (including GDP, population, tourism industry, industrial structure, etc.) and PEK's airspace restriction factors on the TSN passenger flow. As shown in Figures 1 and 2, the longitudinal trends of ten time-series variables are relatively similar and tend to be stable, which implies they may have long-term or short-term relationships.

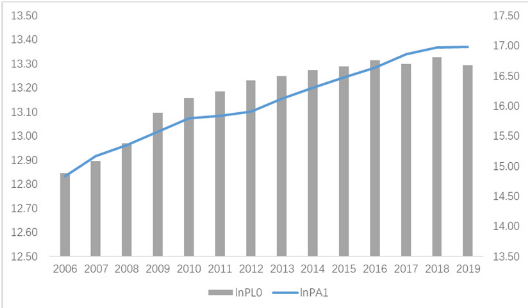


Figure 1. Log-normal evolution of PL0 and PA1 factors from 2006 to 2019.

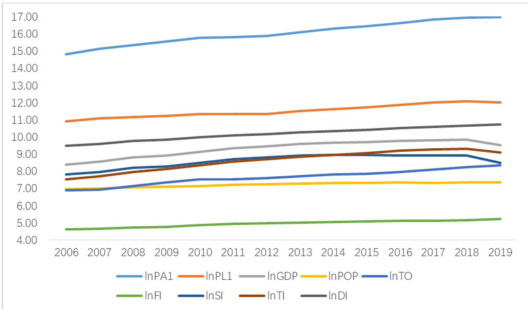


Figure 2. Log-normal evolution of nine factors in Table 2 from 2006 to 2019.

To verify the possible long- and short-term relationships, the data were logarithmized, taking into account data robustness, and the unit root test, co-integration test, residual analysis, CUSUM square test and VAR model stability test were performed when the model was applied. The descriptive statistics of the above log-transformed variables are summarized in Table 3. The log-normal presentation made it possible to convert unstable variables into stable ones and reveal interpretable data patterns more intuitively by interpreting these log-transformed variables in terms of percentage changes.

Table 3. The descriptive statistics results.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
lnPL0	13.1739	13.2400	13.3278	12.8450	0.1613	-0.9928	2.5716
lnPA1	16.0598	16.0170	16.9858	14.8331	0.6850	-0.1753	1.9639
lnPL1	11.5274	11.4355	12.0975	10.9141	0.3839	0.1331	1.7688
lnGDP	9.3386	9.5168	9.8421	8.4160	0.4792	-0.7012	2.1372
lnPOP	7.2277	7.2740	7.3538	6.9801	0.1353	-0.6327	1.9320
lnTO	7.6541	7.6750	8.3512	6.8942	0.4535	-0.2322	2.1285
lnFI	4.9652	5.0193	5.2216	4.6381	0.1880	-0.4666	1.8977
lnSI	8.6134	8.7690	8.9789	7.8232	0.3919	-0.7795	2.2856
lnTI	8.6334	8.7890	9.3081	7.5589	0.5907	-0.5364	1.9498
lnDI	10.1885	10.2313	10.7390	9.4930	0.3957	-0.2850	1.9228

3. Model analysis

This paper aimed to find the dynamic relationships and explore causality between APF, urban development and airspace restrictions of surrounding airports in panel time-series data. A combined ARDL and VAR approach was adopted, where the ARDL bounds testing was used for verifying whether there was a long-term relationship between these independent and dependent variables and examining the existence of co-integration among them (Xin et al. [21]; Xiao-Lei et al. [22]). Meanwhile, VAR was used for finding both short- and long-term effects of two time-series variables (Zhi-Wei and Li [23]). Although the ARDL approach was only used for testing co-integration, unknown structural relationships among these variables were assumed to exist. Their coefficients could be estimated by applying the Granger causality test in VAR. However, the VAR model cannot directly estimate such a relationship between one dependent time series and multiple independent time series simultaneously because VAR directly estimates the speed at which a dependent variable returns to equilibrium after a change in another variable. Therefore, the ARDL model application in this study compensated for this deficiency of the VAR model in the long-term analysis.

The proposed method adopted the ARDL bounds testing approach to verify the long-term equilibrium relationship between these time-series variables. Then, their short-term relationship was assessed via the VAR approach using t-statistics to reveal the Granger causal relations.

3.1. ARDL bounds testing

ARDL outperforms other co-integration methods mainly because it uses a general dynamic specification for finding long-term equilibrium relationships based on the lagged and contemporaneous values of dependent and independent variables. However, it cannot deal with the presence of the I2 series, and it allows only one long-term relationship between variables to be handled. These gaps have to be filled by a comprehensive combination of ARDL and VAR models.

The ARDL model adopted in this study can be described as follows:

$$\begin{aligned}\Delta\ln PA1_t = {} & \propto + \sum_{i=1}^{p} a_i \Delta lnPA1_{t-i} + \sum_{i=1}^{p} b_i \Delta lnPL0_{t-i} + \sum_{i=1}^{p} d_i \Delta lnPL1_{t-i} + \sum_{i=1}^{p} e_i \Delta lnGDP_{t-i} + \sum_{i=1}^{p} f_i \Delta lnPOP_{t-i} \\ & + \sum_{i=1}^{p} g_i \Delta lnTO_{t-i} + \sum_{i=1}^{p} h_i \Delta lnFI_{t-i} + \sum_{i=1}^{p} j_i \Delta lnSI_{t-i} + \sum_{i=1}^{p} k_i \Delta lnTI_{t-i} + \sum_{i=1}^{p} l_i \Delta lnDI_{t-i} \\ & + \beta_{lnPA1} lnPA1_{t-1} + \beta_{lnPL0} lnPL0_{t-1} + \beta_{lnPL1} lnPL1_{t-1} + \beta_{lnGDP} lnGDP_{t-1} + \beta_{lnPOP} lnPOP_{t-1} \\ & + \beta_{lnTO} lnTO_{t-1} + \beta_{lnFI} lnFI_{t-1} + \beta_{lnSI} lnSI_{t-1} + \beta_{lnTI} lnTI_{t-1} + \beta_{lnDI} lnDI_{t-1} + c\end{aligned} \tag{1}$$

