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İÇİNDEKİLER/TABLE OF CONTENTS

RELATIONSHIP AMONG URBANIZATION, ECONOMIC GROWTH, ENERGY INTENSITY, AND CO_2 EMISSION IN UPPER-MIDDLE INCOME………………………………………………………………………..…………………………………**1**

INTERNATIONAL TRADE NETWORK AND THE GRAVITY MODEL……………………………..…………………………………**18**

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RELATIONSHIP AMONG URBANIZATION, ECONOMIC GROWTH, ENERGY INTENSITY, AND CO_2 EMISSION IN UPPER-MIDDLE INCOME

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Abstract

This study examines how urbanization affected CO_2 emissions in selected 24 upper-middle income countries between 1990 and 2014. It contributes to the literature by investigating the nonlinear impact of urbanization while accounting for dynamics of cross-sectional dependency within the sample. By taking advantage of the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) and the Environmental Kuznet Curve (EKC) hypothesis and balanced panel data technique ecological modernization theory has been empirically proved. The evidence showed that, except for a small part of the countries belonging to the sample (Mauritius, Guatemala, Indonesia, China, Azerbaijan, and North Macedonia), the urbanization levels they reached within the analyzed period have already tended to reduce carbon dioxide. Apart from this, economic growth, population, and technology elasticities of carbon emission are positive, that is, in harmony with the existing STIRPAT model literature. The evidence in this article provides a guide for policymakers and urban planners in upper-middle income countries for all steps to be taken to prevent climate change.

Keywords: Urbanization, CO_2 Emission, STIRPAT Model, EKC Hypothesis.

ÜST-ORTA GELİR SINIFI ÜLKELERİNDE KENTLEŞME, EKONOMİK BÜYÜME, ENERJİ YOĞUNLUĞU VE CO_2 EMİSYONU ARASINDAKİ İLİŞKİ

Özet

Bu çalışma, üst-orta gelir sınıfındaki 24 ülkede 1990 ile 2014 yılları arasında, kentleşmenin CO_2 emisyonlarını nasıl etkilediğini incelemektedir. Bu araştırma, hem örneklemdeki yatay kesit bağımlılığını hem de kentleşmenin doğrusal olmayan etkisini araştırarak, literatüre katkı sağlamayı amaçlamaktadır. Bu amaç çerçevesinde, STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) modeli ile EKC (Environmental Kuznet Curve) hipotezi doğrultusunda, dengeli panel veri tekniklerinden faydalanılarak, ekolojik modernizasyon teorisine ampirik kanıtlar sunulmuştur. Bulgular, Mauritius, Guatemala, Endonezya, Çin, Azerbaycan ve Kuzey Makedonya dışındaki ülkelerin, analiz edilen dönemde ulaştıkları kentleşme seviyelerinin, karbondioksiti azaltma eğiliminde olduğunu göstermektedir. Bununla birlikte, karbon emisyonunun ekonomik büyüme, nüfus ve teknoloji esneklikleri STIRPAT modeliyle uyumludur. Bir başka ifadeyle, bu değişkenlerin katsayıları pozitiftir. Bu makalede elde edilen bulguların, politika yapıcılara ve şehir planlayıcılara, iklim değişikliğini önleme konusunda yol gösterici olacağına inanılmaktadır.

Anahtar Kelimeler: Şehirleşme, CO_2 Emisyonu, STIRPAT Modeli, EKC Hipotezi.

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1. INTRODUCTION

Urbanization is a multifaceted socio-economic phenomenon that modifies the built environment, transforming rural areas into urban settlements and altering the spatial distribution of people living in rural to urban areas. The demographic and social structure of both urban and rural areas are altered as a result of changes in the predominant jobs, lifestyle, culture, and behavior (Montgomery et al., 2013). In countries where the rate of increase in urbanization is accelerating, considering factors such as job opportunities and industrialization, which are mutually causality brought by urbanization, urbanization leads to environmental pollution. In addition, even though the fastest urbanization (1.6% increase over the years) ever seen between 1990 and 2018 was seen in upper-middle income countries, it is predicted that this rate of increase will slow down (0.5% increase over the years) between 2030 and 2050 (United Nations, 2019). Considering all these, the effect of environmental pollution of urbanization has attracted the attention of researchers and it is interesting to examine how the decrease in the growth rate of upper-middle income group countries will affect carbon emissions in the future. Moreover, Cities were responsible for 62% of the global greenhouse gas increase and an estimated 67-72% between 2015 and 2020 (IPCC, 2023). Therefore, the link between urbanization and carbon emission has become an attractive problem that has to be solved by some researchers (Wang et. al., 2018; Zhang et. al., 2017).

Studies that have gained momentum in recent decades have shown that the relationship between urbanization and carbon emissions varies from country to country and region to region. Some of the research indicated that urbanization has an increasing effect on carbon emissions (Chen et. al., 2019; Liddle and Lung, 2010; Martínez-Zarzoso and Maruotti, 2011; McGee and York, 2018). In contrast, some research predicted the negative effect between urbanization and carbon emission (Liu et. al., 2023; Niu and Lekse, 2017; Shahbaz et. al., 2016). One of the reasons for the diversity of the results in the literature is related to the applied method and data. However, the most important reason is the heterogeneous structures of countries and regions (e.g., the differences in transportation networks and industrial sector structures).

The study aims to examine the impact of urbanization on carbon emissions in selected upper-middle income countries during the period 1990 and 2014. We employed panel data analysis techniques to test the validity of ecological modernization theory within this group of countries. One of our contributions to the literature is to employ the panel data estimator that considers the cross-sectional dependence among countries. The other important contribution of ours is to test the non-linear relationship between urbanization and carbon emissions in the country group where heterogeneity exists, excluding economic growth. Moreover, the results from the paper not only contribute to the existing literature but also policymakers will be attracted by them.

2. THEORETICAL FRAMEWORK

There are several obstacles to enhancing environmental quality and generating a sustainable energy supply as a result of the rapid expansion in urbanization, particularly in newly industrialized and emerging countries (Voumik and Sultana, 2022) For this reason, the relationship between urbanization and environmental degradation (especially carbon emissions) has been a subject of research (Li et. al., 2012; Rashid et. al., 2018; Churkina, 2016). However, the relationship reflects a network of relationships that are too complex to be explained by a single theory. Such government policies about climate change, energy structure of countries or cities, urban public infrastructure, consumption patterns of countries or cities, and transportation network features can influence environmental degradation in a different way. Three theories have been put forward to examine the relationship between urbanization and environmental degradation. Ecological modernization mostly explains the relationship between urbanization and carbon emissions with the development levels of countries. This theory evaluates the relationship from a more national-level perspective. Although the urban environmental transition and compact city theories make partially similar assumptions regarding ecological modernization they include evaluations at the city level (Poumanyvong and Kaneko, 2010).

According to the broadest definition, ecological modernization is the discourse that acknowledges the structural nature of the environmental problem while still assuming that current political, economic, and social institutions can incorporate environmental protection (Hajer, 1995). In this theory, urbanization is an important determinant of ecological modernization. It is claimed that urbanization will increase ecological degradation at countries' low levels of development. However, at the level of high development of countries, urbanization reduces ecological degradation with the emergence of agglomeration economies, advanced technologies, increasing efficiencies in the use of alternative resources, and increasing trend of service-based growth rather than industrial-based growth (Ehrhardt-Martinez, 1998; Ehrhardt-Martinez et. al., 2002; Poumanyvong and Kaneko, 2010).

Urban environmental Transition theory explains the evolution of environmental problems according to the development level of cities. The theory contends that environmental issues (so-called “Brown” agenda issues such as lack of safe water, inadequate waste management, and pollution control) in underdeveloped cities are frequently immediate, local, and immediately dangerous to health. In middle-income cities, the most urgent environmental issues (so-called “Gray” agenda issues such as air pollutants and chemical water pollutants) are often city-regional particularly large and industrialized ones, and frequently involve both ecological and health risks. The affluent city generally enjoys a healthy living environment, but economic activities such as the consumption patterns of affluent city residents being more resource intensive and lifestyles have a considerable negative impact on the environment and contribute significantly to long-term and global issues (so-called “Green” agenda issues such as non-point source pollution, CO_2 emission, and persistent chemicals) (Jacobi et.al., 2010; Marcotullio and Lee, 2003; Williams, 1997).

The compact city theory is a concept in urban planning and design that encourages mixed land use and a comparatively high residential density. The theory suggests that compact cities will reduce the distance traveled in transportation by using economies of scale in the infrastructure of cities, reduce car dependency, cause less electricity use, and lower carbon emissions (Dempsey and Jenks, 1978). However, the theory has drawn criticism due to the possibility of more serious social issues in densely populated residential areas, the concentration of pollution in living spaces, and the rising risk of congestion (Burton, 2000). Even if compact cities would reduce carbon emissions, without a plausible urban infrastructure it will increase environmental degradation (Burgess, 2002).

3. LITERATURE REVIEW

The degradation caused to nature by the constantly so-called developing human activity has been the subject of study for a long time. As a result of this development, the relationship between urbanization and environmental degradation, especially the relationship with carbon emissions, has become one of the issues that has been focused on a lot in the last 3 decades. It is possible to generally classify the studies examining this relationship between urbanization and carbon emissions as national, regional (or city), and domestic-level studies tested with the either STIRPAT or EKC hypotheses or the analyses that employed both STIRPAT and EKC hypothesis. Due to our topic being held at the national level, we will only compile studies at the national level under literature review. However, some regional studies will be included because the studies will be aforementioned also examine the relationships between urbanization and carbon emissions at the national level by working with the entire sample. In addition, there is no literature which the non-linear effects of urbanization on carbon emission where only the EKC hypothesis is investigated in the context of panel data analysis at the national level.

