Trade Liberalization, Economic Growth, Energy Consumption and the Environment: Time Series Evidence from G-20 Economies

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This study examines the dynamic interrelationships between trade, income growth, energy consumption and CO₂ emissions for G-20 economies in a framework of cointegrated vector autoregression (CVAR). Johansen’s maximum likelihood procedure is used to estimate the coefficients of the cointegrated VAR. The results show that trade and income growth have a favorable effect on environmental quality for the developed G-20 member countries, while they have an adverse effect on the environment for the developing member countries. We also find that energy consumption tends to worsen environmental quality for both the developed and developing countries. Finally, it is found that trade and income to emission and energy causality holds for the developed countries; changes in degree of trade openness and income growth lead to corresponding changes in the rates of growth in emission and energy consumption. Emission and energy to trade and income causality, on the other hand, is found to hold for the developing countries; any shocks in emission and energy consumption cause corresponding fluctuations in income growth and trade openness.

Keywords: Cointegration, Energy, Environment, Growth, Income, Trade, Time-series analysis

JEL Classification: F18, C32, Q56

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무역 자유화, 경제성장, 에너지 소비와 환경: G-20 국가에 대한 시계열분석

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본 논문은 G-20 국가간 무역, 소득증가, 에너지 소비와 이산화탄소 배출의 동적인 연관성에 공적분된 벡터자기회귀의 틀을 사용하여 분석하였다. 공적분된 벡터자기회귀모형의 계수를 추정하기 위하여 Johansen의 최대공산방법을 사용하였다. 무역과 소득증가는 G-20 선진국에 대해서는 환경을 개선하는 효과가 있는 것으로 나타났으나, 개도국에는 부정적인 영향을 미치는 것으로 나타났다. 또한 에너지 소비는 신진 개도국 모두에서 환경을 악화시키는 것으로 분석되었다. 마지막으로 선진국에서는 무역 개방성과 소득 증가에 비례하여 배출증가 및 에너지 소비의 증가가 나타났으며, 이와 반대로 개도국에서는 배출과 에너지 소비에 대한 충격이 이에 상응하는 변동을 무역 및 소득에 가져오는 것으로 나타났다.

핵심용어: 공적분, 에너지, 환경, 성장, 소득, 무역, 시계열분석
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I. Introduction

Over the past three decades, a plethora of studies have been conducted to empirically identify the relationship between environmental quality (e.g., sulfur dioxide (SO$_2$) and carbon dioxide (CO$_2$) emissions) and measures of economic activity such as economic (income) growth and energy consumption. Given the primary focus of empirical analysis, the literature can be classified into three categories. The first group analyzes the (causal) relationship between income (economic) growth and environmental pollutants, referred to as the growth-environment nexus (e.g., Grossman and Krueger 1991; Shafik 1994; Agras and Chapman 1999; Heil and Selden 1999; Friedl and Getzner 2003; Dinda and Coondoo 2006; Managi and Jena 2008). These studies have typically concentrated on identifying the existence of environmental Kuznets curve (EKC). The EKC hypothesizes an inverted U-shaped relationship between (per capita) income and pollution levels; that is, environmental quality first deteriorates and then improves with per capita income (see Dinda (2004) for detailed review of EKC literature). In their seminal work, for example, Grossman and Krueger (1991) find that the EKC holds for North American countries. Agras and Chapman (1999) use a cross-section panel of countries to examine the EKC hypothesis; they find little evidence of the inverted relationship between income and the environment.