where PA1 represents passenger flow at TSN, while PL0 and PL1 represent aircraft sorties, and GDP, POP, TO, FI, SI, TI and DI represent urban economic structure. Note that all the variables are transformed into natural logarithms to attain reliable results. Δ is a difference operator, c is an error term, and p is the maximal lag length. β_{lnPA1}, β_{lnPL0}, β_{lnPL1}, β_{lnGDP}, β_{lnPOP}, β_{lnTO}, β_{lnFI}, β_{lnSI}, β_{lnTI}, β_{lnDI} refer to the long-term relationship. Furthermore, the terms with summation signs represent the error correction dynamics.

To test the null hypothesis of no co-integration, the following condition has to be satisfied: $\beta_{lnPL0} = \beta_{lnPL1} = \beta_{lnGDP} = \beta_{lnPOP} = \beta_{lnTO} = \beta_{lnFI} = \beta_{lnSI} = \beta_{lnTI} = \beta_{lnDI} = 0$. The rejection of the null hypothesis implies the existence of co-integration, i.e., these time-series variables are related in the long run. To confirm or reject the null hypothesis, consider the following three options concerning the comparison of F-statistic and lower and upper critical bounds (Pesaran et al. [24]):

1) If F-statistic > Upper bound, co-integration exists;

2) if Lower bound < F-statistic < Upper bound, the long-term relationship could be obtained by using lagged error correction term;

3) if F-statistic < Lower bound, no co-integration leads to no long-term relationship among variables.

3.2. Vector Auto-regression (VAR) mode

The VAR model used in this study made it possible to assess the dynamic effects of some disturbance in independent variables on dependent ones via the following equation:

$$Y_t = C + A_1 Y_{t-1} + A_2 Y_{t-2} + A_3 Y_{t-3} + \cdots + A_p Y_{t-p} + e_t ; Y_t = \begin{bmatrix} \ln PA1 \\ \ln PL0 \\ \ln PL1 \\ \ln GDP \\ \ln POP \\ \ln TO \\ \ln FI \\ \ln SI \\ \ln TI \\ \ln DI \end{bmatrix} \tag{2}$$

Generally, if no unit root exists, the dynamic relationship could be obtained directly. However, when the unit root exists, the difference in variables should be used to find the dynamic relationship as follows:

$$\Delta Y_t = C + A_1 \Delta Y_{t-1} + A_2 \Delta Y_{t-2} + A_3 \Delta Y_{t-3} + \cdots + A_p \Delta Y_{t-p} + e_t ; Y_t = \begin{bmatrix} \ln PA1 \\ \ln PL0 \\ \ln PL1 \\ \ln GDP \\ \ln POP \\ \ln TO \\ \ln FI \\ \ln SI \\ \ln TI \\ \ln DI \end{bmatrix} \tag{3}$$

A shock (perturbation) of one variable can exhibit itself and influence other endogenous variables via its lag order or structure. In this study, the impulse response function (IRF) method was used to analyze the influences of a standard shock to some independent variables on the values of dependent ones. If the tested variables are all unrelated, the impulse response curves will provide direct and robust proof of that.

4. Empirical analysis

4.1. Verification and analysis of ARDL bounds testing

Unit root analysis is the key to the ARDL bounds testing, aiming at comparing the F-statistic and critical bounds (Pesaran et al. [24]; Faini [25]). The test results are presented in Table 4. The ADF statistics of some variables (such as PA1, PL1 and FI) were not significant, while those of other variables were significant at the levels of 1, 5 or 10%, as shown in Table 4.

Table 4. Unit root test results.