One of the first studies in this field, conducted by (York et. al., 2003) on 146 countries, showed a positive correlation between urbanization and carbon emission and energy footprint. However, they found that affluence and urbanization perpetually raise carbon emissions opposite to the ecological modernization theory. When the STIRPAT model is examined in the context of panel data analysis, (Cole and Neumayer, 2004) employed urbanization, household size, and age structure as control variables on carbon emission and found that urbanization affects carbon emissions positively. Using the STIRPAT model, (Poumanyvong and Kaneko, 2010) reached similar results. They applied the STIRPAT model to high-income, middle-income, and low-income countries, and in all income groups, urbanization was found to affect carbon emissions positively. Liddle and Lung (2010) examined the effect of urbanization on total carbon emissions and carbon emissions from transportation. They showed that the links between urbanization and both two dependent variables are positive but found only its effect on carbon emissions from transportation statistically significant. Nosheen et. al. (2020) reached similar findings on Asian Countries with other studies using dynamic panel data analysis. Surprisingly, Fan et. al. (2006) used the STIRPAT model by grouping the country sets as high-income, upper-middle income, lower-middle-income low-income worldwide, and China. They did not reach a positive link in any group except for low-income countries, while the results were statistically significant only in high-income countries.

Considering the literature in the context of the STIRPAT model based on the time series analysis, Alam et. al. (2007) found that urbanization and high population are positively related to carbon emissions in the long run, but have a negative relationship with economic development. Similarly, Li et. al. (2011) confirmed a positive relationship between urbanization and carbon emissions in China. However, the urbanization elasticity of carbon emission is quite higher than the study of Alam et. al. (2007). Contrary to the literature, Yakubu et. al. (2021) determined the relationship between urbanization and carbon emissions to be negative both in the long run and short run due to environmental policies working effectively despite increasing urbanization in Ghana, as they argued.

Considering the literature in the context of panel data analyses where both the EKC hypothesis and STIRPAT model are applied, Martínez-Zarzoso and Maruotti (2011) performed an analysis of less developed countries and divided countries into endogenously homogeneous groups. The results showed that a threshold level is found for two of the groups, over which the emission-urbanization elasticity is negative and additional increases in the rate of urbanization do not result in increased emissions. He et. al. (2017) divided China into 3 regions and the findings showed that inverted u-type relationship between urbanization and carbon emissions in all groups and the whole sample.

When we look at the time series analysis where both the EKC hypothesis and STIRPAT model are applied, Yeh and Liao (2017) identified an inverted u-shaped carbon urbanization relationship in the study where examined the relationship of other independent variables other than urbanization, which they thought affected carbon emissions in a non-linear way in Taiwan. However, Shahbaz et. al. (2016) found that the u-type relationship between urbanization and carbon emission in Malaysia was contrary to the theory but the coefficients were not statistically significant.

Considering panel data analysis where only EKC hypothesis is applied, Sun et. al. (2022) asserted that Mena countries is highly dependent on primary energy resources (oil, coal, and natural gas). In addition, the study found out that urbanization and economic growth positively related with carbon emission.

Haseeb et. al. (2018) found that urbanization is negatively related to carbon emissions and even increases carbon emissions as economic growth increases, meaning that economic development will not reduce environmental degradation in BRICS countries after a certain level.

Where only the EKC hypothesis is applied in the context of time series analysis, Ozataç et. al. (2017) alleged that trade openness, urbanization, and energy consumption all exhibited positive, statistically significant, and inelastic effects on carbon emission emissions. Moreover, the results revealed an inverted u-type relation between economic growth and carbon emission. Another piece of evidence from Turkey appeared in which the study conducted by Pata (2018) showed an inverted u-type relation between economic growth and carbon emission and a positive link between urbanization and carbon emission in accordance with Ozataç et. al. (2017). The results revealed by Dogan and Turkekul (2016) indicated that there is no inverted u-type relationship between economic growth and carbon emission in the USA but a positive link between urbanization and carbon emission exists.

4. DATA AND METHODOLOGY

This In the first subheading, a detailed explanation will be given about the sources and descriptive statistics of the data used in the article, while in the second subheading, the manipulations we applied to the macro data used in the article, the model definition, and the econometric tools and methods we used will be mentioned.

4.1. Data Source, Definitions and Descriptive Statistics

All variables employed in our analysis are taken from the World Bank's dataset known as World Development Indicators (World Bank, 2023). We analyze the relationships of carbon dioxide emissions with affluence, technology, urbanization, and population. The panel data, which consists of 24 upper-middle income countries (see in table A.3. Appendix A) as a cross-section and annual data starting from 1990 to 2014 as a time series, is used in the analysis.

We turned to account for the carbon dioxide emissions as the independent variable in our analysis. We used the total population to represent the population size in the STIRPAT model, and the GDP per capita variable to represent affluence. We exploit the share of industry and service sectors in GDP and energy intensity variables as proxy variables for technology. In addition to these 5 variables, we also add urbanization to show its pressures on carbon dioxide emission. The definitions and sources of all variables can seen in Table 1. The descriptive statistics of variables can be found in Table 2.

Table 1. Definitions of All Variables Used in The Analysis

Variables	Definitions	Units	Data Sources
Total carbon dioxide emissions (CO_2)	Carbon dioxide emissions stemming from the burning of fossil fuels and the manufacture of cement.	Kiloton	WDI
Energy Intensity (EI)	A kilogram of oil equivalent of energy use per constant PPP GDP	Energy use per 1000$ GDP (constant 2017 PPP)	WDI
Population (POP)	Midyear total population	Number	WDI
GDP per capita (GDP)	Gross domestic product divided by midyear population	US$ per capita (constant 2015 US$)	WDI

Share of service sector in GDP (SOS)	Share of service sector's value added in GDP	Percent	WDI
Share of service sector in GDP (SOI)	Share of service sector's value added in GDP	Percent	WDI
Urbanization (URB)	The share of urban population in the total population	Percent	WDI

Table 2. Descriptive Statistics of Variables

Variables	Obs.	Mean	Std. Dev.	Min	Max
CO_2 (100 kt)	600	3.801,09	11.898,06	11,64	100.000,00
EI (energy use/1000$)	600	137,05	94,88	51,59	607,72
POP (thousand)	600	93.200,00	253.000,00	983,00	1.370.000,00
GDP per capita ($)	600	5.353,33	2.484,02	905,03	14.200,27
SOS (%)	600	49,17	10,14	10,86	73,34
SOI (%)	600	34,48	11,33	16,21	84,80
URB (%)	600	62,88	13,46	26,44	91,38

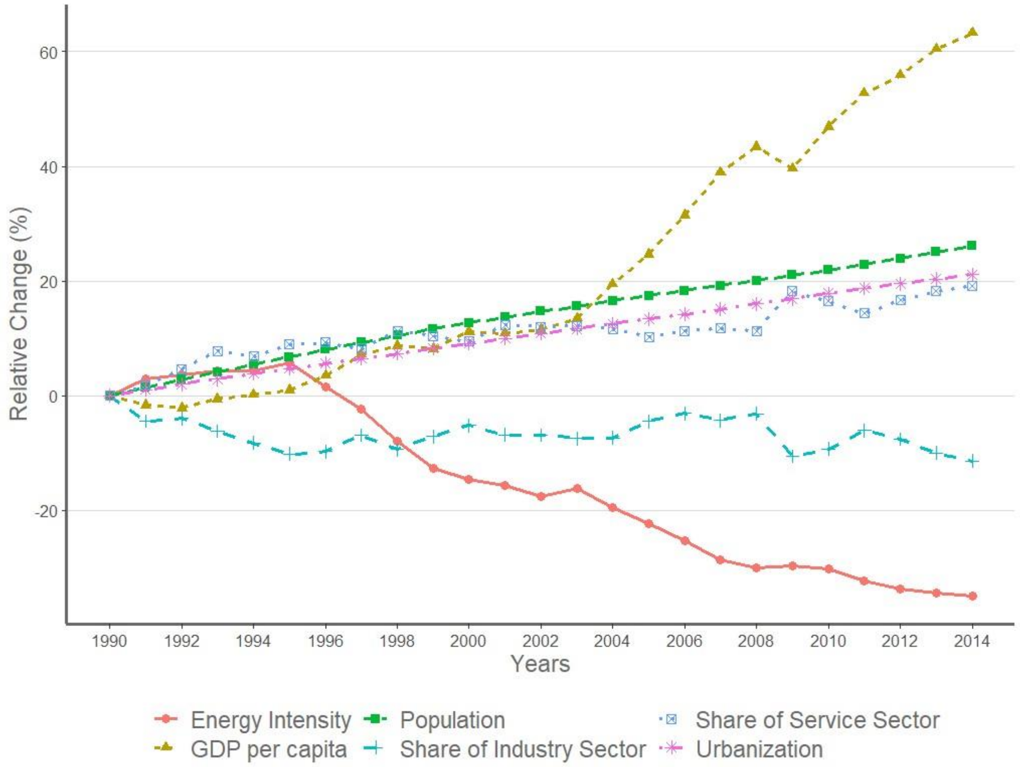
Figure 1 indicates the relative changes of independent variables in the country group during the period 1990-2014. It illustrates that GDP per capita, population, the share of service sector in GDP, and urbanization level increased 63,28%, 26,13%, 19,21%, and 21,13% from 1990 to 2014, respectively. However, energy intensity and the share of industry sector in GDP have declining trends which are 34,99% and 11,37%, respectively from 1990 to 2014 apart from the others.