The second group turns its attention to investigate the relationship between income growth and energy consumption, referred to as the growth-energy nexus (e.g., Kraft and Kraft 1978; Yu and Choi 1985; Glasure and Lee 1997; Soytas et al. 2001; Soytas and Sari 2003; 2006; Akinlo 2008). The central issue of this group is to explore whether economic growth stimulates energy consumption or vice versa (see Ozturk (2010) for detailed literature survey on this issue). Kraft and Kraft (1978), for example, examine the causal linkages between energy consumption and economic growth in the United States; they find that the causal relationship runs from economic growth to energy, but the reverse does not hold. Soytas et al. (2001) analyze income-energy causality in Turkey; they show that economic growth depends on energy consumption, and a decrease in energy con-

Consumption may restrain economic growth. Finally, there has recently been a growing body of literature that has combined the first and second approaches as noted earlier in order to analyze dynamic relationships among income growth, energy consumption and the environment, referred to as the growth-energy-environment nexus (e.g., Soytas et al. 2007; Zhang and Cheng 2009; Soytas and Sari 2009; Jalil and Mahmud 2009). Zhang and Cheng (2009), for example, examine the dynamic interrelationships between energy consumption, output and carbon emission in China; they find that, in the long-run, CO₂ emissions tend to increase as income and energy consumption increase.

An important point frequently overlooked in the literature, however, is that most of studies analyzing the income growth-environment nexus have used cross-section or panel data to examine the relationship between income and pollution level for multiple countries and enough attention has not been given to a country-specific data (e.g., Shafik 1994; Agras and Chapman 1999; Heil and Selden 1999; Friedl and Getzner 2003; Dinda and Coondoo 2006); considering heterogeneity of conditions observed in social, economical and political factors, economic development trajectory for an individual country may not be the same as a pattern of a group of countries. In addition, studies evaluating the growth-energy nexus have mostly employed the standard Granger causality test with little cognizance of a cointegrating relationship among variables; if, in fact, the selected variables are cointegrated in a model, the causality test provides misleading results (Miller and Russek 1990). Further, Granger causality analysis typically focuses on short-run dynamics rather than long-run equilibrium relationships. Although some studies (e.g., Stern 2000; Ghali and El-Sakka 2004) have examined the existence of long-run relationships among variables, they did not investigate the mechanisms through which long-run equilibria restored. Finally, the environmental consequences of trade liberalization have so far received little attention.¹)

¹) Over the years economists have vigorously debated this issue (e.g., Copeland and Taylor 1994; Copeland 2005). Proponents of trade liberalization, for example, claim that, given the fact that environmental quality is a normal good, income growth induced by trade causes people to increase their demand for a clean environment and thus encourages firms to shifts towards cleaner techniques of production, which in turn improves both
words, few studies have combined the three approaches to examine dynamic relationships among trade liberalization, income growth, energy consumption and environmental quality. To our knowledge, Baek et al. (2009) is the only study that has attempted to address this issue. They use the Johansen cointegration analysis in investigating the effect of trade openness on environment quality (i.e., SO₂ emissions) for developed and developing countries; they find that trade and income growth tend to improve environmental quality in developed countries, while they have detrimental effects on the environment in developing countries. However, their cointegration analysis includes only three variables— that is, trade openness, income and SO₂ emissions. Given the claim that emission of greenhouse gases (i.e., anthropogenic carbon dioxide (CO₂) emissions) through combustion of fossil fuels accelerated by (trade-induced) economic growth appears to be the major contributor of global warming, energy consumption should be accounted for when estimating the environmental consequences of trade liberalization.

In this paper, therefore, we attempt to extend the scope of previous work by examining the growth-energy-trade-environment nexus in the framework of individual country-specific data and cointegrated vector autoregression (CVAR). Empirical focus is on the assessment of the long-run effect of trade openness, per capita income and energy consumption on carbon dioxide (CO₂) emissions for G-20 countries. The G-20, officially known as the Group of Twenty Finance Ministers and Central Bank Governors, is made up of finance ministers and central bank governors from 20 economies—19 industrialized and developing countries plus the European Union (EU). The G-20 economies (excluding the EU) account for 76.1% of world GDP, 60.7% of world exports, 61.8% of world imports and 61.5% of the world population (Table 1). To achieve the objective, we use the Johansen multivariate cointegration test. This approach is a convenient specification to investigate dynamic interactions when variables used in the model are non-