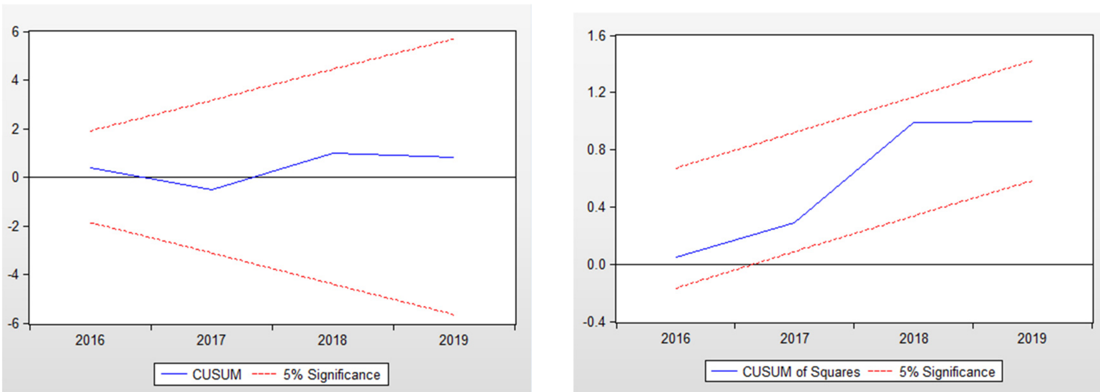
Variable	Inspection form	ADF Statistic	Prob.*	Conclusion
lnPL0	(C,0,2)	-4.0452	0.0113	stationary
lnPA1	(C,0,2)	-2.3073	0.1837	not stationary
lnPL1	(C,T,3)	-3.2154	0.1374	not stationary
lnGDP	(C,0,2)	-3.1039	0.0514	stationary
lnPOP	(C,0,)	-3.4826	0.0287	stationary
lnTO	(C,T,2)	-4.9297	0.0109	stationary
lnFI	(C,0,2)	-1.6834	0.4159	not stationary
lnSI	(0,0,3)	-2.1555	0.0361	stationary
lnTI	(0,0,2)	-2.4341	0.0204	stationary
lnDI	(C,0,2)	-5.0470	0.0023	stationary
D(lnPL0)	(C,T,2)	-3.9670	0.0439	stationary
D(lnPA1)	(0,0,2)	-1.9018	0.0574	stationary
D(lnPL1)	(0,0,2)	-1.9340	0.0540	stationary
D(lnGDP)	(0,0,2)	-3.5648	0.0422	stationary
D(lnPOP)	(C,T,2)	-3.4285	0.0945	stationary
D(lnTO)	(C,T,4)	-12.2293	0.0001	stationary
D(lnFI)	(C,T,2)	-3.6806	0.0662	stationary
D(lnSI)	(C,T,4)	-144.9187	0.0001	stationary
D(lnTI)	(0,0,2)	-3.4412	0.0324	stationary
D(lnDI)	(0,0,2)	-3.0088	0.0069	stationary

Based on the first-order integration of variables, the lag order of variables was determined, and the ARDL boundary co-integration test was carried out. The final determination of the lag order of each variable satisfied (2,2,2,2,2,4,2,4,2,2). Table 5 summarizes the results of the ARDL bounds testing of co-integration under the selected lag lengths. Since the F-statistic (7.56) exceeds the upper critical bound (3.86) at the 1% significance level, the hypothesis of "no long-term relationship" will be rejected, implying that the TSN passenger flow and the related factors were highly related over the period from 2006 to 2019.

Table 5. The ARDL bounds test.

Null Hypothesis: No long-run relationships exist		
Test Statistic	Value	k
F-statistic	7.555442	10
Critical Value Bounds:		
Significance	I0 Bound	I1 Bound
10%	1.83	2.94
5%	2.06	3.24
2.50%	2.28	3.5
1%	2.54	3.86

The model applicability can be proved via the CUSUM Square Test. To check the stability of ARDL, the square test of CUSUM was performed, as shown in Figure 3. These tests proved that the variables were stable during the sample period in all equations.



(a) CUSUM tests for lnPA1 (b) CUSUM of Squares tests for lnPA1

Figure 3. CUSUM plots of square tests.

To further prove the model suitability, the actual values of parameter estimates, fitted values and residuals were processed and plotted in Figure 4. As can be seen in Figure 4, there is smaller data in vertical coordinates, the fluctuation difference between the actual and fitting values was small, and the residual was random. Fitted values and residuals almost overlap, indicating that the model-fitting effect was good.

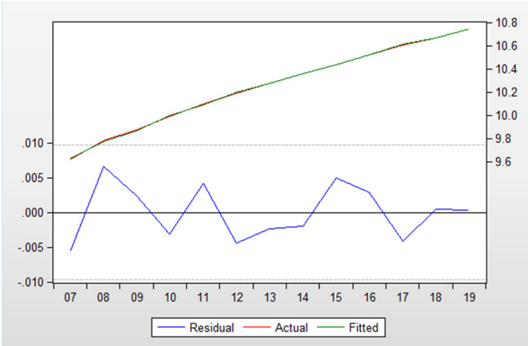


Figure 4. Diagrams of actual values, fitted values and residuals.

According to the unit root test, co-integration test, residual analysis and CUSUM square test results, the ARDL model passed the verification and was further used to study the long-term relationships in this paper. Table 6 reflects the long-term relationship between passenger flow at the TSN and related factors, embodied in the long-term coefficient of related factors and its significance level. All variables were statistically significant according to their t-statistics. The following equation was derived:

$$\begin{aligned}\ln PA1 = 0.1171\ln PA1(-1) - 2.6072\ln PL0 + 0.2048\ln PL1 - 12.8693\ln GDP + \\ 1.7226\ln POP + 1.1608\ln TO - 0.1333\ln FI + 5.4990\ln SI + 7.3288\ln TI \\ -0.2853\ln DI + 32.3739\end{aligned} \tag{4}$$

Table 6. Estimated long-term coefficients of ARDL model.