From base year (1990) until 1995, energy intensity has a moderate increasing trend. Surprisingly, after 1995, it experienced a rapid decline. This is mainly due to the fact that there are several emerging markets in the income group studied. The rapid increase in income levels after the Mexican peso crisis in such countries caused a rapid decrease in the energy intensity variable (Hutchison and Noy, 2006; Han et. al., 2003; Aguiar, 2005).

Another interesting result in the figure is the rapid increase in GDP per capita after 2002. The main reasons for this were the shift of global production to Asia and that there was an acceleration in the growth rates of Latin and Central American countries as an indicator of post-crisis recovery after 2002. The large number of Asian, Latin, and Central American countries in the data set has caused a break in the relative change of GDP per capita after this year (Kharas, 2010; Coremberg, 2014).

Another critical fact is China's individual effects on the changes. When China is excluded from the data set, the relative change in GDP per capita, population, and energy intensity variables creates a significant difference compared to before, which is not surprising. The relative increase of GDP per capita and population are 57,48% and 33,33%, respectively, without China. The relative decrease in energy intensity is 30,14% without China. The relative changes of other variables remain the same with little difference.

Figure 1. The Relative Change of Independent Variable Based on The Analysis Period of 1990 and 2014



4.2. Methodology

Ehrlich and Holdren (1971) asserted a model called IPAT ($I = PAT$) to examine the effects of population, affluence, and technology on environmental impact. In the model, I states environmental impact (generally analyzed energy consumption and greenhouse gas emissions) which is determined by population size (P), per capita consumption (A), and technology (T). In the model affluence and technology are measured as per capita impact in general. Even if the model would be useful, it has some limitations. The most important of these limitations is that the model assumes that the effect of each force on the environment is proportional (Villanueva et. al., 2013).

Afterward, Dietz and Rosa (1994) revisited the IPAT model by taking into account the elasticities of the independent variables. They reformulated the model in a stochastic form called STIRPAT ($I = aP^bA^cT^de$) where a is a constant term, b, c, and d are the parameters of population, affluence, and technology variables respectively, and e is a disturbance term.

In this article, we added urbanization, thought to have a causality with greenhouse gas emissions, in addition to the variables in the STIRPAT model. By taking the natural logarithm of the model in exponential functional form, we both stabilized the variance of the variables in the model and put the function in linear form. For the panel data on CO_2 emissions, we can formulate the empirical models as follows:

$$lnCO_{2_{it}} = \beta_0 + \beta_1 ln(POP_{it}) + \beta_2 ln(GDP_{it}) + \beta_3 ln(SOS_{it}) + \beta_4 ln(SOI_{it}) + \beta_5 ln(EI_{it}) + \beta_6 ln(URB_{it}) + \delta_t + \theta_i + u_{it} \quad (1)$$

$$lnCO_{2_{it}} = \beta_0 + \beta_1 ln(POP_{it}) + \beta_2 ln(GDP_{it}) + \beta_3 ln(SOS_{it}) + \beta_4 ln(SOI_{it}) + \beta_5 ln(EI_{it}) + \beta_6 ln(URB_{it}) + \beta_6 ln(URB_{it})^2 + \delta_t + \theta_i + u_{it} \quad (2)$$

where POP and GDP state total population size and GDP per capita respectively. The shares of service and industry sectors in GDP were denoted by SOS and SOI respectively used as proxy variables so as to explain technology in STIRPAT model as (Shi, 2003) did. In addition to these two variables, technology was also proxied by energy intensity (EI) as used in (Chen et. al., 2019; Martínez-Zarzoso and Maruotti, 2011; Poumanyvong and Kaneko, 2010). In order to measure the effect of urbanization on carbon emission, the urbanization variable denoted as URB was added to the STIRPAT model. While δ is unobservable time-specific effects caused by technological progress, volatility in energy prices, and environmental changes, θ is unobservable country-specific effects resulting from resource endowments, locations, and political decision differentiations that can affect carbon emission (Baltagi and Baltagi, 2008). u shows the error term. While index i specified the country-level cross-sectional data, t specified years. The only difference between equation 1 and equation 2 is to be found the quadratic term of urbanization variable to test the EKC hypothesis in equation 2.

In this paper, we try to estimate the impact of urbanization on carbon emissions in upper-middle income countries. The country classification was made by (World Bank, 2022) classified as upper-middle income according to GNI per capita between $4,046 and $12,535. The purpose of focusing on this group of countries is that it is known that the urbanization rates of the countries have increased relatively more over the years compared to other income groups in the years subject to analysis (Ritchie and Roser, 2018). Moreover, as of 2021, the highest share of carbon emissions of upper-middle income countries in the world is 45.8%, compared to other country groups (high-income, lower-middle income, and low-income) upper-middle income countries is taking first place (Ritchie and Roser, 2023). Therefore, the article aimed to demonstrate the hypothesis that urbanization increases carbon emissions with the sample of selected upper-middle income countries.

Firstly we check whether the data are stationary or not. We applied the heterogeneity test developed by Pesaran and Yamagata (2008) to find out which unit root tests we could apply to the data. The test results show that our data are heterogeneous. Afterward, we applied 4 unit root tests to allow us to include the panel fixed effect. The first test was the LLC test proposed by Levin et. al. (2002). LLC test allows for heterogeneity in panel data by employing a test statistic that combines individual unit root tests, taking into account heterogeneous individual characteristics. The second test was IPS proposed by Im et. al. (2003). IPS test is robust to cross-sectional dependence and is created for heterogeneous panel data. To take into consideration the variation among cross-sectional units, it averages individual unit root statistics. The third test is ADF put forward by Maddala and Wu (1999). This test also considers heterogeneity by employing individual unit root tests and pooling the results while accounting for cross-sectional dependence. The fourth test is the PP test suggested for heterogeneous panel data by Choi (2001). According to the unit root test results, all data are stationary at level. All unit root tests can be seen in Table A.2. (Appendix).

After taking unit root test results, we conducted Pooled Ordinary Least Square (Pooled OLS), Fixed Effect (FE), and Random Effect (RE) estimators. Moreover, an F-test was used to choose whether the fixed-effect model and the pooled OLS model are appropriate. This F-test is done to compare the fixed-effect model's goodness-of-fit to the pooled OLS model. The test showed us that we have a country-specific effect rather than a time-specific effect which also proved the goodness of fixed effect model. Additionally, the Breusch-Pagan LM Test (Breusch and Pagan, 1980) was used to assess which model, the pooled OLS or the random effect model, is more appropriate. After seeing the test result, we deduced that our sample had a random individual effect. The Hausman specification test (Hausman, 1978) was then used to choose between fixed and random effect models as the final model. According to the test result, the fixed effect is more appropriate for our model.

To test heteroscedasticity, autocorrelation, and cross-sectional dependency in our model a range of diagnostic tests were applied. To detect whether the data has heteroscedastic we applied Modified Wald statistic for groupwise heteroskedasticity test in fixed effect model. The result revealed our models has heteroscedasticity. Furthermore, as for serial correlation in panel data, our data has autocorrelation problem. Finally, to check the cross-sectional dependence of our models, we employed a cross-sectional dependency test proposed for balanced panel data by Pesaran (2004). The test result shows that our sample has a cross-sectional dependence problem too for only model 1. Cross-sectional or "spatial" dependency is frequently disregarded, even though the majority of empirical research now produces standard error estimates that are heteroskedasticity and auto-correlation consistent (Hoechle, 2007). Thus, in the article, we used the Driscoll Kray estimator, which gives robust standard errors, paying attention to the problems of heteroscedasticity, serial correlation, and even cross-sectional dependence in panel data.

Since many of the utilized independent variables in this article can be highly correlated such as the population and GDP per capita theoretically, multicollinearity is another common issue. The correlation between independent variables can be seen in Table A.1 (Appendix). The share of service sectors and industry sectors in GDP have high correlations. However, multicollinearity is not a big issue, given that data is gathered from units in panel data models and there are a large number of observations (Tatoglu, 2012).

RESULTS

First of all, we demonstrated the Driscoll-Kray one-way fixed effect estimator results for model 1 and model 2. The results are reported in Table 3. While model 1 expressed our model considering only the STIRPAT model, we employed the Environmental Kuznet Curve (EKC) hypothesis to determine the existence of a non-linear relationship between the urbanization variables and carbon emissions in the upper-middle income countries. In these two models, all coefficients are statistically significant at least at a 5% level except for the share of industry in GDP (SOI) variable. We attribute the reason why the variable is not statistically significant to the high correlation between the service sector's share in GDP variable. In this article, we mainly pay regard to model 2 since it shows the quadratic relationship between Urbanization and Carbon dioxide emission. The fact that the non-quadratic urbanization variable is positive and the quadratic urbanization variable is negative indicates that there is an inverted U-shaped relationship between urbanization and carbon emissions and empirically confirms the EKC hypothesis and ecological modernization theory. Therefore, as urbanization increases, carbon emissions will begin to decrease after a certain level. Furthermore, coefficients of other variables have positive signs, as is expected, in compliance with economic common sense.

The elasticities of population, GDP per capita, energy intensity, the share of the service sector in GDP, and the share of industry sectors in GDP are 0.942, 0.918, 0.776, 0.162, -0.058, respectively, which indicate the effects of population, affluence, and technology variables on carbon emission according to STIRPAT model. We can see that they all are positively related to carbon emission except for the share of the industry sector in GDP in upper-middle income countries. 1% increases in population, GDP per capita, and energy intensity will each increase statistically significantly CO_2 emissions by 0.942%, 0.918%, and 0.776%, respectively, assuming all other factors remain constant. A 1% increase in the share of the service sector to the GDP increases carbon emission by 0.162%, which has a relatively lower impact on CO_2 emissions compared to other factors, assuming all other factors remain constant. The share of the industry sector in GDP is not statistically significant which means it empirically does not affect carbon emission and it both has a negative effect on carbon emission and is quite lower than others.

