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The relationship between transportation demand and supply: Granger-Causality test using time-series data

Ulaşım talebi ve arzı arasındaki bağıntı: Zaman-Seri veri ile Granger nedensellik testi

Yavuz DUVARCI[1*], *Hasan Engin DURAN*[1]

[1]City and Regional Planning Department, Faculty of Architecture, İzmir Institute of Technology, İzmir, Turkey.
yavuzduvarci@iyte.edu.tr, enginduran@iyte.edu.tr

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Abstract

Transport demand and supply are deemed to determine each other in a cyclic manner. The major idea has been that the demand is usually the preceding one. However, in urban cases, usually the land use variables in place of supply interfere this process. Cleansing the land use variables, the regional/national level variable pairs of demand and supply are employed to analyze the cause-effect mechanism. For objectivity, the Granger-causality test (GCT) is used to understand the relationship between transportation demand and supply. The Analyses were made at four dimensions; (a)whether the nexus is one-directional or bi-directional, (b)its significance level, (c)whether demand or supply is the preceding, (d)whether the effects are short-term or long-term. Using the Turkish statistics, the GCT results showed that, in the short/medium run, overwhelmingly the supply variables preceded (mostly in railway mode), mostly unidirectional (one-way causality) manner, however, in the long-run almost no relationship was found. In other transportation modes, no significant relationship is observed. Finally, bi-directional relations were usually observed in suburban rail. The investments then should be made according to known demand. Usually, the effects of supply (especially of railways and roadways) could rather fade away in the long-run. Still, no general statement can be made for the demand/supply causality especially in terms of which one is preceding and of the direction of causality. The chaotic nature of the process reigns over with the changing conditions.

Keywords: Travel demand, Transport(-ation) supply, Granger-causality test, Time-Series approach, Bi-Directional causality.

Öz

Ulaşım arz ve talebinin karşılıklı ve dönüşümlü biçimde birbirlerini belirlediği düşünülür. Aslolan talebin belirlemede öncül olmasıdır. Fakat kentsel bölgelerde, genellikle arz yerine kullanılan arazi kullanım değişkenleri bu sürecin arasına karışmaktadır. Arazi kullanım değişkenlerini temizleyerek, bölgesel/milli arz-talep değişken çiftleri sebep-sonuç mekanizması analizinde kullanılmıştır. Nesnel bir analiz için, Granger-nedensellik testi (GCT), tek-yön ve çift-yön için zaman seri veri kullanılarak, hem öncel olan tarafın ve en etken değişkenlerinin tespitinde kullanılmıştır. Analizler dört seviyede yapılmıştır; (a)bağıntının tek-yönlü veya çift-yönlü olup olmadığı, (b)istatistiki anlamlılık, (c)talep veya arzın başlatıcı olup olmadığı, (d) etkilerin kısa vade veya uzun vade olup olmadığı. Ülkemizin bölge istatistikleri ile GCT sonuçları göstermiştir ki, arz-talep etkileşimi tartışmasına açıklık getirebilecek şekilde tek-yön ilişkide arz tarafı değişkenleri özellikle demiryolları bakımından daha önceldir. Buna mukabil, uzun vadede anlamlı sonuçlar hemen hemen yoktur. Sonuçta, çift-yönlü ilişkiler banliyö tren ulaşımında gözlemlenmiştir. Yatırımlar mutlaka talep bilgisi doğrultusunda olmalıdır. Genellikle, arz etkileri (bilhassa demiryolu ve karayolunda) uzun vadede kaybolma eğilimindedir. Hala, arz/talep nedenselliğinde hangisinin başat olduğu ve nedensellik yönlenimi konusunda genel bir hükme varılamamaktadır. Değişen koşullara göre sürecin karmaşık doğası etkin olmaktadır.

Anahtar kelimeler: Yolculuk talebi, Ulaşım arzı, Granger-Causality testi, Zaman-Seri yaklaşım, Çift-Yönlü nedensellik.

1 Introduction

1.1 Demand-Supply Co-Determination

There arise huge budget deficits of local authorities due to misfits between the supply and the demand that the travelers ask for to realize their trips. Therefore, avoiding these gaps must be one of the prime concerns that transport authorities should address. The current paperwork, thus, first drawing attention to the healthy communication issue between the two sides (supply and demand) of transport, devotes to understanding of the nature of cyclic co-determination, to date an overlooked issue.

Paleti et al. (2017) indeed see land use as supply and accordingly assumed land use and transport relationships exist in all time scales [1].

Few studies have focused on the causality (bi-directional, or, co-determination) between the travel demand and transport supply (afterwards shortly the "demand and supply"), where most have investigated unidirectional causality either from demand side, or vice versa [2]-[6]. Though it is stated that the provided "infrastructure shapes mobility" [2], it is hard to separate the two sides from the two-way causality back and forth. Furthermore, in urban land, the transport supply terminology most of the time mixes with land use terminology, which makes things much complicated.

Commonly, the causality relationships between time series variables can be analyzed by using a Granger-causality test (GCT) [3]-[11]. It is referred as a strong statistical tool that tests and helps understanding whether one variable causes another one, or vice versa [3]-[11]. It is used to figure out the direction and the magnitude of the relationships between variables.

There is a further interfering process here; similar interrelationship does indeed develop between transport and land-use structures as well (Figure 1) in the urban environment, which makes the process more complicated,

*Corresponding author/Yazışılan Yazar

contiguous, and synchronous; the effects are in all directions in a Granger-causality way [7]-[9]. Kitamura (2009) defined such chaotic situation as "labyrinthine ecological system" where whole dynamics of urban system components interact. In such an environment measuring the net effect of a variable onto others seems almost impossible [12].

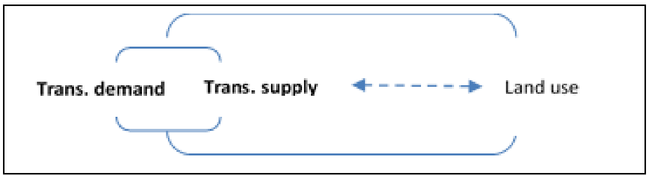

Figure 1. Interrelated cycles of demand/supply and transport/land use [13].

Thus, it is quite unclear which side has a more preceding effect onto the other, and how many effects they can cause on the demand-supply cycle. It is not even clear whether the interactions are one after another, or two-way simultaneously. For two-way causality (not necessarily meaning cyclic), Granger-causality test (GCT) has been proposed [3]-[9] yet with the caution that Granger-causality does not necessarily mean real causation but somehow a "relationship". Though GCT explains variables' relations, it cannot explain between the variables' causal relationships and magnitudes.

The fact that whenever a change is introduced in the supply side (e.g., increase in frequency departures in a tram line), the demand will automatically respond and change accordingly is a simple input/output (black-box) derivation [14]-[16]; the changed demand, in turn, similarly begins to affect the supply and investments over time. In turn the response of demand is much directly related to the cost (price), determined from supply (availability of product) side [17]. If the supplies are scarce or limited, or the provision due to some inefficiencies is costly, then the service provision or infrastructure costs will be higher, even if the provider gets the coverage fee from the users (representing demand). Abundance of supplies may have inducement impact on demand together with the decrease in costs (thus, price) [12],[17]. Thus, the supply continues to affect through time, when, in the meantime, affected and changed demand will continue to affect the supply after a while. The process in demand side is not in discrete moves but in continuum; in response to the continuity in the demand, the supply changes accordingly in discrete amounts due to "lumpy" capacity increases or decreases [17]. A new transit line proposal, for example, as response to an increased demand in time, is a total lump sum increase (causing change in demand not observable in months but in years probably). Yet, the effects most of the time appear with some time lag. Ma & Lo's study (2012) showed that the effects will rather appear in long-term durations [18].