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LNPA1(-1)	0.1171	0.3259	0.3592	0.7804
LNPL0	-2.6072	6.4954	-0.4014	0.7570
LNPL1	0.2048	1.4893	0.1375	0.9130
LNGDP	-12.8693	26.6624	-0.4827	0.7137
LNPOP	1.7226	4.7785	0.3605	0.7797
LNTO	1.1608	2.4845	0.4672	0.7217
LNFI	-0.1333	2.2229	-0.0600	0.9619
LNSI	5.4990	11.4987	0.4782	0.7160
LNTI	7.3288	15.5273	0.4720	0.7193
LNDI	-0.2853	2.9910	-0.0954	0.9395
C	32.3739	97.8518	0.3308	0.7966

According to Eq (4), the passenger flow of TSN is influenced by the long-term influence of the previous year's passenger flow, urban economic structure and the aircraft sorties of PEK, which is a comprehensive weighted influence. A negative relationship was obtained between aircraft sorties of PEK, GDP, per capita disposable income, the primary industry of Tianjin City and the TSN passenger flow. These findings reveal that a 1% increase in PEK aircraft sorties, GDP, per capita disposable income and primary industry of Tianjin City will reduce the TSN passenger flow by 2.61, 12.87, 0.29 and 0.13%, respectively, over the period from 2006 to 2019. Meanwhile, other related factors, such as

TSN aircraft sorties, population, tourism and secondary and tertiary industries of Tianjin city, show a positive relationship with the TSN passenger flow. For example, based on the overall study time phase, a 1% increase in the tertiary industry of Tianjin city corresponds to a TSN passenger flow increase of 7.33%, and a 1% increase in the secondary industry of Tianjin city corresponds to a TSN passenger flow increase of 5.50%.

4.2. Verification and analysis of VAR model

Similarly, the application of the VAR model requires a stability test to verify its feasibility. As shown in Figure 5, all points in the unit circle prove that the VAR model was stable and usable for investigating the short-term dynamic relationship.

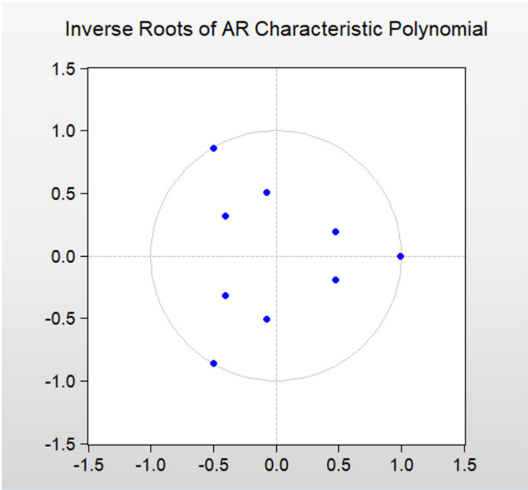


Figure 5. VAR model stability test results.

Table 7 reflects the short-term influence mechanism of these dependent variables (in rows) on independent variables (in columns). The two numbers in the cells of the table represent the estimated and *T* values, respectively. If lnPA1 in the second column is treated as a dependent variable, the TSN passenger flow has a significant coefficient of -0.0185%, in which a 1% increase in aircraft sorties of TSN (i.e., lnPL1 of the first row) in the previous year will lead to a -0.0185% reduction in the TSN passenger flow in the next year. Hence, there is a negative short-term relationship between aircraft sorties and the TSN passenger flow. However, the latter has a significant coefficient of 1.8751%, which indicates that a 1% increase in PEK aircraft sorties (i.e., ln PL0 of the third row) in the previous year will lead to a 1.8751% increase in the TSN passenger flow in the next year. Results also show a lagging effect of the TSN passenger flow: previous-year numbers positively influence next-year ones. Specifically, a 1% rise in the TSN passenger flow in the previous year is associated with its 0.0394% increase in the next year. Meanwhile, if lnPL1 is a dependent variable, the industrial structure and per capita disposable income harm the TSN aircraft sorties in the short-term perspective. In addition, it is worth noting that this short-term lagged effect acts through a certain proportion of weighting into the long-term influence mechanism, resulting in different impact effects rather than mere addition and subtraction.

4.3. Granger causality analysis within the VAR framework

Within the framework of the VAR approach, the Granger causality test can be effectively used to test the causality between variables and verify their interaction. Table 8 reflects the causal relationships between the TSN passenger flow and the other nine factors. The two numbers in the table cells represent Chi-squared statistic and *P* values, respectively. The larger the value of the first number in the parentheses is, the closer the relationship between row and column variables of the cell. For example, it shows a single directional causality of PEK aircraft sorties (lnPL0) and the TSN passenger flow (lnPA1), as indicated by the significant F-statistic of 115.1870. This finding is consistent with the long-term estimate results of ARDL, which imply that PEK aircraft sorties will limit the TSN passenger flow. In general, according to the Granger causality test results, the PEK aircraft sorties have the closest relationship with the TSN passenger flow, followed by GDP, tertiary industry, secondary industry, per capita disposable income, primary industry, aircraft sorties of TSN, population, and tourism industry.

4.4. IRF analysis based on VAR model

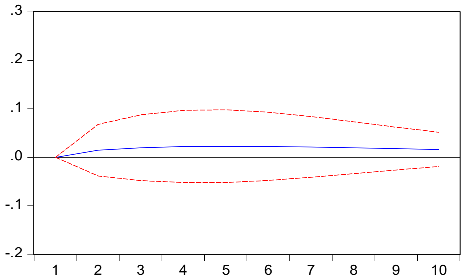
To further explore the interactions between variables, the IRF analysis was used to study the evolution trend of the TSN passenger flow when a certain factor was varied. In this case, the IRF analysis based on the co-integration analysis can measure the changed value of the target variable by the innovation originated from the shock in the input variables. Figure 6 reflects the evolution of the TSN passenger flow in ten periods under the shocks in the other nine factors. In Figure 6, the solid line represents the trend of lnPA1 when it is impacted, while dashed lines on both sides represent twice the standard error of the trend. The scale unit of the abscissa is the unit time estimated by the VAR model, namely, ten periods. The vertical axis is measured in units of each variable, showing the percentage change. For example, the impulse of lnPL0 in Figure 6(a) will increase lnPA1 in the first and second periods. However, lnPA1 will become smooth in the long run. The impulses of lnPL1 in Figure 6(b) will decrease lnPA1 and reach a peak level in the third period.