This pattern supports the claim made by the ecological modernization hypothesis, according to which there may be serious environmental problems as a result of modernization. Further modernization, however, can mitigate these issues. Urbanization, as a result of modernization, increases carbon emission to a certain level and decreases after this level in accordance with Martínez-Zarzoso and Maruotti's (2011) findings. Urbanization and CO_2 have an inverse U-shaped relation. Emissions rise until an inflection point, up until 58% urbanization for upper-middle income countries, and it will decrease after this urbanization level. With respect to analyze period and countries, Mauritius, Guatemala, Indonesia, China, Azerbaijan, and North Macedonia were under this level. However the other countries were above the level that decreases the carbon emissions. Since the square of urbanization is statistically significant, this finding supports the view suggested by Ehrhardt-Martinez et. al., (2002) and York et. al., (2003) that urbanization can be used as a proxy to indicate modernization. The inverted u-shaped relationship between urbanization and carbon emission shows that the increase in urbanization rates in upper middle-income countries does not create environmental problems, on the contrary, the high level of urbanization will already reduce carbon emissions, consistent with the common findings in the literature (Martínez-Zarzoso and Maruotti, 2011; He et. al., 2017; Yeh and Liao, 2017).

Table 3. Driscoll-Kray Estimation Results for Carbon Emission

Variables	Driscoll-Kray FE Estimator (Model 1)	Driscoll-Kray FE Estimator (Model 2)
Constant	-16,113***	-36,726***
	(-2,711)	(3,992)
lnPOP	0,732***	0,942***
	(-0,093)	(0,098)
lnGDP	0,947***	0,918***
	(-0,127)	(0,124)
lnSOS	0,305***	0,162**
	(-0,076)	(0,064)
lnSOI	0,085	-0,058
	(-0,08)	(0,073)
lnEI	0,808***	0,776***

	(-0,12)	(0,122)
lnURB	0,327**	9,826***
	(-0,133)	(0,792)
$lnURB^2$		-1,210***
		(0,110)
Country Dummies	Yes	Yes
Year Dummies	No	No
R2	0,78	0,80
Autocorrelation Test	F=10,41***	F=11,60***
Heteroscedasticity Test	12.475,03***	6.028,98***
Cross Sectional Dependence Test	Peseran test statistic=4,546***	Pesaran test Statistic=1,378
Observations	600	600

Notes: ln denotes the natural logarithm of the variables. POP, GDP, SOS, SOI, EI, and URB indicate population, GDP per capita, the share of service sector in GDP, the share of industry sector in GDP, energy intensity, and urbanization respectively. The number in parenthesis show driscoll-kray standart error. ***, **, and * denote significance at level 1%, 5%, and 10%, respectively.

Concluding to the results, population, GDP per capita, energy intensity, and the share of service sector in GDP have statistically significant positive correlation with carbon emission, as is expected. The share of the industry sector in GDP appears to have a negative correlation with carbon emissions, indeed it is not statistically significant.

CONCLUSION

In this work, we have conducted static panel data analysis on factors that influenced carbon emission in upper-middle income categories between 1990 and 2014 time period. We have conducted the EKC hypothesis and STIRPAT model on the selected group and tested the assertions of ecological modernization theory on urbanization as being an important determinant of carbon emission. We predicted two models one of which is the model we established to measure the non-linear effect of urbanization and the STIRPAT model. In model 1, while the technology variable is proxied by the share of the service sector and industry sector in GDP and energy intensity data in addition to population and affluence in the STIRPAT model, we also tested the effect of urbanization on carbon emissions. Furthermore, we added the quadratic term of urbanization variable to the model 1 as being in model 2.

The results show that the population and affluence elasticity of carbon emission is positive as expected and they have almost a unit effect on carbon emission. While the share of the service sector in GDP and energy intensity variable, as proxy variables of technology, confirm the hypothesis that technology has a positive effect on carbon emissions in the STIRPAT model, the industry sector's share in GDP does not represent technology. It cannot explain carbon emissions in upper-middle income countries as can be seen from its quite lower and and statistically insignificant elasticity.

We confirmed the ecological modernization theory in upper-middle income countries using the EKC hypothesis on urbanization. The finding showed that the urbanization elasticity of carbon emission is positive and revealed that there is an inverted u-type relation between urbanization and carbon emission. In addition, The findings demonstrated that, for the majority of the nations between 1990 and 2014, except Mauritius, Guatemala, Indonesia, China, Azerbaijan, and North Macedonia, further increases in the pace of urbanization do not result in higher emissions. Thus the results have significant policy implications. In addition to making recommendations for urban planners and policymakers, this article also contributed to the literature with its predictions taking into account cross-sectional dependence among the upper-middle income countries.

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APPENDIX

Appendix A.1. The Correlation Matrix of Dependent Variables

Variables	lnPOP	lnGDP	lnSOS	lnSOI	lnURB	lnEI
lnPOP	1					
LnGDP	-0.033	1				
lnSOS	0.0171	0.4749	1			
lnSOI	0.1224	-0.2323	-0.8164	1		
lnURB	0.0213	0.6186	0.1967	-0.0758	1	
lnEI	0.3096	-0.4719	-0.4633	0.3257	-0.0898	1

Appendix A.2. Unit Root Tests

Variables	Unit root tests at level				Unit root tests at first difference			
	LLC	PP	ADF	IPS	LLC	PP	ADF	IPS
$lnCO_2$	-4.15***	51.02	43.03	-3.03***	-5.35***	576.09***	36.65	-12.60***
lnPOP	-7.21***	144.01***	92.45***	-5.23***	-4.67***	246.15***	113.07***	-9.24***
LnGDP	-0.89	82.61***	53.56	8.32***	-2.96***	63.96*	33.63	-2.18**
lnSOS	-4.57***	135.37***	28.50	-4.91***	-12.83***	530.43***	32.68	-12.82***
lnSOI	-3.61***	80.97***	27.52	-4.08***	-9.31***	551.92***	31.89	-12.25***
lnURB	-5.97***	105.86***	65.29**	2.61***	-2.78***	125.75***	97.40***	-4.83***
lnEI	-1.37*	48.16	57.85	-3.55***	-5.84***	474.68***	66.52**	-12.01***

Notes: Individual effects and time trend included in all data. ***, ** and, * specify rejection of the null hypothesis of nonstationary at significance level 1%, 5%, and 10%, respectively.

Appendix A.3. Countries Used in The Analysis

Country List		
Argentina	Costa Rica	Malaysia
Azerbaijan	Dominican Republic	Mauritius
Belarus	Ecuador	Mexico
Botswana	El Salvador	North Macedonia
Brazil	Gabon	Paraguay
Bulgaria	Guatemala	Russian Federation
China	Indonesia	South Africa
Colombia	Iraq	Turkiye

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INTERNATIONAL TRADE NETWORK AND THE GRAVITY MODEL*

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Abstract

In this paper, we analyze the effects of geographical characteristics and trade network positions of the countries on the international trade. For this purpose, we employ a gravity model of international trade and combine gravity, network, and trade datasets for the years between 1995 and 2010. In this study, country-specific properties such as GDP, population, and other geographical variables for the countries are emplyed. Besides, we also divide the data into developed and developing countries to analyze the differences among countries in terms of economic development. Apart from explanatory variables which are country-specific properties, network variables such as degree, strength, closeness, and eigenvector are utilized. Our findings show that the network variables positively and significantly affect bilateral trade. Since these variables are related with the position of the countries in the network, we conclude that countries having central role in international trade network involve in higher trade volumes.

Keywords: International Trade Network, Gravity Model, Geography.

ULUSLARARASI TİCARET AĞI VE ÇEKİM MODELİ

Özet

Bu makalede, ülkelerin coğrafi özelliklerinin ve ticaret ağındaki konumlarının uluslararası ticaretteki etkilerini analiz edilmektedir. Bu amaçla, uluslararası ticarette bir tür çekim modeli kullanılmakta ve 1995 ile 2010 arasındaki yıllar için çekim, ağ ve ticaret veri setlerini birleştirilmektedir. Bu çalışmada, ülkeler için GSYİH, nüfus ve diğer coğrafi değişkenler gibi ülkeye özgü özellikleri kullanılmaktadır. Ayrıca iktisadi gelişmişlik açısından ülkeler arasındaki farklılıkları analiz etmek için verileri gelişmiş ve gelişmekte olan ülkeler olarak da ayrılmaktadır. Ülkeye özgü özellikler olan açıklayıcı değişkenlerin yanı sıra derece, kuvvet, yakınlık ve özvektör gibi ağ değişkenleri de kullanılmaktadır. Bulgularımız ağ değişkenlerinin ikili ticareti olumlu ve anlamlı bir şekilde etkilediğini göstermektedir. Bu değişkenler, ülkelerin ağdaki konumlarıyla ilgili olduğu için, uluslararası ticaret ağında merkezi role sahip olan ülkelerin daha yüksek ticaret hacimlerine sahip olduğu sonucuna varılmaktadır.

Anahtar Kelimeler: Uluslararası Ticaret Ağı, Çekimi Modeli, Coğrafya.