The cycle of influence may absorb the effects of the policy (supply) interruption into the system in addition to the ongoing influential process, or they may converge towards an equilibrium. In the meantime, echoes of influence may cross over other turns of the influence cycle; the effects will not stone-wall stop but overflow to the next time lags in incremental sequences. If a neighborhood has an increasing trend of bicycle use over a period of time, the natural response from the local government would be the provision of bikeways for this development and related urban design, assuming the government is sensitive to the community needs. This policy response may induce a second wave of biking demand (even beyond the need), and this furthered effect will continue on and on, reinforcing the habit of biking on people. Yet, biking ways would not be successful alone in attracting demand unless they are well integrated with the public transport systems [19].

In this sort of cause-effect relations, there are many sides to look into. One basic aim of this study is to observe the precedence of (rather than to deterministically measure the causality itself) interdependencies that may include some socio-cultural aspects. Thus, data pairs of demand and supply will be analyzed to measure the influence of supply factors on the demand side, and vice versa. With the Granger-causality concept, it is the main purpose to show the most preceding side in the dual relationship between the demand and supply (in two-way causality), and thus, whether the relationship is bi-directional.

Usually the GCT method is used in defining the causality between the regional growth and the transportation facilities [20],[21]. A Chinese research found that regional economy influenced the development of local railroads in short-term in a bi-directional causality, however, in the longer term, freight transportation of local railroads influenced regional economy [20]. Using the panel data of 178 countries, only unidirectional causality is seen from real economic growth to the financial development for the less developed countries [21]. They also found that the variables converged to equilibrium quickly but, through time, faded away in the long run.

This study also draws attention to the missing gap in the literature that the supply-demand interrelationship is complex and mixed up with the land use-transport interaction interference that adds to the complicacy. Attention must be given to this issue of obtaining more accurate results from the mentioned relationships. In the urban context, mostly the transport supply terms are mixed up with the "land use" variables inevitably; urban environment would rather be disrupted with land use interference for such analyses. As further complicacy, the positive feedbacks in the cycle may contribute to this mixed view [22]. For clear analysis, the demand/supply issue will be analyzed rather at non-urban context (regional) that is deemed to be cleansed from land use effects within the scope.

The scope of the paper does not, in general, include the freight demands but only those of passenger (human transportation).

2 Literature background

2.1 The cycle of demand-supply interaction

Most of the time the demand-supply relationship is taken together with the linkages between land use and transportation in urban context mistakenly, and supply is usually regarded as land use proxy in an urban area [23],[24]. Researchers have not paid much attention to the cyclic nature of the supply (as not land use) and demand interaction itself *per se*; rather, the supply variables were taken as if part of the land use unwittingly. Thus, demand - supply interactions cannot be healthily analyzed in urban contexts. Thus, the conclusions derived out of these studies may be misleading.

To many [3],[22],[25], the demand and supply are the (usually, as two-way) Granger-causality determinants through time-lags to each other, very similar to the land use-transport relationship in urban context. That is, the demand and supply have causalities within the transport domain itself (as shown in Figure 1), aside the interaction with the land use which is not much elaborated issue in the literature. As an example to this confusion, though car parking supply is in fact a transport supply term, it is many times mistaken as “land use”, which causes noise in the demand-supply cyclic causality process and disturbs getting healthy results. Furthermore, the research by now has also focused on unidirectional effects mostly, probably because the interrelationship between the two is one of "inseparable" interdependence.

While the supply side represents physical transport infrastructure and the service provision (public transport, etc.) to be met by the local governments, the demand side represents the users’ real travel needs, desires, and potential along with the demographic (personal or household) attributes and preferences. Ideally, the supply must be responsive to the demand, whereas the demand estimation is linked to supply through indicators of future land use [16], or physical provisions which can, thus, be related to the land use variables in a way, and which creates an untraceable environment for urban cases. Yet, planners need to trace the influential process between the two to avoid the costs accruing upon public. There is no stagnant equilibrium but oscillation in avoiding over-supply or under-supply, which all indicate an effort to reduce the costs to the public and the users. In particular, a recent study [26] that emphasized an important misfit using an international benchmarking assessment for Spain’s inter-urban transport investments is about the great discrepancy between the supply and demand sides in a transportation service provision that results in enormous waste of public resources due to either over-supply or under-capacity (under-supply) utilization. However, Gruyter et al (2020) found in their recent Melbourne study that 10-unit increase in public transport provision could cause only around 1-unit decrease in the car park demand; i.e., not one-to-one causality [27].

In addition, some supply variables are falsely interpreted as being a part of the land use/transportation relationship, confusing the supply side (representing the built environment) with the misconception of land use through the “urban design” and “infrastructure” linkages. Of course, changes in land use itself can have inevitable modifications in the transport realm (spilling on both supply and travel demands) and the changes occurring in transport system (i.e., the supply) can have unplanned influences on land use in turn [12],[24],[28]. Kitamura (2009), yet, separated the supply from land use, the accessibility and the demand as well. Accordingly, rate of attraction as well as trip production represents the function of variables related to land use and socio-demographic structure (not accessibility) (assumed to be defined by the supply) [12]. Accessibility can affect mobility indirectly rather, not directly, thus, the causality view gets mixed up when urban land use and accessibility are involved in [12]. So, the causality view gets mixed up. Thus, the relationship between the demand and supply side, and whether it is one-way or two-way causality can safely be analyzed at non-urban environment than urban, taking other interferences out of the view.

As another complicacy, that the demand is determined by user statements will remain a problem because the statements are primarily matter of perception and partly of taste, and cultural phenomena [29]. For example, whilst most people usually have positive attitudes towards cycling and walking, their behaviors do not reflect what they state; the real data (a modal share as low as 5% for biking) show that walking or cycling habit is, in contrary, declining in the case of the UK [29]. Therefore, the stated demand may not fit well into the supply situation. Thus, rather institutional and statistical data are better for obtaining robust correlations with the supply data. Yet, the statistical data do not most of the time provide real (or, latent) demand but the user statements, many advise rather the use of preference data (stated), though perceptive, in order to reveal the genuine demand [30],[31].

Predominance in influence (or, the pre-determining side) is also matter of question. Usually most researchers have taken into account the unidirectional effects of one side on the other (in especially modelling). Usually how the created environment, or how neighborhood design characteristics (actually land use) influence the traveler’s behavior, or vice versa, that the planners can define the design guidelines and relevant policy measures for sustainable forms of transportation, starting the quest from one side [32]-[35]. Many studies discussed the fact that the built environment and lifestyle, and demographic indicators (income, age, education, size of household, etc.) of society can have an influence on travel patterns, behavior and car use, whilst the magnitude of these effects varies from one society to another [15],[36]-[39]. That is, at the backside of the demand indicators, there exist the household socio-economic factors and the land use impacts (so, land use is mixed up at demand side, too). This perplex view is hard to dissolve as other socio-cultural differences are added to this complexity. In addition to household demographics, residential self-selection has been conjectured to have another combined effect on travel demand [37],[40]. Thus, household constraints, physical environment and individual preferences interact to influence the travel behavior, that is the demand side.