environment and income growth. Opponents of trade liberalization, by contrast, argue that if production techniques do not change, then globalization could aggravate environmental damage through an increased scale of economic activity, thereby having a detrimental effect on environmental quality. As such, trade liberalization/globalization should be accounted for when estimating the growth-energy-environment nexus accurately.
Table 1. G–20 economic indicators (2008)

| Country       | GDP  (billion $) | GNI per capita ($) | Exports (billion $) | Imports (billion $) | Population (million) |
|---------------|------------------|--------------------|---------------------|---------------------|----------------------|
| Argentina     | 328              | 7,190              | 70                  | 55                  | 40                   |
| Australia     | 1,015            | 40,240             | 189                 | 194                 | 21                   |
| Brazil        | 1,575            | 7,300              | 198                 | 173                 | 192                  |
| Canada        | 1,501            | 43,640             | 463                 | 399                 | 33                   |
| China         | 4,327            | 2,940              | 1,435               | 1,074               | 1,325                |
| France        | 2,857            | 42,000             | 605                 | 692                 | 62                   |
| Germany       | 3,649            | 42,710             | 1,498               | 1,232               | 82                   |
| India         | 1,159            | 1,040              | 188                 | 315                 | 1,140                |
| Indonesia     | 511              | 1,880              | 140                 | 117                 | 227                  |
| Italy         | 2,303            | 35,460             | 546                 | 547                 | 60                   |
| Japan         | 4,911            | 38,130             | 746                 | 708                 | 128                  |
| Korea         | 929              | 21,530             | 433                 | 427                 | 49                   |
| Mexico        | 1,088            | 9,990              | 291                 | 309                 | 106                  |
| Russia        | 1,679            | 9,660              | 472                 | 292                 | 142                  |
| Saudi Arabia  | 469              | 17,870             | 313                 | 101                 | 25                   |
| South Africa  | 276              | 5,820              | 86                  | 91                  | 49                   |
| Turkey        | 735              | 9,020              | 141                 | 194                 | 74                   |
| UK            | 2,674            | 46,040             | 467                 | 641                 | 61                   |
| USA           | 14,093           | 47,930             | 1,281               | 2,117               | 304                  |
| World         | 60,557           | 8,654              | 15,755              | 15,666              | 6,697                |

Note: GNI per capita indicates gross national income per capita. The European Union (EU) is excluded.

Source: World Bank, World Development Indicators.

stationary and cointegrated. In addition, the Johansen approach is used to identify the cointegrating, or long-run, relationships among the selected variables. As Dinda and Coondoo (2006) point out, the environmental consequences of trade and other measures of economic activity are basically a long-run concept; hence, the use of cointegration method is indeed desirable to examine the true relationship among the environment, trade, income growth and energy consumption. Finally, coefficients of the long-run relationship can be tested to determine if any variable can be treated as a weakly exogenous variable. Following Baek et al. (2009),
therefore, results of a weakly exogenous test are used to identify a driving variable that influences the long-run movements of the other variables but is not affected by the other variables in the model.

The remainder of this paper is organized as follows. The next section discusses the theoretical model related to the environmental consequences of trade and other measures of economic activity, as well as the empirical method associated with the Johansen approach. The following section describes the dataset used in the analysis and empirical procedure. The last two sections discuss the empirical results, and make some concluding remarks.

II. The Model

1. The links between growth, energy, trade and the environment

In examining the environmental consequences of trade and other measures of economic activity, we have initially relied on a theoretical framework developed by Baek et al. (2009). In its simple form, this model can be stated as:

\[ E = f(T, Y) \]  
(1)

where \( E \) is the emission level; \( T \) is the trade openness; and \( Y \) is the (per capita) income. If trade openness leads to economic growth through an increase in the scale of economic activity in a country, it could be hypothesized that trade has a positive relation with income \((\partial Y / \partial T > 0)\). Assuming that an economy follows the full trajectory of the environmental Kuznets curve (EKC), it could be hypothesized that emission level increases with growing income up to a threshold level \((\partial E / \partial Y > 0)\) beyond which emission level declines with higher income level \((\partial E / \partial Y < 0)\). Given the heated debate on the close link between global warming and emission of greenhouse gases (i.e., CO\(_2\) emissions), energy consumption \((EN)\) is thought to be of another potential factor influencing
emission levels. In the empirical model used here, therefore, we extend equation (1) to represent the relationship between the environment and measures of economic activity including energy consumption as follows:

\[ E = f(T, Y, EN) \]  