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1. INTRODUCTION

The geographical characteristics of the countries have been generally neglected in the traditional theories of international trade. In these models, the comparative advantages of countries determine both the level and direction of trade with each other. Instead of the traditional Heckscher-Ohlin model, Krugman's new economic geography model becomes widespread in the literature in the 1990s. To explain the differences in trade caused by geographical distances between countries, the gravity equation in physics was firstly adapted by Tinbergen (1962) to international trade. This model has been widely used in the literature and developed in many perspectives.

The gravity model successfully explains the trade flows; however, the interaction and link formation of the countries are also worth thinking about. This idea brings us to the international trade network literature. According to these network models, which are defined as "International Trade Network" (ITN), "World Trade Network" (WTN) or "World Trade Web" (WTW), countries are treated as nodes and trade between them is shown as links and network indices are calculated. Trade networks are complex systems and explain the interaction of trade partners in terms of their links. The network theory usually deals with the connections which are irrelevant of geography. An increasing number of studies treats international trade as a complex system and employs network techniques to discover the topological properties of the trade network.

In this paper, the gravity model with the network approach of international trade is employed and we try to explore the trade effects of network and geographical characteristics of the countries. For this purpose, gravity, network, and trade datasets from the CEPII are combined and the factors affecting the trade flows in the international trade network are analyzed. Main innovation of this work is bringing these datasets together and analyzing the international trade network and the gravity model both with all countries and considering developed and developing countries separately. We organize this paper as follows. The next section reviews the literature. The third section describes the data, the fourth section explains the methodology, and the fifth section discusses the empirical results. And finally, the sixth section concludes.

2. LITERATURE REVIEW

An increasing number of studies treats international trade as a complex system and employs network techniques to discover the topological properties of the trade network. Hilgerdt (1943) is a seminal effort defining international trade as a network. A later work, Smith and White (1992) analyze the structure of the trade network by using the relational distance algorithm and find that the countries are slowly altering from their positions over time, which are defined as the core, semi-periphery, and periphery.

Garlaschelli and Loffredo (2005) define the world trade web as a directed and evolving network and affirm the phenomenon of relationship between this topology and wealth of the countries. Serrano and Boguna (2003) find that the international trade network shows complex network features, and it addresses topological features of the network. They argue that international trade must be considered as a whole, complex system since the globalization tends to eliminate most of the geographical, economic, and technical limitations.

Another work, Kali and Reyes (2007) suggest a network approach to international economic integration instead of the classical measures based on trade volumes. They find that a country's economic growth and its network position are strongly related. Schweitzer et al. (2009) concern with challenges originated from the global crisis that affects the whole complex system. They argue that economic policies favoring network structures resistant to economic shocks should be proposed.

Substantial efforts in the ITN literature deals especially with the topological properties of the network. Topology refers to the metrics like degree, strength as we discussed above. They employ various examinations to discuss these networks properties. Fagiolo et al. (2008) examine the topology of trade network by employing a weighted-network analysis. They show that most of the trade links are weak relationships and there is a linear relationship between the intensity of trade connections and clustering.[1] Barigozzi et al. (2010) and Barigozzi et al. (2011) are another strand of the literature related with the topological properties of ITN, which analyzes the commodity-specific trade relations. De Benedictis et al. (2014) is a comprehensive paper analyzing world trade using network techniques. Working with the CEPII BACI dataset for the years between 1995 and 2010, they calculate local and global centrality measures for the countries and describe the binary and weighted topology of the trade network with supporting network representations both in aggregate and sectoral levels.

The gravity model is widely used in the international trade literature as we discussed in the introduction part. Chaney (2008) employs a type of gravity model which deals with intensive and extensive margin of trade with firm heterogeneity in productivity. Chaney (2014) studies the frictions in the international trade since they have importance on affecting the trade between countries. According to this work, the exports of the firms are only directed to the markets that they have a contact. Thus, the dynamic formation of the exporters' network in the is characterized by the theory of the study with trade frictions.

Some works on the ITN literature deal with the shortcomings of the gravity model. They argue that the gravity model cannot estimate the zero trade flows, which results in failure in reproducing links in the trade network. To overcome this drawback, Picciolo et al. (2012) employ exponential random graphs and treat distances as constraints. They conclude that trade network does not strongly depend on the distances between countries. Squartini and Garlaschelli (2014) suggest a probabilistic approach taken from the physics, by adopting quantum-mechanical paradigm. Their results indicate that these methods explain binary topological properties much better than weighted metrics of the international trade network.

Another strand of the ITN literature combines network indices with the gravity model for empirical analysis. De Benedictis and Tajoli (2011) utilize network metrics such as density, closeness, betweenness, and degree centrality as well as various country characteristics such as income, population, and geographical location. They employ these network metrics as dependent variables in a classical gravity equation on the traditional country-specific variables to provide additional explanatory power. Duenas and Fagiolo (2013) also explain the international trade network through the gravity model. According to the authors, the gravity model is insufficient to account for the high-level statistics such as clustering. To explain the topological properties of the network, the gravity model and network-related variables should be combined.

Our contribution in this work to the ITN literature is to employ the gravity model with the network approach of international trade and empirically examine the trade effects of characteristics and network indices of the countries. For this purpose, we combine gravity, network, and trade datasets from the CEPII and analyze the factors affecting flows in the trade network to discover the dynamics of ITN. Main innovation of this work is not only to bring these datasets together but also is to analyze the impact

[1]See Fagiolo et al. (2009) and Fagiolo (2010) for the related work.

of geography and international trade network on trade by considering developed and developing countries separately.

3. DATA

We basically combine three datasets together which are taken from the CEPII for 178 countries. Firstly, trade data is from the BACI dataset based on UN Comtrade[2] dataset. Export volumes come from this dataset. Originally, the BACI dataset is disaggregated at the Harmonized System (HS) 6 level, and we then aggregate export shares as of total export of each country to another. We also make use of the network trade dataset, which includes network indices. These are out-degree, out-strength, out-closeness, and out-eigenvector centrality. Lastly, we include the gravity dataset, which is consisted of the geographical characteristics of countries[3]; which are the weighted distance, GDP per capita, population, area, contiguity, common currency, common language, and GATT/WTO membership. Note that, the CEPII BACI dataset covers the years between 1995 and 2015. However, since the network trade dataset lasts by the year 2010, our combined dataset is limited by the years 1995 and 2010.

Table 1 displays the descriptive statistics. Export and GDP per capita values are in thousand dollars and deflated by 2010 U.S. CPI. In our dataset, export and GDP per capita observations are thus much fewer than the other variables we have since there are some missing values for some of the countries and years. Variables are named as the "origin" for country i, and the "destination" for country j. For these variables, understandably, summary statistics take the same values.

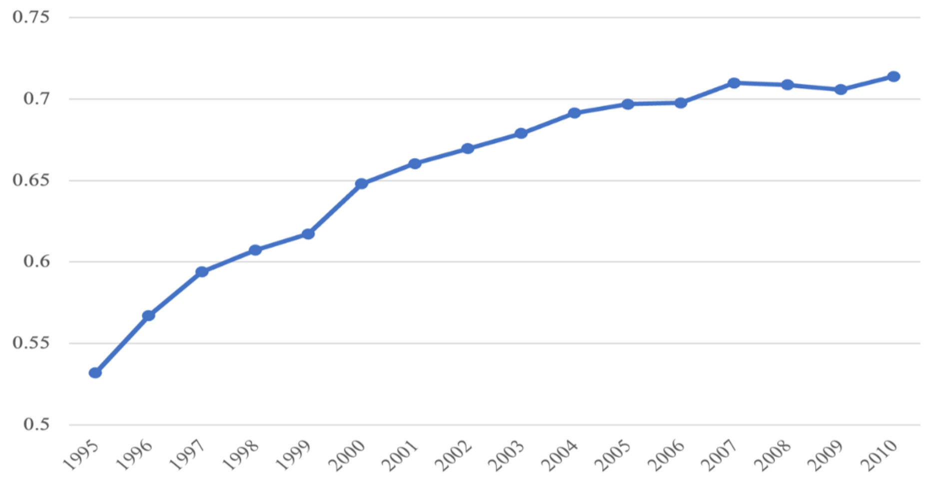
Table 1. Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Export	299186	$2.19x10^9$	$5.49x10^{11}$	930.91	$2.96x10^{14}$
Distance (km)	504096	7929.49	4497.06	60.77	19781.39
Origin GDP per capita	434004	38034.39	1201817	207.37	$5.95x10^7$
Destination GDP per capita	434004	38034.39	1201817	207.37	$5.95x10^7$
Origin population (million)	503565	35.29	129.08	0.02	1337.71
Destination population (million)	503565	35.29	129.08	0.02	1337.71
Origin area (km^2)	504096	741708.1	1983853	25	$1.71x10^7$
Destination area (km^2)	504096	741708.1	1983853	25	$1.71x10^7$
Contiguity	504096	0.02	0.13	0	1
Common currency	504096	0.01	0.10	0	1
Common language	504096	0.14	0.35	0	1
GATT/WTO (origin)	504096	0.74	0.44	0	1
GATT/WTO (destination)	504096	0.74	0.44	0	1
Out-degree centrality	504096	0.65	0.25	0.05	1
Out-strength centrality	504096	1829488	2591063	500.55	9996222
Out-closeness centrality	504096	0.77	0.15	0.51	1
Out-eigenvector centrality	504096	0.07	0.02	0.01	0.11

[2]See Gaulier and Zignago (2010).
[3]See Head et al. (2010) and Head and Mayer (2014).