For example, the self-selection attitude such as the priority decision of owning a car, or a residence and adjusting the travel habits accordingly, single-handedly and strongly dominates the co-determination procedure negatively, because one side (for example, the demand) determines the other habits and controls them overwhelmingly. Due to many advantages of car use and household conditions such as time constraints with children and dependents, walking and biking would not be efficient alternatives, even though they “projected quite positive images” of walking and bicycling according to the surveys [19],[29]. In this sense, demand and supply do not seem sensitive to each other as expected. An earlier study done in 2001 found that the country-wide provision of a 20,000 km traffic-free bicycle network (the UK NCN) has not been as effective in encouraging bicycling as expected [41]. Similar other studies especially working on the effect of reducing road supply on the public transport demand supported this kind of findings [13],[30],[42],[43] especially implying that large investments have not had much reactions in the demand side. In parallel to this, some [13],[44] found out that public transport supply, and rail transit investments also did not have significant effect in reducing the automobile use (as the demand indicator), and congestion levels as well, noting that though some effects can appear in short-run, in the long-run the effects might disappear. If one has a car, s/he may decide his/her travel attitudes accordingly, but not according to the real needs, or may feel like s/he doesn’t need walkways (or, bikeways). The self-selection of car ownership even precedes the design and/or supply factors (such as dense neighborhood, or improved walkways) that could have been more effective in travel choices than the other factors.

Şenbil and Yetişkul-Şenbil's (2020) study based on provincial data for Turkey showed that during the auto-mobilization trend, both supply and demand have mutually stripped out from their constraints such that, by the increase in household incomes in time and the credit easements, the demand has also increased and, by the increase in the automobile production capacity in the country, the supply has increased in the same duration [45]. Interestingly, for the final period of the growth trend, the demand for car ownership has been increasing especially in the low-income provinces for probably the unfilled demand.

2.2 Supply variables disrupted by land use variables in urban context

The previous basic dimensions of the built areas, density, diversity, and urban design (the 3 Ds), later as has been updated to 7 D's, including also demographic structure, destination accessibility, demand management and distance to transit that some authors as Cervero continued to consider as land use variables, are primarily studied over a long time [14],[27],[36],[46],[47]. Commonly, the diversity and work/residence use ratios are usually found in negative correlation with automobile use by many [48]-[51]. Design parameter indicated as small block sizes and dense street layout, which could have been considered as the supply variable, is found negatively correlated with car use [52],[53]. At the neighborhood level, the possible effects of street design on travelling or car ownership have not been adequately examined [54]-[56] (See [62],[63] for further information). Although providing accessibility to urban amenities and especially to public transport facilities such as railway stations within walking distance can discourage car use, the effect of urban design in general has been found many times not as significant as thought [57],[58]. As an example, subway station locations and accessibility are found to be important factors (as the supply variables) in positively changing commuting behavior for subway use [57]-[59]. The proximity to light rail stations significantly lowers the rate of car use [59]. As some pointed out, in transit-oriented cities, the total number of trips and miles travelled by vehicle can decrease by up to 30% [60],[61]. Yet, providing accessibility through land use and/or design is distinct (and can be taken as land use variables) from providing accessibility through means of transportation. However, former is sort of land use, and the latter is supply variable, here. Another study found that, for the neighborhoods of Jinan, China, street characteristics, neighborhood permeability, and parking supply (again the supply variables) have influences on car usage (they also used mixture of land use and supply variables) [64]. According to their findings, mostly the supply parameters could affect the demand (different than the previous finding in the previous section). Accordingly, the street diversity, special transit lanes or bikeways, etc. and the street design (all being supply), addressing to the attractiveness of walking through the design elements are assumed to be among the land use characteristics [32],[64]-[66]. But again, these are the supply elements of transport taken as proxy variables to land use, which are sometimes named as "land side" accessibility [67].

According to Kitamura (2009), if we assume that the added supply will affect the travel demands, then a supply variable should have taken place in trip generation modelling, which is missing in the conventional modelling and trips for non-work purposes are often more vulnerable to the supply conditions [12].

Again, providing nearby railway stations (like providing road infrastructure) is not a land use but rather a supply variable of transport [68]. While deployment of vehicle fleet for public transport by the local government is supply, car ownership by individuals is a demand indicator, and yet, may dictate urban design components. However, car ownership level is controlled strongly by household demographics [16]; then indirectly, the demographics basically determine the land use and the design, (and the supply) but, car ownership can also be boosted by the man-shaped design, which, in turn, starts reshaping the environment toward the one that is less permeable and less accessible to utilities, etc. This goes on in a vicious cycle in such car-based community. Thus, the relations are not indeed straightforward and unidirectional, but indirect (in long term probably).

Car ownership demand variable is not even determined primarily by the availability of parking (i.e., supply), or roads built, though the contrary is advocated many times, but, behind the veil, by income and household demographics (i.e., demand), which rather dictates the parking supply [12],[39] that is, demand rather determines the supply, though it looks the other way around: demographics (such as income) indirectly determine the supply situation in balancing the demand/supply co-determination. Here, the land use impacts intervene into the cycle, and the term 'built' has so far created a confusion here due to the fact that supply variables are of the transport realm, but not land use.

It has been emphasized by now that if the densities are increased at homes or work places, by means of the land use mix, pedestrian facilities, and more permeable street network (grid) with better transit accessibility, then lower private car ownership, car use, and VKT (or, shorter commuting distances) can be obtained even in developing nations [51],[69],[70]. However, the prevailing confusion here is that, except the land use mix variable, the other variables seem to be rather supply variables. Again, the transport supply and infrastructure variables such as paved roadways or parking areas should be separated from the other land use ones for obtaining undisrupted healthy results. This is because, though the former is used in the transport supply, the latter is used in the domain of land use in terms of design, land use mix, and density [59], [67] which should be looked in land use/transportation relationship area. Most of the times, in the literature, these are all mixed up, and supply is considered as capacity level only. When the conceptualization is a mixed one, land use and transport interrelationship can fuse in the cross-effect process. This way of handling produces probably wrong results. For this problem, the demand - supply determination analysis, thus, need to be done, first, away from urban areas, for the time being, and data examples must be chosen from regional level for clarity.

Clearly, the household's socio-economic structure, demographics and/or life style usually have also imprints on the demand (travel behavior) side. Travelers from large households drive less, but walk, or cycle, and young members use public modes [71]. Middle-income groups tend to use the subway and high-income groups tend to use car, while lower-income groups rather prefer walk and non-motorized modes. Thus, design (and land use) factors appear "associative" (or endogenous) rather than causal: rather household demographics have more implications on travel behavior (i.e., demand). Yet, some studies inversely advocate that the travel need is due to activities that are strongly bound to land use factors (or, attributes) [72],[73]. Further, while activity attracts people (and encourages traveling), the quality, infrastructure (i.e., the supply), and attractiveness of the space or services themselves can have the same impact in attracting people, though not as much as the activities themselves [74],[75]. Household demographics have also significant influence on car use; this is particularly the case in the large households with children (as dependents), which have a greater travel need for health, education and sport activities, and these trips are usually made by car for safety and convenience. However, these may indirectly create pressures on the infrastructure requirements [76].

The view gets perplexed such that both supply and demand may have sensitivities to the land use as well as to each other. The household demographics side seems the major drive, and the determinant, and thus, preceding one behind the demand view. Still, there is a cycling influential process; if these two realms do indeed influence each other from their respective viewpoints, then there can be a continuous cycle of co-determination between the supply and demand sides (as between the land use and transport sides), which creates uncertainty with regard to which came first (i.e., the egg/chicken) paradox in time [24]. Thus, as once stated previously that "a unidirectional impact onto the other cannot be causal" cannot be valid because the interrelationship would not be a one-sided relation but an interactive and continuous one with echoing effects in the chain [40]. The correlation values, thus, do provide a convenient indication of interdependencies, be they causal or associative, in a cyclic system.

Therefore, for the above mentioned reasons and the methodology adopted in this paperwork, to cleanse probable land use effects of urban environment from the supply domain of transport, we need firstly to test the granger-causality between the demand and supply duality in a regional context, using regional/national data rather than the urban.