Table 7. Estimated coefficients of short-term analysis from the VAR model.

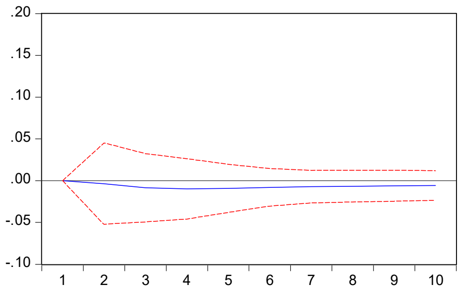
	lnPL1	lnPA1	lnPL0	lnGDP	lnPOP	lnTO	lnFI	lnSI	lnTI	lnDI
lnPL1(−1)	-1.2528	-0.0185	-0.6865	-3.0382	0.0930	0.2990	0.3512	-3.6729	-2.8468	0.5898
	[-0.9956]	[-0.0279]	[-8.3962]	[-8.5864]	[0.3881]	[0.1660]	[0.8988]	[-3.1610]	[-6.9602]	[4.0935]
lnPA1(−1)	1.0978	0.0394	0.8270	3.5713	-0.1113	-0.1450	-0.4648	4.4709	3.1973	-0.5310
	[0.9256]	[0.0631]	[10.7325]	[10.7093]	[-0.4929]	[-0.0855]	[-1.2623]	[4.0827]	[8.2946]	[-3.9104]
lnPL0(−1)	0.2393	1.8751	-0.0270	-2.2749	0.1511	1.9810	0.0019	-2.6608	-2.1749	0.5449
	[0.1380]	[2.0527]	[-0.2399]	[-4.6670]	[0.4577]	[0.7985]	[0.0035]	[-1.6623]	[-3.8601]	[2.7450]
lnGDP(−1)	32.0844	20.6113	-18.1671	18.6498	4.4749	-10.0664	2.4206	50.7122	-8.5700	7.4023
	[1.3351]	[1.6277]	[-11.6354]	[2.7600]	[0.9781]	[-0.2927]	[0.3244]	[2.2855]	[-1.0972]	[2.6902]
lnPOP(−1)	10.7638	6.7987	-5.1725	3.8386	1.6305	-5.5118	1.5580	8.6707	-0.2275	2.2253
	[2.0991]	[2.5161]	[-15.5253]	[2.6623]	[1.6702]	[-0.7511]	[0.9787]	[1.8313]	[-0.1365]	[3.7901]
lnTO(−1)	0.0075	-0.2018	0.0687	0.2007	-0.0314	-0.2813	-0.0886	0.5841	-0.0477	-0.3357
	[0.0170]	[-0.8640]	[2.3838]	[1.6100]	[-0.3722]	[-0.4434]	[-0.6437]	[1.4271]	[-0.3310]	[-6.6139]
lnFI(−1)	-4.0114	-4.1068	1.0184	-3.5658	-0.9243	-0.2617	-0.7086	-7.2524	-0.7174	-1.2266
	[-1.4958]	[-2.9062]	[5.8450]	[-4.7288]	[-1.8104]	[-0.0682]	[-0.8510]	[-2.9289]	[-0.8231]	[-3.9946]
lnSI(−1)	-16.2665	-10.5052	8.8812	-8.2482	-1.9426	4.8761	-1.0607	-22.5196	3.9297	-3.5288
	[-1.4473]	[-1.7738]	[12.1622]	[-2.6101]	[-0.9079]	[0.3032]	[-0.3040]	[-2.1700]	[1.0758]	[-2.7422]
lnTI(−1)	-15.8077	-10.0764	10.6137	-5.4217	-2.4448	5.5201	-2.0762	-20.8701	8.2347	-4.4560
	[-1.2271]	[-1.4844]	[12.6806]	[-1.4968]	[-0.9969]	[0.2994]	[-0.5191]	[-1.7545]	[1.9667]	[-3.0209]
lnDI(−1)	-1.0245	1.1936	-0.8546	-7.8082	0.1394	2.3950	1.3498	-11.8103	-5.2882	1.7601
	[-0.5960]	[1.3177]	[-7.6515]	[-16.1545]	[0.4259]	[0.9735]	[2.5291]	[-7.4408]	[-9.4651]	[8.9425]
C	-45.6835	-44.1994	69.8273	43.6571	-11.2858	17.9614	-27.9768	18.1139	75.4739	-37.0963
	[-0.8301]	[-1.5242]	[19.5296]	[2.8214]	[-1.0772]	[0.2281]	[-1.6375]	[0.3565]	[4.2197]	[-5.8874]

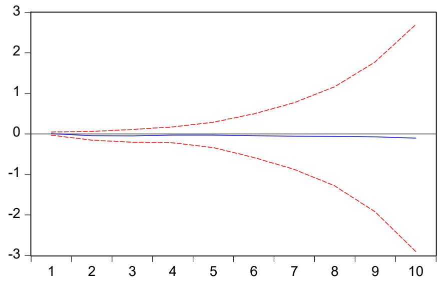
Table 8. VAR Granger causality results.