(2)

To the extent that an increase in energy consumption induced by economic growth brings about a proportionate increase in emission level, it could be hypothesized that energy consumption positively affect emission level \( \frac{\partial E}{\partial EN} > 0 \). With the modification, then, it is this model which provides the theoretical basis for the growth-energy-trade-environment nexus.

It is important to note that, since individual countries experience different levels of income and openness, and therefore energy consumption corresponding to their process of development, the true form of the pollution-income-openness-energy relationship mainly depends on where an economy is currently located in a development trajectory (Baek et al. 2009). For example, as for individual countries that move beyond the EKC turning points with energy consumption stimulated by growth and have a higher degree of openness, trade liberalization may result in structural change towards less polluting industries and enforcement of environmental regulations with little or no adverse effect on economic growth, thereby improving environmental quality. On the other hand, as for individual countries that have not reached income levels high enough to reach their turning points with energy induced growth, trade liberalization may lead to more rapid growth of pollution-intensive industries in those countries and, in turn, restrictions on the use of energy through enforcement of environmental regulations may adversely affect economic growth and trade. As such, the effect of trade liberalization on income, energy consumption and the environment is essentially an empirical phenomenon and depends on various characteristics of the economy under consideration such as stages of economic development, openness levels and stringency of environmental regulations.
2. The Johansen cointegration approach

To estimate the long-run relationships among the selected variables in equation (2), we use the Johansen maximum likelihood estimation procedure. Following Johansen (1988), the cointegrated vector autoregression (VAR) model can be defined as follows:

$$\Delta z_t = \Gamma_1 \Delta z_{t-1} + \ldots + \Gamma_{k-1} \Delta z_{t-k+1} + \Pi z_{t-k} + \mu + u_t,$$

(3)

where $z_t$ is a $(4 \times 1)$ vector of endogenous variables (i.e., $z_t = [T_t, Y_t, EN_t, E_t]$); $\Delta$ is the difference operator; $\Gamma_1, \ldots, \Gamma_{k-1}$ are the coefficient matrices of short-term dynamics; $\Pi = -(I - \Pi_1 + \cdots + \Pi_k)$ are the matrix of long-run coefficients; $\mu$ is a vector of constant; and $\mu_t$ is the white noise. Granger’s representation theorem asserts that if the coefficient matrix $\Pi$ has reduced rank—i.e., there are $r \leq (n - 1)$ cointegration vectors present, then the $\Pi$ can be decomposed into a matrix of loading vectors ($\alpha$) and a matrix of cointegrating vectors ($\beta$), that is $\Pi = \alpha \beta'$. Here, $r$ is the number of cointegrating relations, $\alpha$ represents the speed of adjustment to equilibrium, and $\beta'$ is a matrix of long-run coefficients. For four endogenous non-stationary variables in this analysis, for example, the term $\beta' z_{t-1}$ in equation (3) represents up to three linearly independent cointegrating relations in the system. The number of cointegration vectors, the rank of $\Pi$, in the model is determined by the likelihood ratio test (Johansen 1988).

When the number of cointegration vectors ($r$) has been determined, it is possible to test hypotheses under $r$ by imposing linear restrictions on the matrix of cointegration vectors, $\beta$, and loadings, $\alpha$ (Johansen and Juselius 1992). The tests for these linear restrictions are asymptotically $x^2$ distributed. Testing for weak exogeneity, for example, is formulated by establishing all zeros in row $i$ of $\alpha_{ij}$, $j = 1, \ldots, r$, indicating that the cointegration vectors in $\beta$ do not enter the equation determining $\Delta z_{it}$. This means that, when estimating the parameters of the model ($\Gamma_i, \Pi, \alpha, \beta$), there is no loss of information from not modeling the determinants.
of $\Delta z_{tt}$; thus, this variable is weakly exogenous to the system and can enter on the right-hand side of the VAR model (Harris and Sollis 2003).