2.3 Regional transport demand & supply characteristics

Instead of taking the complex view of urban areas, regional cases in analysis of the demand/supply causality would pose clearer results. Yet, still not many research could be obtained so far for the causality between transport demand and supply, but rather between the transport supply and the economy. The results from a study (Önen 2020) where ARIMA method was used revealed that the air transportation has positive effects on the economic development (there is bi-directional relationship between the two) [81]. The transport share of airway carriage increased continuously over the recent years and expected to increase its share more [81],[82] (Further Data Sources: [77]-[80]). When looking at the competition amongst the land transport modes, especially the differentiation in products, cargo carrying distances, and carrying capacities, etc. have been influential in preferring railroad carriage as the external factors (though the truck carriers are more competitive for long hauls). But, for example, such other continental differences as the high-price motorway tolls in EU than US comprise the other influences [83],[84] Jain et al. (2020) points out to the role of technology that recently major disparities and unbalanced situation between the demand and supply could be removed to a greater extent by the ICT applications and online freight sector [84].

Altuntaş and Kılıç (2021) also confirmed the contribution of air carriers to the economic growth using the Toda-Yamamoto causality analysis as well as ARDL, similar to the GCT, such that the economic growth was observed upon the gradual increase in the supply of airways in Turkey (from 150 to 515 airplanes between the years 2002 and 2018 [85],[82]. Besides the most frequently applied GCT tests, in the related literature various similar methods such as ARDL, Johansen, Cointegration methods, Kao, Pedroni, Breitung, Toda & Yamamoto Causality, Dumitrescu-Hurlin Heteregenous Panel Causality, etc. arrived at the similar results (See, [86],[89]-[92] and [82] for more details). Kiracı (2018), in his Toda-Yamamoto analysis, found endogeneity relationship between the average income and the air transportation developments. Toda-Yamamoto test differently does not have to be dependent on the condition of cointegration [86],[87]. The similar Hatemi-J method allows for the exploration of the asymmetric causality between the data series [87],[88]. Finally, a bi-directional causality was found in the relationship between the GNP and the demand at domestic and international airway investments.

3 Method of GCT application

Empirically, Granger-causality test has commonly been employed by researchers in economic and social sciences literature [7]-[9]. There exist number of studies that analyze the causality between transportation and economic growth. For instance, one study found out a long-run positive causality between public transportation investments and economic growth for a period 1980-2003 in Turkey by applying an Engle-Granger (1987) causality tests [4],[7]-[9] Similarly, another similar study was implemented by Algaic in 2017 [5]. He focused on the transportation and economic growth relationship in US for a period 2000-2015. There, he found that transportation causes the evolution of GDP, but not vice versa. Another study found a positive relationship among transportation and GDP in fifteen European countries for a period 1970-2008 by using Granger-causality tests [6].

The relationship between transportation demand and supply has been investigated in a quite few numbers of paper by adopting Granger-causality Tests. Only one example of such a study was conducted [3]. In his study in Sweden, he found that transport supply as measured by vehicle-kilometers (Granger) cause the transportation demand for a period 1986 and 2001; i.e., the supply is the preceding one. In addition, Granger-causality technique has rarely been employed in the context of public transportation demand and supply. That is why we prefer adopting this method, due to the fact that it explicitly shows the magnitude and direction of the causality. The Granger-causality method is especially meaningful for two-way and cyclic interaction between one side and the other. Therefore, it is one of the most suitable analysis techniques to be applied in such demand-supply cyclic interrelationship.

Bivariate Granger Causality test tries to test, which variable drives (determines) the other one [7]-[10]. The logic of the test works in the following way: Let x and y are time series variables, then, it has been run the following bi-variate regressions [9],[10],[93];

$$"y_t = \partial_0 + \partial_1 x_{t-1} + \cdots. + \partial_n x_{t-n} + \gamma_0 + \gamma_1 y_{t-1} + \cdots. + \gamma_n y_{t-n} + e_t \quad (1)$$

$$x_t = \partial_0 + \partial_1 x_{t-1} + \cdots. + \partial_n x_{t-n} + \gamma_0 + \gamma_1 y_{t-1} + \cdots. + \gamma_n y_{t-n} + u_t" \quad (2)$$

The explanations of GCT, equations 1,2 and related text has been adapted from Eviews 4 User's guide (page 222) [10] and Granger (1969) [9]. Suppose one would like to test whether x causes y [7]-[10]. In such case, x denotes the independent variable whereas y represents the dependent variable. Then, the null and alternative hypotheses will appear as [7]-[10].

Ho : x variable does NOT cause y, (Null Hypothesis) $\partial_0 = \partial_1 \ldots = \partial_n = 0$

Ha : x variable causes y (Alternative Hypothesis), $\partial_0 \neq \partial_1 \ldots \neq \partial_n \neq 0$

The null hypothesis is tested via F-Test statistics [11]. In case the null hypothesis is rejected, this would mean that x causes significantly y. Following a similar logic, one can test whether y causes x by applying equations (1) and (2).

GCT method is a useful tool to determine both strength and the causality direction between the two variables [3]-[6], [9]-[11]. In terms of magnitude, the calculated F-statistics shows the extent of the impact of one variable on another [3]-[11]. Hence, higher F-values and lower corresponding p-values indicate more significant impact of that variable to the other one.

Possibly, the statistical mechanism works in the following way: consider a case in which the impact of transportation supply on transportation demand is being analyzed, if F-statistics is very high, this means that preceding values of supply has a powerful/significant impact on current values of demand [3]-[11]. (as in equation 1,2). That is why, in such case, it can be said that supply causes demand.

In terms of the causality direction, GCT is able to test both the impact of supply on demand and also the impact of demand on supply. In the former case, if F-Statistics is significant but not in the latter case, then this would mean that x causes y but not the other way round [3]-[11]. On the contrary, if F-statistics is significant in the latter case but not in the former case, then, it would mean that demand causes supply [3]-[11]. If f-statistics is significant in both cases, then bidirectional (circular) causality would be present. The fact that GCT is able to test this circularity is a merit. It provides, thus, advantages over other methods. For instance, alternative methods such as simple OLS (Ordinary Least Squares) or one-way ANOVA analyses, which are very commonly applied in the literature, do not provide this opportunity [3]-[11]. They test whether supply has a significant impact on demand but not the circularity of the relationship has been incorporated [3]-[11]. Hence, GCT is considered as a powerful statistical tool that measures causality, the magnitude and the direction of the relationship between variables.

4 Data

Since this study is Turkey-based, the regional data of Turkey are used as the most relevant approach. Turkey, being one of the biggest economies of the world, it has a growing economy and dynamic trade and transportation restructuring phase since the 2000's, with also having the young and dynamic population assets. For instance, the total population is quite large and young (total population: 83.6 Million (2020), median age is 32.7 (2020)), population growth is recently 0.55% (2020) and GDP growth is 7.4 (2021/3rd quarter) (Data Source: Turkstat, [77]) Turkey, between Europe and Asia with the latest mega project attempts, is lately attempting renewing its transportation infrastructures and becoming hub point of energy and transportation networks on the way from Europe to Far East. Therefore, analyzing the demand and supply interrelationships in such dynamic context would pose a punctual case for the intended analyses, here.

Due to the disruption problem both by the land use cyclic impacts on the transport in urban environments rather than the urban kind and the mentioned confusion on the definition of land use/supply parameters, the data at national/regional level (i.e, the demand/supply variable pairs) will be taken as the data cases. Both demand and supply time-series (annual) data of one example (or, case) together is defined as one set of data. Typically, the automobile sales (as demand data) each year and the lengths (km) of roads provided (as supply data) each year, for the same periods (for example from 2010 to 2017) can be a suitable set (pair) of data, for example. Since monthly data would not provide reliable results for the time lag effect necessitated (effects appear in longer durations) in the GCT analysis, we tried to employ yearly data instead. Also, monthly data are not much available (usually the institution release yearly data).