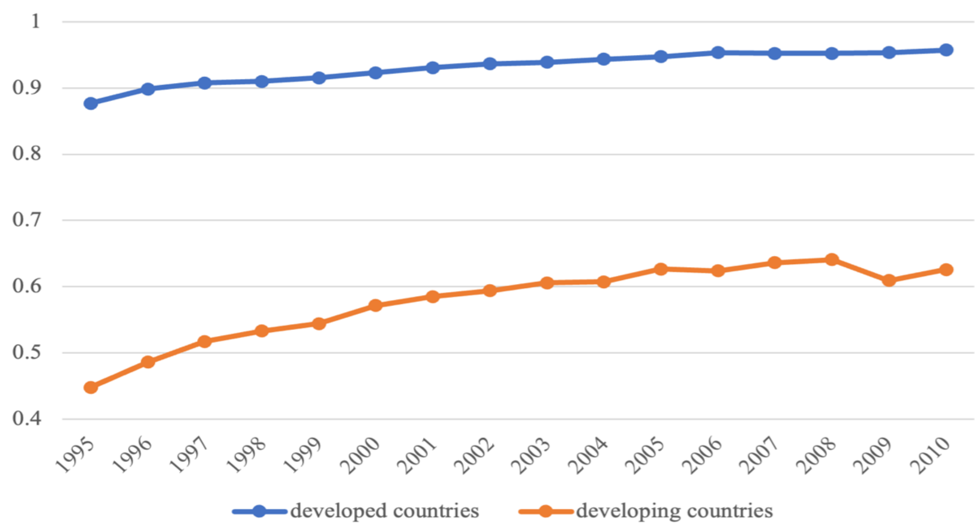
In this section, we represent network related figures and tables below by employing our 178-country dataset described above. Since the aim of our empirical analysis in this paper is to explain the dynamic changes in the international trade from the network perspective, we first calculate the density of the whole trade network, following De Benedictis et al. (2014). The density is defined as the proportion of actual trade links to maximum possible ones. We can observe from Figure 1 that, the density of ITN mostly increases between the years 1995 to 2010, except from the years near 2008 financial crisis.

Figure 1. Network Density of 178 Countries



For the links indicating trade flows out and in, we calculate and demonstrate the change in average values of out-degree and in-degree centralities. Figures 2 and 3 present the difference between out and in trade flows. We also divide data for 35 developed and 143 developing countries[4] to see how different countries behave over time. Note that, degree centralities are calculated for each country, then we take the averages of these values for 178 countries.

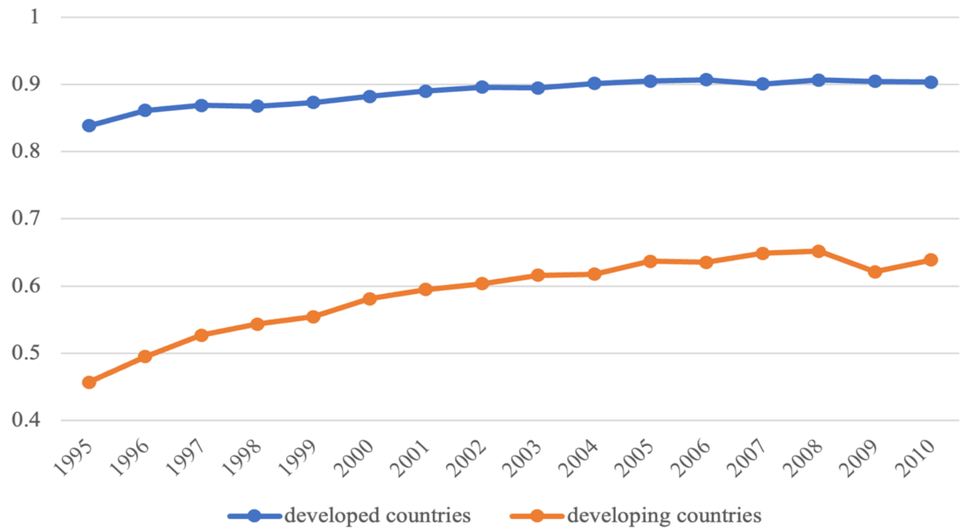
Figure 2. Average Out-Degree Centrality



[4]See Appendix for these countries.

Figure 2 shows the average out-degree centralities of developed and developing countries. For the developed countries, values range between 0.88 and 0.95 for the years between 1995 and 2010. Developing countries' average out-degree centrality starts from 0.45 in 1995 and increases to 0.65 in 2008. After the 2008 global crisis, we observe a decline especially for the developing countries though.

Figure 3. Average In-Degree Centrality



As can be seen from Figure 3, similarly, the average in-degree centralities for the developed countries increases from 0.84 to 0.90. Developing countries' in-degree centralities come up against a decline from 0.65 to 0.62 after the crisis, which has increased steadily from 0.45 since 1990. These two figures indicate that developed countries have substantially higher degree centralities and the position of developed countries in the trade network is less affected from the 2008 crisis than that of developing countries is.

Table 2. Out-Strength Centrality (1995 and 2010)

1995			2010		
Rank	Country	Out-strength	Rank	Country	Out-strength
1	U.S.	3384770	1	China	9996222
2	Germany	2786351	2	Germany	6705292
3	Japan	2579884	3	U.S.	6610431
4	France	1539471	4	Japan	4415181
5	UK	1284979	5	France	2880275
6	Italy	1255030	6	South Korea	2679725
7	China	1151677	7	Italy	2424068
8	Canada	1063366	8	Netherlands	2356322
9	Netherlands	957603	9	UK	2187866
10	Belgium	857750	10	Canada	2142547
…			…		
169	Seychelles	402.882	169	Saint Vincent	786.511
170	Armenia	354.513	170	Maldives	759.471

171	Samoa	324.756	171	Central African R.	686.148
172	Bosnia and Her.	312.950	172	Guinea-Bissau	524.097
173	Antigua and Bar.	265.744	173	Saint Lucia	480.173
174	Rwanda	251.977	174	Samoa	467.743
175	Bhutan	240.245	175	Saint Kitts.	394.072
176	Saint Kitts	234.620	176	Gambia	371.713
177	Marshall Isl.	156.370	177	Dominica	323.509
178	Vanuatu	151.737	178	Micronesia	307.672

In Table 2, we list 10 countries with highest and 10 with lowest out-strength centrality for the years 1995 and 2010, which are the first and the last years of our dataset. The strength centrality is simply trade weighted version of degree centrality. Thus, we can claim that countries with high trade volumes and trade links have also high out-strength centralities. For example, we can easily see the surge of China to the first rank in 2010 due to its recent spectacular performance in the world trade.

Table 3. Out-Closeness Centrality (1995 and 2010)

1995			2010		
Rank	Country	Out-closeness	Rank	Country	Out-closeness
1	Belgium	1	1	China	1
2	Denmark	1	2	Germany	1
3	Germany	1	3	U.S.	1
4	Italy	1	4	France	1
5	Netherlands	1	5	Italy	1
6	Sweden	1	6	Netherlands	1
7	UK	1	7	UK	1
8	China	0.994	8	Spain	1
9	Japan	0.989	9	India	1
10	U.S.	0.989	10	Malaysia	1
…			…		
169	Bhutan	0.550	169	Equatorial G.	0.586
170	Guinea-Bissau	0.550	170	Saint Lucia	0.584
171	Saint Kitts	0.550	171	Saint Kitts	0.582
172	Solomon Isl.	0.546	172	Marshall Isl.	0.577
173	Equatorial G.	0.543	173	Samoa	0.571
174	Iraq	0.538	174	Vanuatu	0.567
175	Samoa	0.536	175	Bhutan	0.567
176	Vanuatu	0.532	176	Solomon Isl.	0.560
177	Marshall Isl.	0.521	177	Guinea-Bissau	0.557
178	Micronesia	0.513	178	Micronesia	0.545

Closeness and eigenvector centralities in principle measure different values. The former can be defined as easiness of a node when reaching to other nodes, whereas the latter quantifies the importance of linked neighbors of the node. In Table 3 and Table 4, we demonstrate the top and bottom 10 countries with out-closeness and out-eigenvector centralities in 1995 and 2010. We rank the countries with their out-strength centrality if their closeness or eigenvector centralities are equal. We observe that although the ranking is somewhat different, both two list consist of very similar countries. The reason for this is probably a country which easily reach to another country, having high closeness centrality, has also important neighbors, having high eigenvector centrality.

Table 4. Out-Eigenvector Centrality (1995 and 2010)

1995			2010		
Rank	Country	Out-eigenvector	Rank	Country	Out-eigenvector
1	Germany	0.112	1	China	0.096
2	UK	0.112	2	Germany	0.096
3	Italy	0.112	3	U.S.	0.096
4	Netherlands	0.112	4	France	0.096
5	Belgium	0.112	5	Italy	0.096
6	Sweden	0.112	6	Netherlands	0.096
7	Denmark	0.112	7	UK	0.096
8	China	0.112	8	Spain	0.096
9	Switzerland	0.111	9	India	0.096
10	Japan	0.111	10	Malaysia	0.096
…			…		
169	Solomon Isl.	0.029	169	Equatorial G.	0.034
170	Bhutan	0.028	170	Saint Lucia	0.033
171	Aruba	0.025	171	Saint Kitts	0.033
172	Saint Kitts	0.024	172	Marshall Isl.	0.032
173	Equatorial G.	0.024	173	Samoa	0.029
174	Samoa	0.023	174	Bhutan	0.028
175	Iraq	0.022	175	Vanuatu	0.028
176	Vanuatu	0.020	176	Solomon Isl.	0.026
177	Marshall Isl.	0.014	177	Guinea-Bissau	0.024
178	Micronesia	0.009	178	Micronesia	0.020

4. METHODOLOGY

To discover the impacts of the geography and ITN on trade, we first combine both network indices and country-specific characteristics with the gravity model, based on the earlier studies such as De Benedictis and Tajoli (2011). The gravity model provides us to find the geographical effects on bilateral trade of the countries, which is frequently used in the trade literature. In our model, we incorporate the network indices to determine how the network positions of the countries affect the bilateral trade. Network indices used in this analysis are degree, strength, closeness, and eigenvector centrality. We also put country characteristics such as GDP, population, and geographical properties in the following gravity equation.

$$\ln T_{i,j} = \beta_0 + \beta_1 lnX_{i,j} + \beta_2 lnC_i + \beta_3 lnC_j + \beta_4 D_{i,j} + ln\beta_5 N_{i,j} + \epsilon_{i,j} \quad (1)$$

In this model, T denotes trade flow from country i to country j. The distance between the countries is shown as X in the model. C_i and C_j are country-specific properties such as GDP per capita, population, and area. Dummy variables are also added to the model, which are contiguity, common currency, common language, and GATT/WTO membership, denoted by $D_{i,j}$. Finally, $N_{i,j}$ denotes network indices, and we only use "out" values of these indices since we assume trade flows as exports from country i to country j.