	lnPL0	lnPA1	lnPL1	lnGDP	lnPOP	lnTO	lnFI	lnSI	lnTI	lnDI	C
lnPL0	——	4.2136 (0.0401)	0.0191 (0.8902)	21.7809 (0.0000)	0.2095 (0.6471)	0.6376 (0.4246)	0.0000 (0.9972)	2.7634 (0.0964)	14.9000 (0.0001)	7.5350 (0.0061)	0.0088 (0.9253)
lnPA1	115.1870 (0.0000)	——	0.8568 (0.3546)	114.6897 (0.0000)	0.2429 (0.6221)	0.0073 (0.9319)	1.5935 (0.2068)	16.6684 (0.0000)	68.8004 (0.0000)	15.2908 (0.0001)	0.1338 (0.7145)
lnPL1	70.4974 (0.0000)	0.0008 (0.9777)	——	73.7257 (0.0000)	0.1506 (0.6980)	0.0276 (0.8682)	0.8078 (0.3688)	9.9919 (0.0016)	48.4438 (0.0000)	16.7567 (0.0000)	0.1386 (0.7097)
lnGDP	135.3817 (0.0000)	2.6493 (0.1036)	1.7825 (0.1818)	——	0.9567 (0.3280)	0.0857 (0.7698)	0.1053 (0.7456)	5.2233 (0.0223)	1.2039 (0.2725)	7.2371 (0.0071)	0.8556 (0.3550)
lnPOP	241.0345 (0.0000)	6.3309 (0.0119)	4.4063 (0.0358)	7.0879 (0.0078)	——	0.5641 (0.4526)	0.9578 (0.3278)	3.3537 (0.0671)	0.0186 (0.8914)	14.3649 (0.0002)	0.9237 (0.3365)
lnTO	5.6824 (0.0171)	0.7465 (0.3876)	0.0003 (0.9864)	2.5920 (0.1074)	0.1386 (0.7097)	——	0.4143 (0.5198)	2.0365 (0.1536)	0.1095 (0.7407)	43.7431 (0.0000)	0.1665 (0.6832)
lnFI	34.1637 (0.0000)	8.4459 (0.0037)	2.2375 (0.1347)	22.3619 (0.0000)	3.2774 (0.0702)	0.0046 (0.9456)	——	8.5784 (0.0034)	0.6775 (0.4105)	15.9564 (0.0001)	0.5308 (0.4663)
lnSI	147.9193 (0.0000)	3.1464 (0.0761)	2.0947 (0.1478)	6.8124 (0.0091)	0.8243 (0.3639)	0.0919 (0.7618)	0.0924 (0.7611)	——	1.1573 (0.2820)	7.5195 (0.0061)	0.8564 (0.3547)
lnTI	160.7971 (0.0000)	2.2033 (0.1377)	1.5057 (0.2198)	2.2403 (0.1345)	0.9937 (0.3188)	0.0896 (0.7648)	0.2695 (0.6037)	3.0784 (0.0793)	——	9.1261 (0.0025)	0.8278 (0.3629)
lnDI	58.5455 (0.0000)	1.7362 (0.1876)	0.3552 (0.5512)	260.9663 (0.0000)	0.1814 (0.6702)	0.9478 (0.3303)	6.3963 (0.0114)	55.3660 (0.0000)	89.5871 (0.0000)	——	0.2960 (0.5864)
C	381.4034 (0.0000)	2.3232 (0.1275)	0.6891 (0.4065)	7.9605 (0.0048)	1.1604 (0.2814)	0.0520 (0.8196)	2.6813 (0.1015)	0.1271 (0.7215)	17.8062 (0.0000)	34.6615 (0.0000)	——