For comparison, a set of different but topic-relevant data (i.e., demand/supply interrelationship) are taken, mostly from Turkish Statistical Institute (TURKSTAT), (along with all other data sources related national level transportation data [77],[85],[94]-[97]. The institute collects and issues almost all basic national statistics (economic, sectoral, social, demographic, etc.) at various scales and time periods. The data are limited in terms of variety and time span. In the data obtained from the institution, only one set of data from Izmir is about the sub-regional scale (suburban rail). Whether the data of supply and demand are time-referenced (from the same period) is important for coherence of the two data, which also explains the scarcity of the data. In the current part of the study, interaction between transport demand and supply was tested by using bi-variate GCTs. The details of the variables are given below in Table 1. All variables are second differenced (in natural logarithms), meaning they are calculated twice the differences with respect to time. Moreover, we applied an ADF (Augmented Dickey Fuller) test which is a useful method to examine the stationarity of time series variables [98]-[103]. Having assumed 1 year-time lag, all variables (second differenced) are shown to follow significantly stationary process except the two variables which have ADF statistic values close to the critical values (Table 2) [98]-[103]. Thus our variables can conveniently be used in Granger Causality analysis since they have significantly stationary evolution. The two exceptional variables have the test statistics close to the critical values. That's why they are included in the study as well. However, these two variables did not give any significant result.

5 The test results

In transportation realm, the effects between supply and demand usually appear in the long term. although some contrarily advocated that long-term effects will eradicate through time [43],[44]. Thus, instead of monthly, the yearly data, but cautiously not too far-fetched data were chosen for the GCT analyses. And, such data are usually aggregated at regional or national level, due to the dubious urban data. The GCTs are performed for the variables defined in Table 1. The results are presented in Table 3. Natural logarithmic and second differenced versions of the variables have been adopted to ensure the stationary property of the variables. Conveniently, 2-4 (short/medium term) and 10-12 (long-term) years' time-lag length have been employed for each data pair (demand-supply data pairs).

Table 1. Definition of the variables.

Mode	Name of Variables	Type	Definition	Spatial Unit	Source	Period
Railway	r_tr_d_loadamount	Demand	Total Amount of load carried in railways	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], General Directorate of Turkish State Railways [96]	1977-2016
Railway	r_tr_d_nrpassanger	Demand	Total Number of Passengers	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], General Directorate of Turkish State Railways [96]	1977-2016
Railway	r_tr_d_passangerkm	Demand	Total Km traveled by Passengers	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], General Directorate of Turkish State Railways [96]	1977-2016
Railway	r_tr_d_tonkm	Demand	Total km of load carried in railways	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], General Directorate of Turkish State Railways [96]	1977-2016
Railway	r_tr_s_linelengthkm	Supply	Total Railway line length	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], General Directorate of Turkish State Railways [96]	1977-2016
Railway	r_tr_s_railkm	Supply	Total km of Railway traveled by trains	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], General Directorate of Turkish State Railways [96]	1977-2016
Railway	r_trsub_d_nrpassanger	Demand	Number of Passengers in Suburban Trains	Suburban-Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], General Directorate of Turkish State Railways [96]	2001-2016
Railway	r_trsub_s_seatkm	Supply	Total km of seats traveled by Suburban trains	Suburban-Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], General Directorate of Turkish State Railways [96]	2001-2016
Highway	h_tr_d_totalroadkm	Demand	Total km of road and highway traveled by vehicle	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], KGM (General Directorate of Highways)[94]	2001-2016
Highway	h_tr_d_totalpasskm	Demand	Total km of road and highway traveled by passengers	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], KGM (General Directorate of Highways)[94]	2001-2016
Highway	h_tr_s_totalroadkm	Supply	Total km of available road and highway	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], KGM (General Directorate of Highways)[94]	1984-2016
Highway	h_tr_d_highwaypasskm	Demand	Total km of highway traveled by passengers	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], KGM (General Directorate of Highways)[94]	2001-2016
Highway	h_tr_s_highwaykm	Supply	Total km of available highway	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], KGM (General Directorate of Highways)[94]	1984-2016
Highway	h_tr_d_tonkm	Demand	Total ton-km freight traveled in highways	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], KGM (General Directorate of Highways)[94]	2001-2016

Table 1. Continued.

Mode	Name of Variables	Type	Definition	Spatial Unit	Source	Period
Highway	h_izm_s_newhighway	Supply	Km of newly added highway	İzmir	Turkstat (Turkish Statistical Institute) [77], KGM (General Directorate of Highways)[94]	2000-2017
Highway	h_izm_d_autoincr	Demand	Increase in automobiles	İzmir	Turkstat (Turkish Statistical Institute)[77], KGM (General Directorate of Highways) [94], Uzun (2018) [106], EGM (General Directorate of Public Security)[97]. In construction of this variable, the data in Figure 3.9 (page 24) of [106] Uzun (2018)'s study were used.	2000-2016
Airway	a_tr_s_seatcap	Supply	Airways seat capacity	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], (SHGM) Directorate General of Civil Aviation [85] and (DHMI) General Directorate of State Airports Authority [95]	2002-2016
Airway	a_tr_d_nrpassanger	Demand	Total number of airway passengers	Aggregate Turkey	Turkstat (Turkish Statistical Institute) [77], (SHGM) Directorate General of Civil Aviation [85] and (DHMI) General Directorate of State Airports Authority [95]	2002-2016
Airway	a_izm_s_takeofflanding	Supply	Total Number of take off and landings	İzmir	Turkstat (Turkish Statistical Institute) [77], (SHGM) Directorate General of Civil Aviation [85] and (DHMI) General Directorate of State Airports Authority [95]	2004-2016
Airway	a_izm_d_totalpass	Demand	Total number of airway passengers	İzmir	Turkstat (Turkish Statistical Institute) [77], (SHGM) Directorate General of Civil Aviation [85] and (DHMI) General Directorate of State Airports Authority [95]	2004-2016

Table 2. Augmented dickey fuller test, source: own estimation.

Variable	ADF Test Stat	Variable	ADF Test Stat
r_tr_d_loadamount	-8.94***	h_tr_s_totalroadkm	-6.66***
r_tr_d_nrpassanger	-7.88***	h_tr_d_highwaypasskm	-2.4
r_tr_d_passangerkm	-7.09***	h_tr_s_highwaykm	-4.73***
r_tr_d_tonkm	-9.53***	h_tr_d_tonkm	-3.48**
r_tr_s_linelengthkm	-7.29***	h_izm_s_newhighway	-3.46**
r_tr_s_railkm	-9.85***	h_izm_d_autoincr	-3.81**
r_trsub_d_nrpassanger	-4.48***	a_tr_s_seatcap	-2.17
r_trsub_s_seatkm	-4.74***	a_tr_d_nrpassanger	-3.96**
h_tr_d_totalroadkm	-5.21***	a_izm_s_takeofflanding	-3.66**
h_tr_d_totalpasskm	-4.66***	a_izm_d_totalpass	-2.93*

Note: *represents the statistical significance at 10% (where 0.05<p-value<0.1), ** at 5 % (where 0.01<p-value<0.05),*** at 1 % (p-value<0.01). This notation is valid for the entire study and other tables. McKinnon critical value for -2.4 is -2.71, for -2.17 it is -2.73 [101]- [103]. Analysis in this paper (in Table 2 and Table 3) is implemented in Eviews 4 Software Package [10].