We note that our model has shortcoming in explaining bilateral trade with network variables, which is the endogeneity bias. Our dependent variable is exports, and we employ network centralities as independent variables. However, there is a possible reverse causality issue between these variables since the trade volume might have impact on the network position of the country. We leave this issue for the future research.

5. EMPIRICAL RESULTS

Firstly, we perform the OLS regressions with four centrality measures for all countries. We then estimate our model for four different country groupings. We begin with our regression results concerning the geographical and network effects on exports with our dataset for all countries, which are displayed in Table 5. We perform the regressions for out-degree, out-strength, out-closeness, and out-eigenvector centralities individually and report the results in four columns in the table respectively. All centralities have positive effect on exports, and the coefficient of out-closeness centrality is the greatest one. It is interesting that the coefficient of out-strength centrality is lower than out-degree centrality. That is, if we weigh trade links by trade volumes for strength centrality instead of calculating degree centrality using the number of trade links, the effect of network on trade would be lower. We also find that out-eigenvector centrality has positive impact on exports.

As expectedly, the distance between the countries negatively affects the trade volume. GDP and population of both the origin and the destination countries have positive and significant coefficients. The areas of the countries have negative effects on the bilateral trade. Almost all dummies apart from a GATT membership of the origin country have significantly positive coefficients.

Table 5. ITN and Exports (All Countries)

ln (export)	(1)	(2)	(3)	(4)
ln (weighted distance)	-1.146***	-1.170***	-1.150***	-1.145***
	(0.006)	(0.006)	(0.006)	(0.006)
ln (origin GDP per capita)	0.976***	1.139***	0.845***	0.990***
	(0.004)	(0.003)	(0.004)	(0.004)
ln (destination GDP per capita)	0.916***	0.895***	0.925***	0.911***
	(0.003)	(0.003)	(0.003)	(0.003)
ln (origin population)	0.987***	1.171***	0.873***	1.003***
	(0.004)	(0.004)	(0.005)	(0.004)
ln (destination population)	1.021***	1.002***	1.027***	1.020***
	(0.004)	(0.004)	(0.004)	(0.004)
ln (origin area)	-0.067***	-0.094***	-0.052***	-0.071***
	(0.003)	(0.003)	(0.003)	(0.003)
ln (destination area)	-0.139***	-0.136***	-0.139***	-0.140***
	(0.003)	(0.003)	(0.003)	(0.003)

Contiguity	1.233***	1.175***	1.243***	1.225***
	(0.028)	(0.029)	(0.028)	(0.028)
Common currency	0.848***	0.726***	0.787***	0.874***
	(0.035)	(0.035)	(0.034)	(0.035)
Common language	1.057***	0.982***	1.080***	1.054***
	(0.012)	(0.012)	(0.012)	(0.012)
GATT/WTO (origin)	0.083***	0.329***	-0.030**	0.135***
	(0.012)	(0.012)	(0.012)	(0.012)
GATT/WTO (destination)	0.283***	0.278***	0.288***	0.300***
	(0.012)	(0.012)	(0.012)	(0.012)
ln (out-degree centrality)	1.387***			
	(0.019)			
ln (out-strength centrality)		0.034***		
		(0.002)		
ln (out-closeness centrality)			4.488***	
			(0.043)	
ln (out-eigenvector centrality)				1.589***
				(0.023)
Constant	6.745***	4.553***	8.458***	10.22***
	(0.078)	(0.078)	(0.081)	(0.107)
Observations	265,154	265,154	265,154	265,154
R-squared	0.667	0.661	0.674	0.666
F-Test	40905.22	39718.12	42086.55	40745.60
RMSE	2.1196	2.1196	2.1404	2.0994

Notes: Standard errors in parentheses. ***, **, and * denote 1, 5, and 10 percentages of significance.

For the second step, we estimate our model for the two groups of countries, developed and developing, with each four centrality measures. We report the regressions for out-degree, out-strength, out-closeness, and out-eigenvector centralities in the Appendix. The first column of each table (1-1) shows the trade flows between developed countries, and the second column (0-0) displays trade flows between developing countries. The third column (1-0) is the regression results for the export flows from developed countries to developing countries, and the fourth column (0-1) is vice versa.

Like the full sample regressions, we obtain very similar results for these four sub-groups for the distance, GDP per capita, and the population. However, the areas of the origin and the destination country now raise bilateral trade volumes when the flow is between developed countries, otherwise it has negative trade effect as we report regressions for all countries. Almost all dummy variables have positive and significant effects on trade. When the trade flows from developing country to developed country, both country's GATT memberships negatively affect the trade. If the trade flows from developed to developing country, the origin country's GATT membership has negative effect whereas the destination has positive effect on bilateral trade.

All centralities positively affect the export volumes except out-strength centrality when the flow is between developing to developed country. In this case, out-strength centrality of developing country has statistically significant and negative effect on export of developing country to developed country. Like in all country regressions, the coefficient of out-strength centrality is smaller than other centralities for all versions of trade flows between developed and developing countries.

6. CONCLUSION

In this paper, we begin with defining the basic concepts of network theory, and then we combine gravity, network, and trade datasets from the CEPII, to analyze the effects of country-specific properties and network indices on the international trade. We also separate our data into developed and developing countries to observe the differences between the groups of countries. By using the gravity model with the network indices, we first analyze the factors affecting export volumes for all countries, and then for the flows between developed and developing countries.

When we look at the trade flows for all countries, we find that centrality measures, which are out-degree, out-strength, out-closeness, and out-eigenvector centrality, significantly raise countries' bilateral trade. These measures are related to the position of the countries in the network. Thus, countries with high centralities are more likely to have higher trade volumes than the others have. We re-run the regressions for the four sub-group of countries and evaluate the differences when the flow is from a developed or a developing country. Our results show that apart from developed countries, developing countries with high centrality measures tend to have higher trade volumes.

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APPENDIX

Table A1. Developed Countries

Developed Countries		
Australia	Germany	Norway
Austria	Greece	Poland
Belgium	Hungary	Portugal
Bulgaria	Iceland	Romania
Canada	Ireland	Slovakia
Croatia	Italy	Slovenia
Cyprus	Japan	Spain
Czech Republic	Latvia	Sweden
Denmark	Lithuania	Switzerland
Estonia	Malta	United Kingdom
Finland	Netherlands	United States
France	New Zealand	

Table A2. Developing Countries

Developing Countries	
Afghanistan	Dem. Peop. Rep. of Korea
Albania	Dem. Rep. of the Congo
Algeria	Dominica
Angola	Dominican Rep.
Antigua & Barbuda	Ecuador
Argentina	Egypt
Armenia	El Salvador
Aruba	Equatorial Guinea
Azerbaijan	Ethiopia
Bahrain	Fiji
Bangladesh	FMR Sudan
Barbados	FS Micronesia
Belarus	Gabon
Belize	Gambia
Benin	Georgia
Bermuda	Ghana
Bhutan	Guatemala
Bolivia	Guinea
Bosnia Herzegovina	Guinea-Bissau
Br. Virgin Isds	Guyana
Brazil	Haiti
Brunei Darussalam	Honduras
Burkina Faso	Hong Kong
Burundi	India
Cambodia	Indonesia
Cameroon	Iran
Cayman Isds	Iraq
Central African Rep.	Israel
Chad	Jamaica
Chile	Jordan
China	Kazakhstan
Colombia	Kenya
Congo	Kuwait
Costa Rica	Kyrgyzstan
Côte dIvoire	Lao Peop. Dem. Rep.
Cuba	Lebanon

Table A2. Developing Countries (continued)

Developing Countries	
Liberia	Saint Vincent & Grenadines
Libya	Samoa
Macao	Saudi Arabia
Madagascar	Senegal
Malawi	Serbia and Montenegro
Malaysia	Seychelles
Maldives	Sierra Leone
Mali	Singapore
Marshall Isds	So. African Customs Union
Mauritania	Solomon Isds
Mauritius	Somalia
Mexico	Sri Lanka
Mongolia	Suriname
Morocco	Syria
Mozambique	Taiwan
Myanmar	Tajikistan
Nepal	TFYR of Macedonia
Neth. Antilles	Thailand
New Caledonia	Togo
Nicaragua	Trinidad and Tobago
Niger	Tunisia
Nigeria	Turkey
Oman	Turkmenistan
Pakistan	Uganda
Panama	Ukraine
Papua New Guinea	United Arab Emirates
Paraguay	United Rep. of Tanzania
Peru	Uruguay
Philippines	Uzbekistan
Qatar	Vanuatu
Republic of Korea	Venezuela
Republic of Moldova	Viet Nam
Russian Federation	Yemen
Rwanda	Zambia
Saint Kitts and Nevis	Zimbabwe
Saint Lucia	