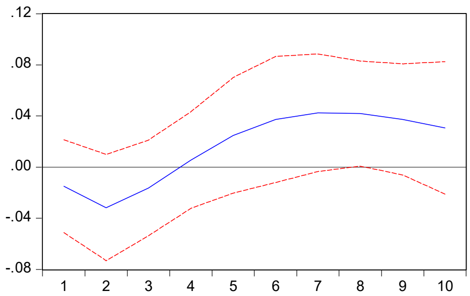
(a) lnPA1 to lnPL0

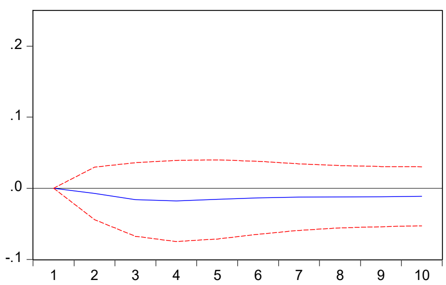




(b) lnPA1 to lnPL1

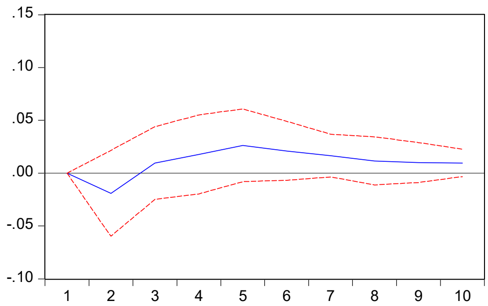
(c) lnPA1 to lnGDP

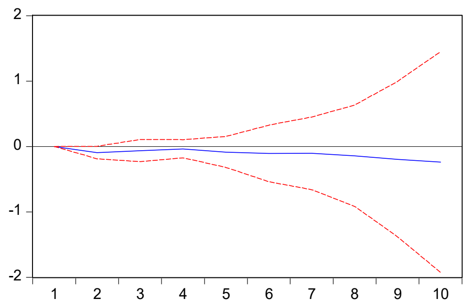




(d) lnPA1 to lnPOP

(e) lnPA1 to lnTO



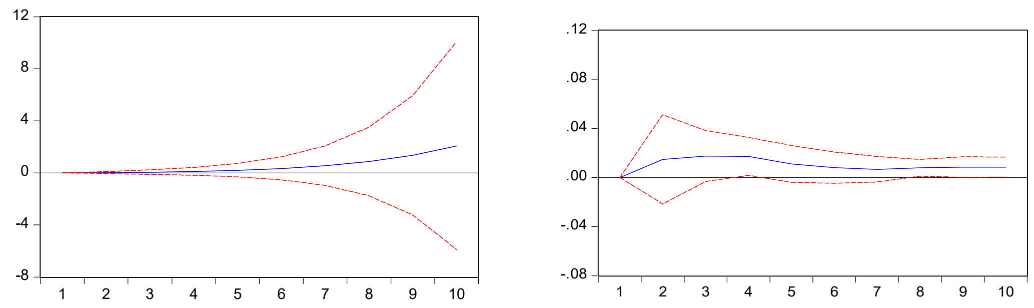


(f) lnPA1 to lnFI

(g) lnPA1 to lnSI

continued on next page

Figure 6. The IRF analysis results for various pairs of factors.



(h) lnPA1 to TI (i) lnPA1 to lnDI

Figure 6. The IRF analysis results for various pairs of factors.

5. Conclusions and Discussion

This paper revealed the long- and short-term relationships between airport passenger flow (APF), urban development and airspace restriction of surrounding airports via the combined ARDL and VAR approaches using panel data for the Tianjin airport (TSN) in China from 2006 to 2019. The main findings of the study can be summarized as follows:

1) On the whole, the TSN aircraft sorties, GDP, population, tourism industry, tertiary industry and per capita disposable income of Tianjin city positively impact the TSN passenger flow. The aircraft sorties of Beijing Capital Airport (PEK), primary industry and secondary industry of Tianjin city harm the TSN passenger flow. In the importance ranking, the PEK aircraft sorties rank first, followed by GDP, tertiary industry, secondary industry, primary industry, per capita disposable income of Tianjin city, TSN aircraft sorties, population and tourism of Tianjin city.

2) Population of Tianjin city has a positive impact on the TSN passenger flow both in the long- and short-term perspectives. Both GDP and per capita disposable income of Tianjin city have long-term negative and short-term positive effects on the TSN passenger flow. Therefore, actively increasing the urban population is undoubtedly the best measure. At the same time, the growth of GDP and per capita disposable income of Tianjin city should not be neglected because the effects of these two variables are observed in a short-term perspective.

3) The impact of the tourism industry on the TSN passenger flow is positive in the long run but negative in the short run. Based on the results, it is expedient to develop the tourism industry to increase APF in the future. However, this effect is self-evident from a marketing standpoint.

4) In the industrial structure, the primary industry of Tianjin city harms the long-term and short-term impacts. Tianjin city's secondary and tertiary industries both promote the long-term TSN passenger flow but harm the short-term one. The industrial development of Tianjin city should be continuously shifted from primary industry to tertiary and secondary ones.

5) The TSN aircraft sorties have long-term positive and short-term negative effects on the TSN passenger flow. In contrast, the effect of PEK's aircraft sorties on the TSN passenger flow is negative in the long run but positive in the short run. As a long-term factor affecting passenger flow, increasing TSN aircraft sorties and reducing the PEK ones can reduce their competition and increase the TSN passenger flow.

The results demonstrate strong long- and short-term relationships between parameters of airports, cities and surrounding airports. This strong relationship is of great significance to the study of passenger flow changes and airport coordination. This study's limitation is that the analyzed period did not cover the latest "downshifting" trends attributed to Covid-19 and respective flight/airport restrictions. However, the latest time-series data analysis might also produce a spurious causal relationship due to the omission of other time-varying covariates that may significantly affect the models. Therefore, our follow-up study will incorporate other time-varying covariates in the analysis by using multivariate econometric frameworks yielding more robust results.

Acknowledgments

This study was jointly supported by the Central College Basic Scientific Research Operating Expenses in the Civil Aviation University of China (3122020079).

Conflicts of interest

The authors declare no conflicts of interest.