Table 3. Granger causality results. lag length=2. source: Own estimation.

Mode	Independent Variable	Dependent Variable	F-Stat	Result
Railway	r_tr_d_loadamount	r_tr_s_linelengthkm	*0.40643*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_loadamount	*0.48061*	*No Relationship*
	r_tr_d_nrpassanger	r_tr_s_linelengthkm	*2.6727**	*Demand Causes Supply*
	r_tr_s_linelengthkm	r_tr_d_nrpassanger	*2.00852*	*No Relationship*
	r_tr_d_passangerkm	r_tr_s_linelengthkm	*0.93176*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_passangerkm	*3.06951**	*Supply Causes Demand*
	r_tr_d_tonkm	r_tr_s_linelengthkm	*0.47463*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_tonkm	*0.5099*	*No Relationship*
	r_tr_d_loadamount	r_tr_s_railkm	*0.22623*	*No Relationship*
	r_tr_s_railkm	r_tr_d_loadamount	*0.95815*	*No Relationship*
	r_tr_d_nrpassanger	r_tr_s_railkm	*0.53104*	*No Relationship*
	r_tr_s_railkm	r_tr_d_nrpassanger	*1.44712*	*No Relationship*
	r_tr_d_passangerkm	_tr_s_railkm	*0.09884*	*No Relationship*
	r_tr_s_railkm	r_tr_d_passangerkm	*2.07898*	*No Relationship*
	r_tr_d_tonkm	r_tr_s_railkm	*0.94485*	*No Relationship*
	r_tr_s_railkm	r_tr_d_tonkm	*1.28009*	*No Relationship*
	r_trsub_d_nrpassanger	r_trsub_s_seatkm	*6.66112***	*Demand Causes Supply*
	r_trsub_s_seatkm	r_trsub_d_nrpassanger	*29.2851****	*Supply Causes Demand*
Highway	h_tr_d_totalroadkm	h_tr_s_totalroadkm	*0.33627*	*No Relationship*
	h_tr_s_totalroadkm	h_tr_d_totalroadkm	*0.44376*	*No Relationship*
	h_tr_d_totalpasskm	h_tr_s_totalroadkm	*0.08187*	*No Relationship*
	h_tr_s_totalroadkm	h_tr_d_totalpasskm	*0.22491*	*No Relationship*
	h_tr_d_highwaypasskm	h_tr_s_totalroadkm	*0.29445*	*No Relationship*
	h_tr_s_totalroadkm	h_tr_d_highwaypasskm	*0.49487*	*No Relationship*
	h_tr_d_totalroadkm	h_tr_s_highwaykm	*0.81132*	*No Relationship*
	h_tr_s_highwaykm	h_tr_d_totalroadkm	*0.6111*	*No Relationship*
	h_tr_d_totalpasskm	h_tr_s_highwaykm	*1.73784*	*No Relationship*
	h_tr_s_highwaykm	h_tr_d_totalpasskm	*1.97948*	*No Relationship*
	h_tr_d_highwaypasskm	h_tr_s_highwaykm	*2.30062*	*No Relationship*
	h_tr_s_highwaykm	h_tr_d_highwaypasskm	*1.61378*	*No Relationship*
	h_tr_d_tonkm	h_tr_s_highwaykm	*6.32109***	*Demand causes Supply*
	h_tr_s_highwaykm	h_tr_d_tonkm	*1.99650*	*No Causality*
	h_tr_d_tonkm	h_tr_s_totalroadkm	*0.44319*	*No Causality*
	h_tr_s_totalroadkm	h_tr_d_tonkm	*1.26785*	*No Causality*
	h_izm_d_autoincr	h_izm_s_newhighway	*0.154*	*No Relationship*
	h_izm_s_newhighway	h_izm_d_autoincr	*1.057*	*No Relationship*
Airway	a_tr_d_nrpassanger	a_tr_s_seatcap	*0.20532*	*No Relationship*
	a_tr_s_seatcap	a_tr_d_nrpassanger	*0.01249*	*No Relationship*
	a_izm_d_totalpass	a_izm_s_takeofflanding	*0.59549*	*No Relationship*
	a_izm_s_takeofflanding	a_izm_d_totalpass	*1.34933*	*No Relationship*
Granger Causality Results, lag length=4.				
Railway	r_tr_d_loadamount	r_tr_s_linelengthkm	*1.30698*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_loadamount	*0.75712*	*No Relationship*
	r_tr_d_nrpassanger	r_tr_s_linelengthkm	*1.65495*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_nrpassanger	*8.53363****	*Supply Causes Demand*
	r_tr_d_passangerkm	r_tr_s_linelengthkm	*0.46649*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_passangerkm	*4.32068****	*Supply Causes Demand*
	r_tr_d_tonkm	r_tr_s_linelengthkm	*1.34487*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_tonkm	*0.38913*	*No Relationship*
	r_tr_d_loadamount	r_tr_s_railkm	*1.778*	*No Relationship*
	r_tr_s_railkm	r_tr_d_loadamount	*1.38731*	*No Relationship*
	r_tr_d_nrpassanger	r_tr_s_railkm	*0.65872*	*No Relationship*
	r_tr_s_railkm	r_tr_d_nrpassanger	*1.10897*	*No Relationship*
	r_tr_d_passangerkm	r_tr_s_railkm	*1.17234*	*No Relationship*
	r_tr_s_railkm	r_tr_d_passangerkm	*1.5924*	*No Relationship*
	r_tr_d_tonkm	r_tr_s_railkm	*1.2254*	*No Relationship*
	r_tr_s_railkm	r_tr_d_tonkm	*0.38665*	*No Relationship*
	r_trsub_d_nrpassanger	r_trsub_s_seatkm	*4.45461*	*No Relationship*
	r_trsub_s_seatkm	r_trsub_d_nrpassanger	*59.098**	*Supply Causes Demand*
Highway	h_tr_d_totalroadkm	h_tr_s_totalroadkm	*0.25282*	*No Relationship*
	h_tr_s_totalroadkm	h_tr_d_totalroadkm	*1.01618*	*No Relationship*
	h_tr_d_totalpasskm	h_tr_s_totalroadkm	*0.12525*	*No Relationship*
	h_tr_s_totalroadkm	h_tr_d_totalpasskm	*11.8089*	*No Relationship*
	h_tr_d_highwaypasskm	h_tr_s_totalroadkm	*0.01689*	*No Relationship*

Table 3. Continued.