Table A3. Out-Degree Centrality and Exports

ln (export)	1-1	0-0	1-0	0-1
ln (weighted distance)	-1.006***	-1.232***	-1.203***	-0.685***
	(0.008)	(0.009)	(0.012)	(0.015)
ln (origin GDP per capita)	0.893***	0.965***	1.180***	0.974***
	(0.011)	(0.006)	(0.011)	(0.008)
ln (destination GDP per capita)	0.827***	0.711***	0.879***	1.033***
	(0.010)	(0.005)	(0.005)	(0.014)
ln (origin population)	0.822***	0.926***	1.045***	0.982***
	(0.008)	(0.007)	(0.008)	(0.010)
ln (destination population)	0.780***	0.980***	1.015***	1.342***
	(0.006)	(0.006)	(0.006)	(0.008)
ln (origin area)	0.019***	-0.068***	-0.095***	-0.048***
	(0.006)	(0.005)	(0.005)	(0.006)
ln (destination area)	0.031***	-0.184***	-0.151***	-0.262***
	(0.006)	(0.005)	(0.004)	(0.007)
Contiguity	0.539***	1.430***	1.339***	2.389***
	(0.032)	(0.038)	(0.094)	(0.121)
Common currency	0.0912***	1.206***	0.872***	0.722*
	(0.026)	(0.052)	(0.322)	(0.413)
Common language	0.690***	0.864***	1.007***	1.246***
	(0.030)	(0.018)	(0.023)	(0.031)
GATT/WTO (origin)	0.089*	0.173***	-0.385***	-0.271***
	(0.048)	(0.018)	(0.056)	(0.023)
GATT/WTO (destination)	0.292***	0.245***	0.088***	-0.355***
	(0.039)	(0.017)	(0.016)	(0.062)
ln (out-degree centrality)	1.189***	1.590***	2.664***	1.757***
	(0.104)	(0.030)	(0.115)	(0.035)
Constant	5.527***	10.02***	6.378***	3.358***
	(0.159)	(0.134)	(0.169)	(0.201)
Observations	19,036	126,861	61,250	58,007
R-squared	0.858	0.549	0.727	0.672
F-Test	8803.46	11853.81	12526.17	9128.02
RMSE	0.94	2.37	1.64	2.10

Notes: Standard errors in parentheses. ***, **, and * denote 1, 5, and 10 percentages of significance levels, respectively.

Table A4. Out-Strength Centrality and Exports

ln (export)	1-1	0-0	1-0	0-1
ln (weighted distance)	-1.011***	-1.212***	-1.205***	-0.724***
	(0.008)	(0.009)	(0.012)	(0.015)
ln (origin GDP per capita)	0.843***	1.135***	1.090***	1.152***
	(0.013)	(0.006)	(0.013)	(0.007)
ln (destination GDP per capita)	0.827***	0.691***	0.875***	1.018***
	(0.010)	(0.005)	(0.005)	(0.014)
ln (origin population)	0.795***	1.188***	0.989***	1.294***
	(0.009)	(0.006)	(0.009)	(0.008)
ln (destination population)	0.779***	0.955***	1.011***	1.312***
	(0.006)	(0.006)	(0.006)	(0.008)
ln (origin area)	0.0276***	-0.116***	-0.0787***	-0.110***
	(0.006)	(0.004)	(0.005)	(0.006)
ln (destination area)	0.0331***	-0.180***	-0.150***	-0.254***
	(0.006)	(0.004)	(0.004)	(0.007)
Contiguity	0.530***	1.370***	1.372***	2.468***
	(0.032)	(0.039)	(0.094)	(0.123)
Common currency	0.0992***	1.015***	0.709**	1.117***
	(0.026)	(0.052)	(0.322)	(0.422)
Common language	0.679***	0.867***	0.971***	1.227***
	(0.030)	(0.018)	(0.023)	(0.031)
GATT/WTO (origin)	0.342***	0.393***	0.149***	0.0112
	(0.040)	(0.017)	(0.048)	(0.022)
GATT/WTO (destination)	0.295***	0.232***	0.0909***	-0.183***
	(0.039)	(0.017)	(0.016)	(0.064)
ln (out-strength centrality)	0.0934***	0.0654***	0.188***	-0.00731*
	(0.008)	(0.003)	(0.008)	(0.004)
Constant	4.505***	6.928***	4.184***	1.249***
	(0.143)	(0.134)	(0.150)	(0.209)
Observations	19,036	126,861	61,250	58,007
R-squared	0.858	0.540	0.727	0.657
F-Test	8805.59	11475.25	12520.84	8557.71
RMSE	0.94	2.39	1.64	2.15

Notes: Standard errors in parentheses. ***, **, and * denote 1, 5, and 10 percentages of significance levels, respectively.

Table A5. Out-Closeness Centrality and Exports

ln (export)	1-1	0-0	1-0	0-1
ln (weighted distance)	-1.003***	-1.275***	-1.203***	-0.737***
	(0.008)	(0.009)	(0.012)	(0.015)
ln (origin GDP per capita)	0.860***	0.818***	1.128***	0.890***
	(0.011)	(0.007)	(0.012)	(0.008)
ln (destination GDP per capita)	0.829***	0.726***	0.880***	1.035***
	(0.010)	(0.005)	(0.005)	(0.013)
ln (origin population)	0.797***	0.705***	1.015***	0.863***
	(0.008)	(0.008)	(0.008)	(0.010)
ln (destination population)	0.781***	0.996***	1.016***	1.334***
	(0.006)	(0.006)	(0.006)	(0.008)
ln (origin area)	0.021***	-0.020***	-0.092***	-0.020***
	(0.006)	(0.005)	(0.005)	(0.006)
ln (destination area)	0.030***	-0.185***	-0.151***	-0.255***
	(0.006)	(0.004)	(0.004)	(0.007)
Contiguity	0.544***	1.418***	1.341***	2.228***
	(0.032)	(0.038)	(0.094)	(0.120)
Common currency	0.083***	1.156***	0.934***	0.744*
	(0.026)	(0.051)	(0.322)	(0.409)
Common language	0.687***	0.864***	1.008***	1.198***
	(0.030)	(0.018)	(0.023)	(0.030)
GATT/WTO (origin)	0.048	0.059***	-0.381***	-0.298***
	(0.046)	(0.017)	(0.054)	(0.022)
GATT/WTO (destination)	0.285***	0.259***	0.088***	-0.399***
	(0.039)	(0.017)	(0.016)	(0.062)
ln (out-closeness centrality)	2.287***	5.995***	4.414***	5.416***
	(0.153)	(0.072)	(0.163)	(0.089)
Constant	5.966***	12.31***	6.992***	5.090***
	(0.165)	(0.136)	(0.174)	(0.205)
Observations	19,036	126,861	61,250	58,007
R-squared	0.858	0.563	0.728	0.678
F-Test	8853.51	12565.10	12581.68	9396.21
RMSE	0.94	2.33	1.64	2.08

Notes: Standard errors in parentheses. ***, **, and * denote 1, 5, and 10 percentages of significance levels, respectively.

Table A6. Out-Eigenvector Centrality and Exports

ln (export)	1-1	0-0	1-0	0-1
ln (weighted distance)	-1.010***	-1.227***	-1.207***	-0.676***
	(0.008)	(0.009)	(0.012)	(0.015)
ln (origin GDP per capita)	0.919***	0.981***	1.266***	0.936***
	(0.011)	(0.006)	(0.010)	(0.008)
ln (destination GDP per capita)	0.829***	0.703***	0.873***	1.055***
	(0.010)	(0.005)	(0.005)	(0.013)
ln (origin population)	0.849***	0.959***	1.128***	0.932***
	(0.007)	(0.008)	(0.007)	(0.010)
ln (destination population)	0.778***	0.976***	1.013***	1.348***
	(0.006)	(0.006)	(0.006)	(0.008)
ln (origin area)	0.017***	-0.078***	-0.104***	-0.046***
	(0.006)	(0.005)	(0.005)	(0.006)
ln (destination area)	0.033***	-0.186***	-0.152***	-0.267***
	(0.006)	(0.005)	(0.004)	(0.007)
Contiguity	0.532***	1.420***	1.325***	2.438***
	(0.032)	(0.039)	(0.095)	(0.120)
Common currency	0.122***	1.199***	0.706**	0.647
	(0.026)	(0.052)	(0.323)	(0.411)
Common language	0.690***	0.858***	0.997***	1.255***
	(0.030)	(0.018)	(0.023)	(0.030)
GATT/WTO (origin)	0.289***	0.224***	0.168***	-0.270***
	(0.043)	(0.018)	(0.050)	(0.022)
GATT/WTO (destination)	0.355***	0.255***	0.099***	-0.199***
	(0.040)	(0.017)	(0.017)	(0.062)
ln (out-eigenvector centrality)	0.864***	1.705***	0.811***	2.495***
	(0.123)	(0.038)	(0.123)	(0.044)
Constant	6.922***	13.72***	6.703***	9.137***
	(0.348)	(0.183)	(0.360)	(0.241)
Observations	19,036	126,861	61,250	58,007
R-squared	0.857	0.546	0.725	0.676
F-Test	8759.47	11736.91	12387.99	9287.44
RMSE	0.94	2.37	1.65	2.09

Notes: Standard errors in parentheses. ***, **, and * denote 1, 5, and 10 percentages of significance levels, respectively.