References

1. F. Dobruszkes, G. V. Hamme, Impact of the current economic crisis on the geography of air traffic volumes: an empirical analysis, *J. Transp. Geogr.*, **19** (2011), 1387–1398. https://doi.org/10.1016/j.jtrangeo.2011.07.015
2. J. D. Kasarda, J. D. Green, Air cargo as an economic development engine: a note on opportunities and constraints, *J. Air Transp. Manage.*, **11** (2005), 459–462. https://doi.org/10.1016/j.jairtraman.2005.06.002
3. J. G. Brida, M. A. Rodríguez-Brindis, S. Zapata-Aguirre, Causality between economic growth and air transport expansion: empirical evidence from Mexico, *Transp. Res. Rec.*, **6** (2016), 1–15. https://doi.org/10.1504/WRITR.2016.078136
4. K. John-Button, S. Lall, R. Stough, M. Trice, High-technology employment and hub airports, *J. Air Transp. Manage.*, **5** (1999), 53–59. https://doi.org/10.1016/S0969-6997(98)00038-6
5. K. John-Button, J. Yuan, Airfreight transport and economic development: An examination of causality, *Urban Stud.*, **50** (2013), 329–340. https://doi.org/10.1177/0042098012446999
6. E. Van-De-Vijver, B. Derudder, F. Witlox, Exploring causality in trade and air passenger travel relationships: the case of Asia-Pacific, 1980–2010, *J. Transp. Geogr*, **34** (2014), 142–150. https://doi.org/ 10.1016/j.jtrangeo.2013.12.001
7. N. Baltaci, G. Akbulut-Yildiz, Ö. Ipek, The relationship between air transport and economic growth in turkey: cross-regional panel data analysis approach, *JEBS*, **7** (2015), 89–100. https://doi.org/ 10.22610/jebs.v7i1(J).566
8. R. K. Green, Airports and economic development, *Real Estate Econ.*, **35** (2007), 91–112. https://doi.org/ 10.1111/j.1540-6229.2007.00183.x
9. M. Marazoo, R. Scherre, E. Fernandes, Air transport demand and economic growth in Brazil: A time series analysis, *Transp. Res. Part E: Logist. Transp. Rev.*, **46** (2009), 261–269. https://doi.org/ 10.1016/j.tre.2009.08.008

10. A. Alexander-Anfofum, S. Saheed, C. Iluno, Air transportation development and economic growth in Nigeria, *J. Econ. Sustainable Dev*, **6** (2015), 1–11. https://api.semanticscholar.org/CorpusID:73719580
11. R. Higgoda, W. Madurapperuma, Air passenger movements and economic growth in Sri Lanka: Co-integration and causality analysis, *J. Transp. Supply Chain Manage.*, **14** (2020), 1–13. https://doi.org/ 10.4102/jtscm.v14i0.508
12. J. Bride, D. Bukstein, S. Zapata-Aguirre, Dynamic relationship between air transport and economic growth in Italy: a time series analysis, *Int. J. Aviat. Manage.*, **3** (2016), 52–67. https://doi.org/ 10.1504/IJAM.2016.078660
13. Y. H. Chang, Y. W. Chang, Air cargo expansion and economic growth: Finding the empirical link, *J. Air Transp. Manage.*, **15** (2009), 264–265. https://doi.org/ 10.1016/j.jairtraman.2008.09.016
14. B. Mehmood, K. M. Kiani, An inquiry into nexus between demand for aviation and economic growth in Pakistan, *Acad: Int. Multidiscip. Res. J.*, **3** (2013), 200–211. https://api.semanticscholar.org/CorpusID:155416387
15. L. Y. Chang, International air passenger flows between pairs of APEC countries: A non-parametric regression tree approach, *J. Air Transp. Manage.*, **20** (2012), 4–6. https://doi.org/ 10.1016/j.jairtraman.2011.04.001
16. A. Adetayo-Olaniyi, A. Emmanuel-Adewale, O. Oluwaseun-Jubril, Establishing the Concept of Research Hypothesis through the Relationship between Demand in Nigeria International Air Passenger Traffic and Economic Variables, *Int. J. Econ. Behav. Organ.*, **5** (2017), 105–113. https://doi.org/ 10.11648/j.ijebo.20170505.12
17. M. Aldonat-Beyzatlar, M. Karacal, H. Yetkiner, Granger-causality between transportation and GDP: A panel data approach, *Transp. Res. Part A: Policy Pract.*, **63** (2014), 43–55. https://doi.org/ 10.1016/j.tra.2014.03.001
18. J. Chi, J. Baek, Dynamic relationship between air transport demand and economic growth in the United States: A new look, *Transp. Policy*, **29** (2013), 257–260. https://doi.org/ 10.1016/j.tranpol.2013.03.005
19. D. Baker, R. Merkert, M. Kamruzzaman, Regional aviation and economic growth: cointegration and causality analysis in Australia, *J. Transp. Geogr.*, **43** (2015), 140–150. https://doi.org/ 10.1016/j.jtrangeo.2015.02.001
20. M. Mahbubul-Hakim, R. Merkert, The causal relationship between air transport and economic growth: Empirical evidence from South Asia, *J. Transp. Geogr.*, **56** (2016), 120–127. https://doi.org/ 10.1016/j.jtrangeo.2016.09.006
21. X. Li, Y. Fan, L. Wu, CO2 emissions and expansion of railway, road, airline and in-land waterway networks over the 1985–2013 period in China: A time series analysis, *Transp. Res. Part D: Transp. Environ.*, **57** (2017), 130–140. https://doi.org/ 10.1016/j.trd.2017.09.008
22. X. Ma, X. Zhang, X. Li, X. Wang, X. Zhao, Impacts of free-floating bikesharing system on public transit ridership, *Transp. Res. Part D: Transp. Environ.*, **76** (2019), 100–110. https://doi.org/ 10.1016/j.trd.2019.09.014
23. Z. Zhang, B. Li, Impulse response function analysis of Shandong residential electricity demand based on the VAR model, *IOP Conf. Ser.: Earth Environ. Sci.*, **603** (2020), 012–014. https://doi.org/ 10.1088/1755-1315/603/1/012004

24. H. Pesaran, Y. Shin, R. J. Smith, Bounds testing approaches to the analysis of level relationships, *J. Appl. Econ.*, **16** (2001), 289–326. https://doi.org/ 10.1002/jae.616
25. R. Faini, Foreign aid and fiscal policies in Senegal, *J. Int. Dev.*, **18** (2006), 1105–1122. https://doi.org/ 10.2139/ssrn.918229