Mode	Independent Variable	Dependent Variable	F-Stat	Result
Highway	h_tr_s_totalroadkm	h_tr_d_highwaypasskm	*5.78735*	*No Relationship*
	h_tr_d_totalroadkm	h_tr_s_highwaykm	*2.2863*	*No Relationship*
	h_tr_s_highwaykm	h_tr_d_totalroadkm	*253.646***	*Supply Causes Demand*
	h_tr_d_totalpasskm	h_tr_s_highwaykm	*0.31486*	*No Relationship*
	h_tr_s_highwaykm	h_tr_d_totalpasskm	*17.2892*	*No Relationship*
	h_tr_d_highwaypasskm	h_tr_s_highwaykm	*1.84705*	*No Relationship*
	h_tr_s_highwaykm	h_tr_d_highwaypasskm	*1.01018*	*No Relationship*
	h_tr_d_tonkm	h_tr_s_highwaykm	*0.41128*	*No Relationship*
	h_tr_s_highwaykm	h_tr_d_tonkm	*2.02812*	*No Relationship*
	h_tr_d_tonkm	h_tr_s_totalroadkm	*0.50103*	*No Relationship*
	h_tr_s_totalroadkm	h_tr_d_tonkm	*6.12858*	*No Relationship*
	h_izm_d_autoincr	h_izm_s_newhighway	*0.54642*	*No Relationship*
	h_izm_s_newhighway	h_izm_d_autoincr	*3.09087*	*No Relationship*
Airway	a_tr_d_nrpassanger	a_tr_s_seatcap	NA	
	a_tr_s_seatcap	a_tr_d_nrpassanger	NA	
	a_izm_s_takeofflanding	a_izm_d_totalpass	NA	
	a_izm_d_totalpass	a_izm_s_takeofflanding	NA	
Granger Causality Results, lag length=10.				
Railway	r_tr_d_loadamount	r_tr_s_linelengthkm	*2.3254*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_loadamount	*0.77042*	*No Relationship*
	r_tr_d_nrpassanger	r_tr_s_linelengthkm	*0.99972*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_nrpassanger	*1.94633*	*No Relationship*
	r_tr_d_passangerkm	r_tr_s_linelengthkm	*1.44095*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_passangerkm	*1.06455*	*No Relationship*
	r_tr_d_tonkm	r_tr_s_linelengthkm	*6.099**	*Demand Causes Supply*
	r_tr_s_linelengthkm	r_tr_d_tonkm	*0.521*	*No Relationship*
	r_tr_d_loadamount	r_tr_s_railkm	*0.68493*	*No Relationship*
	r_tr_s_railkm	r_tr_d_loadamount	*0.41533*	*No Relationship*
	r_tr_d_nrpassanger	r_tr_s_railkm	*2.56968*	*No Relationship*
	r_tr_s_railkm	r_tr_d_nrpassanger	*1.76216*	*No Relationship*
	r_tr_d_passangerkm	r_tr_s_railkm	*2.37392*	*No Relationship*
	r_tr_s_railkm	r_tr_d_passangerkm	*2.47761*	*No Relationship*
	r_tr_d_tonkm	r_tr_s_railkm	*0.99922*	*No Relationship*
	r_tr_s_railkm	r_tr_d_tonkm	*0.3523*	*No Relationship*
	r_trsub_d_nrpassanger	r_trsub_s_seatkm	NA	
	r_trsub_s_seatkm	r_trsub_d_nrpassanger	NA	
Highway	h_tr_d_totalroadkm	h_tr_s_totalroadkm	NA	
	h_tr_s_totalroadkm	h_tr_d_totalroadkm	NA	
	h_tr_d_totalpasskm	h_tr_s_totalroadkm	NA	
	h_tr_s_totalroadkm	h_tr_d_totalpasskm	NA	
	h_tr_d_highwaypasskm	h_tr_s_totalroadkm	NA	
	h_tr_s_totalroadkm	h_tr_d_highwaypasskm	NA	
	h_tr_d_totalroadkm	h_tr_s_highwaykm	NA	
	h_tr_s_highwaykm	h_tr_d_totalroadkm	NA	
	h_tr_d_totalpasskm	h_tr_s_highwaykm	NA	
	h_tr_s_highwaykm	h_tr_d_totalpasskm	NA	
	h_tr_d_highwaypasskm	h_tr_s_highwaykm	NA	
	h_tr_s_highwaykm	h_tr_d_highwaypasskm	NA	
	h_tr_d_tonkm	h_tr_s_highwaykm	NA	
	h_tr_s_highwaykm	h_tr_d_tonkm	NA	
	h_tr_d_tonkm	h_tr_s_totalroadkm	NA	
	h_tr_s_totalroadkm	h_tr_d_tonkm	NA	
	h_izm_d_autoincr	h_izm_s_newhighway	NA	
	h_izm_s_newhighway	h_izm_d_autoincr	NA	
Airway	a_tr_d_nrpassanger	a_tr_s_seatcap	NA	
	a_tr_s_seatcap	a_tr_d_nrpassanger	NA	
	a_izm_s_takeofflanding	a_izm_d_totalpass	NA	
	a_izm_d_totalpass	a_izm_s_takeofflanding	NA	
Granger Causality Results, lag length=12				
Railway	r_tr_d_loadamount	r_tr_s_linelengthkm	*55.4649*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_loadamount	*0.62092*	*No Relationship*
	r_tr_d_nrpassanger	r_tr_s_linelengthkm	*0.21054*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_nrpassanger	*1.04619*	*No Relationship*
	r_tr_d_passangerkm	r_tr_s_linelengthkm	*1.2916*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_passangerkm	*0.79284*	*No Relationship*

Table 3. Continued.

Mode	Independent Variable	Dependent Variable	F-Stat	Result
Railway	r_tr_d_tonkm	r_tr_s_linelengthkm	*52.0187*	*No Relationship*
	r_tr_s_linelengthkm	r_tr_d_tonkm	*1.74051*	*No Relationship*
	r_tr_d_loadamount	r_tr_s_railkm	*1.63135*	*No Relationship*
	r_tr_s_railkm	r_tr_d_loadamount	*0.2415*	*No Relationship*
	r_tr_d_nrpassanger	r_tr_s_railkm	*1.30439*	*No Relationship*
	r_tr_s_railkm	r_tr_d_nrpassanger	*1.78484*	*No Relationship*
	r_tr_d_passangerkm	r_tr_s_railkm	*0.55366*	*No Relationship*
	r_tr_s_railkm	r_tr_d_passangerkm	*3.31839*	*No Relationship*
	r_tr_d_tonkm	r_tr_s_railkm	*0.1011*	*No Relationship*
	r_tr_s_railkm	r_tr_d_tonkm	*0.21567*	*No Relationship*
	r_trsub_d_nrpassanger	r_trsub_s_seatkm	NA	
	r_trsub_s_seatkm	r_trsub_d_nrpassanger	NA	
Highway	h_tr_d_totalroadkm	h_tr_s_totalroadkm	NA	
	h_tr_s_totalroadkm	h_tr_d_totalroadkm	NA	
	h_tr_d_totalpasskm	h_tr_s_totalroadkm	NA	
	h_tr_s_totalroadkm	h_tr_d_totalpasskm	NA	
	h_tr_d_highwaypasskm	h_tr_s_totalroadkm	NA	
	h_tr_s_totalroadkm	h_tr_d_highwaypasskm	NA	
	h_tr_d_totalroadkm	h_tr_s_highwaykm	NA	
	h_tr_s_highwaykm	h_tr_d_totalroadkm	NA	
	h_tr_d_totalpasskm	h_tr_s_highwaykm	NA	
	h_tr_s_highwaykm	h_tr_d_totalpasskm	NA	
	h_tr_d_highwaypasskm	h_tr_s_highwaykm	NA	
	h_tr_d_tonkm	h_tr_s_highwaykm	NA	
	h_tr_s_highwaykm	h_tr_d_tonkm	NA	
	h_tr_d_tonkm	h_tr_s_totalroadkm	NA	
	h_tr_s_totalroadkm	h_tr_d_tonkm	NA	
	h_tr_s_highwaykm	h_tr_d_highwaypasskm	NA	
	h_izm_d_autoincr	h_izm_s_newhighway	NA	
	h_izm_s_newhighway	h_izm_d_autoincr	NA	
Airway	a_tr_d_nrpassanger	a_tr_s_seatcap	NA	
	a_tr_s_seatcap	a_tr_d_nrpassanger	NA	
	a_izm_s_takeofflanding	a_izm_d_totalpass	NA	
	a_izm_d_totalpass	a_izm_s_takeofflanding	NA	

Briefly, the major results obtained are;

In short/medium-term cases;

i. For the railway modes, generally, the supply has preceding effects on the demand. This effect becomes more and more dominant as the time-lag length (duration) of the impact increases, when lag length is 4,

ii. For the suburban railways, both demand and supply interact having effects equally in the short run, and uniquely, and it is evident that there is a both-way (reciprocal) relationship,

iii. Regarding the highways, in the short/medium run, generally neither demand nor supply is dominant and no significant relationships are observed in general.

That is to say, neither the demand nor the supply has unidirectional or bi-directionally precede (most determinant on the other) the other. Sometimes, demand can (or, even cannot) have the determinant role in defining the supply amounts and the necessary investments, and sometimes the supply proposed can define the demand levels. Yet, when and under which conditions these happen cannot be easily determined.

iv) Regarding airways, there is no general linkage at all between demand and supply, which is astonishingly interesting, too.

Though this result of no linkage is certainly the most surprising one to us, too, for the airways always has shown strong causality between the investments (the supply) and the economic growth, etc., the causality relationship to the demand would be indirectly through the economy related variables. Then, we can say there can be linkages hidden under economy related parameters, but still very early to state this.

In long-run cases;

i. In railway modes, neither supply nor demand seemed dominant. There are no significant relationships in general.

Similar to the situation of short/medium term highways, again there seemed no (even if small level of relationship) significant level of causality between the demand and supply to say about confirmed causality, due to (1) the once occurred short-term effects may have faded away in the long run, which must be quite peculiar to railways, as often emphasized in various views in the literature, and/or 2) bi-directional influences may neutralize all cross-effects in time.

6 Evaluation of the results and discussion

When the cross-effects between transport supply and travel demand are analyzed through the GCT overwhelmingly regional/national data (i.e., only the data of Izmir metropolitan area are used) data, we have both quite interesting and unexpected results. For the interesting results, we can evaluate the results in various categories; short/medium term and long-term and with regard to different transportation modes.

7 Short/Medium term results

With regard to the results in the short/medium run, in the two and four lag setting, we observed different statistically significant relationships. In railway mode, at the country level, demand causes supply only in one case; number of passengers causes line length of railway lines at the country level. Supply however, causes demand in 3 different cases; length of railway lines cause railway kilometers traveled by passengers, length of railway lines cause number of railway passengers in both 2 and 4 years lag length.

Once, the sub-urban railway demand and supply are analyzed, it is observed a bi-directional relationship in the short-run (when k=2) but uni-directional impact from supply to demand in the medium-run (when k=4).

In airway mode, no statistical relationship was observed.

8 Long term results

Generally, no significant relationship is found in none of the analysis. Indeed, many tests in the long-run did not return a result, possibly due to insufficient number of observations (denoted by "NA" in Table 3).

Hence, in the long-run, no relationship is detected in general. One may, therefore, argue that neither demand nor supply is dominant in long-run relationships.

9 The absence of significant relation

Thus, it has been observed that supply is a more dominating factor compared to demand. It is at least true in short-term/medium-term dynamics and for railway mode. It is particularly evident when four- year lag length was employed. Bi-directional relationship was not true in the majority of cases but only in sub-urban demand and supply, a significant two-way relationship was observed.

It is observed surprisingly and generally no significant relationships between demand and supply in certain transportation modes, particularly, in highways (short/medium/long run), airways (short/medium/long run) and railways (long-run), context

Although such empirical results may be observable, they are surprising too. One possible explanation is based on the following argument: in these transportation modes, supply of ways is found to have no relationship with demand. This might be due to the fact that an increase in supply of the ways (or capacities) does not necessarily create additional demand as alternative transportation nodes in that zone are also increasing.

It might also be due to the fact that depending on the time period analyzed, demand factors (such as increase in consumption patterns and trends) may sometimes be dominant in certain years, while supply-side factors (such as increase in unit costs) may be dominant in other years. Consecutively, none of the supply or demand becomes dominant in causality analysis which returns an insignificant relationship between demand and supply.

Freight demand variables at the regional level were not generally taken into consideration for this study, since the scope of the paper is limited to passenger travels and the related data. However, freight data also should be considered in another study elsewhere.

10 Conclusions

In the urban studies, usually the transport supply variables have been disrupted with the land use (or, urban design) variables and terminology, which further blur the view in addition to the difficulty of cause-effect analysis of the demand/supply interaction. For cleansing the land use/transport cyclic effects from the supply/demand cyclic ones, which are usually observed in urban data cases, rather the regional/national data were analyzed for obtaining clear view, here, or to see clearer interaction between the transport demand and supply. As of the basic findings of this study, the effects (not necessarily cause-effect type by definition of Granger-causality) were four levels:

a) Whether there exists one-directional or bi-directional (two-way) effect in general, or none at all,

b) Significance level of the effect,

c) Whether either the demand or the supply is the most preceding one, and

d) Whether the time-lag effect (if exists) appears in the short-run (2nd year, 4 year) or late in the long-run (10^{th} or 12^{th}).

Utilizing the Granger-causality Test (GCT) method, we analyzed the data bi-directional (from both sides) way between the demand and supply, and observed that; first, there are some significant relations and mostly the relationship is unidirectional (one-way), and not in reciprocal co-determination, just as put in Yu et al.'s that also used GCT method [104]. The two-way relationship appears only in the demand and supply data of the suburban railways transport sector only (for all time-lags). Some findings appear to be significant according to the F-test findings of the method, but not all. Yet, the significance is higher in the short/medium term. Dominantly, transportation supply determines demand in railway and highways context. That is, the effects usually appear with some delay, a few years later. But the airline sector showed no any significant relations at all. In the long-run, no relationship is detected, that implies the fact that neither demand nor supply is dominant in long-run relationships.

Obviously, besides a detailed statistical approach followed in the current paper, deeper analysis on the causes of transport demand and supply (beyond statistical examinations) is a valuable future research area.

Of the major aim of this study, it is intended to determine firmly which side would be the most preceding one. From the limited data we analyzed the cases in Turkish context, as region level data cleansed from land use variables in urban context, which, yet, might deliver different results in another culture. Non-urban data provided much clearer view: the investment amounts and the capacities provided predetermined the demand amounts and other demand-related configurations. The future research should devote to the urban data reconsidering the land use variable disruption (ie, including land use-free, or undisrupted, urban transport supply data).

Knowing that the supply has more effects on the demand in short/medium-term, and considering their huge costs, transport investment plans should regard these results (provided in this study) and the investments should be provided where there are true and known demands, cleansed from the interruption of economic development indicators, such that supply determination would function in the short/medium run but would fade away in the long run when they make investment proposals. Especially, road and railway investments are of this kind. Again, the demand-supply inter-dependence consideration must be free from external impact on economic development as railways cause especially to the regional economy [105] (for it is a separate issue), which resembles to the land use-transport interaction in urban context. Consequently, if decision-maker wills a triggering effect on the demand, they can use this kind of investment strategies, and refrain from long run projects that would be far-fetched for avoiding associated cost deficits (arising from unbalanced demand-supply), for political short-run concerns if known not to be effective in the long run or there exists uncertainty in satisfying the demand (aside from economic boost impact). That is to say, it is not so clear yet whether this happens due to the decision-maker's triggering effect or to the demand/supply causality mechanism. A further study can elaborate on this issue.

11 Symbols

Y : Dependent time series variable in Granger Causality test regressions,

X : Independent time series variable in Granger Causality test regressions.

12 Declaration of authors' contribution

In this article, Yavuz DUVARCI contributed to the stages of general structure, the method, the 1st and 2nd (literature background) parts and the general evaluation of the results.

Hasan Engin DURAN contributed to development of the statistical analysis methods, performing, explanation and presentation of the analyses that take place in the 3rd, 4th and 5th parts of the article.

13 Declaration of ethics committee approval and conflict of interest

"The article does not necessitate a research ethics commitee approval".

"There is no conflict of interest issue with any person/institution throughout this paper work".

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