III. Data and Econometric Procedure

1. Data

Using the theoretical framework described above, we compile annual time-series data on carbon dioxide (CO$_2$) emissions, income, trade openness and energy consumption for G-20 economies for the time span 1960-2006. The per capita CO$_2$ emissions (measured in metric ton) are used as a proxy for environmental quality and are collected from the World Development Indicators (WDI) provided by the World Bank. The per capita real GDP (measured in real purchasing power parity (PPP) adjusted dollars) is used as a proxy for income and is obtained from the Penn World Table (PWT 6.3) compiled by the Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania. The energy per capita data (measured in kg of oil equivalent per capita) is used as a proxy for energy consumption and is taken from the WDI. The degree of openness of an economy (defined as the ratio of the value of total trade to real GDP) is used a proxy for trade openness (liberalization) and is obtained from the Penn World Table. Finally, all variables are converted to natural logarithms and used throughout.

2) Since energy consumption can only be traced back to 1971 for Argentina, Brazil, China, India, Indonesia, Korea, Mexico, Saudi Arabia, South Africa and Turkey, the data for these countries cover the period from 1971 to 2006. In addition, because of limited availability of data (unavailability of CO$_2$ emissions for Germany and limited time-series observations for Russia), Germany and Russia are excluded from the analysis. Finally, the main purpose of this study is to examine the environmental consequences of trade and other measures of economic activity with individual country-specific data; hence, the EU is excluded from the analysis as well.
2. Econometric procedure

Prior to conducting the Johansen test, one of the specification issues to be addressed is determining whether the variables are nonstationary. The presence of a unit root in $z_t$ is tested using the Dickey-Fuller generalized least squares (DF-GLS) test (Elliot et al. 1996). The DF-GLS optimizes the power of the augmented Dickey-Fuller (ADF) test using a form of detrending and works well in small samples.3) The results show that the levels of all the variables (68 series) are nonstationary, while the first differences are stationary, indicating that all the variables are non-stationary $I(1)$ processes; hence, cointegration analysis can be pursued on those variables.4)

The second specification issue to be address is the determination of the lag length for the VAR model. Maddala and Kim (1998) show that the Johansen procedure is sensitive to changes in lag structure. The lag length ($k$) for the model is selected based on the likelihood ratio (LR) tests. This method compares the models of different lag lengths to see if there is a significant difference in results (Doornik and Hendry 1994). Of the 17 countries, for example, the null hypothesis that there is no significant difference between a one- and a two-lag model cannot be rejected for 8 countries; hence, one lag ($k = 1$) is chosen for those eight countries in our cointegration analysis. Similarly, for the remaining 9 countries, the VAR model with $k = 2$ is determined for six countries (Korea, USA, Brazil, China, Turkey and South Africa) and $k = 3$ for three countries (Australia, Italy and Canada). Diagnostic tests on the residuals of each equation and corresponding vector test statistics support the VAR model with the selected lag length(s) as a sufficient description of the data (Table 2).

3) When dealing with finite samples, especially with small numbers of observations, the power of the standard ADF test is known to be notoriously low (Maddala and Kim 1998; Harris and Sollis 2003). In other words, the ADF test has high probability of accepting the null hypothesis of nonstationarity when the true data-generation process is, in fact, stationary.

4) The results are not reported here for brevity but can be obtained from the authors upon request.
Table 2. Results of Johansen cointegration tests and misspecification tests for residuals

| Country      | Cointegration | Misspecification tests |
|--------------|---------------|------------------------|
|              |               | Serial correlation     | Heteroskedasticity | Normality |
| Argentina    | ×             | 0.74                   | 0.90              | 6.47      |
| Australia    | ○             | 1.12                   | 1.06              | 14.26*    |
| Brazil       | ○             | 0.76                   | 1.90              | 4.16      |
| Canada       | ○⁺            | 0.87                   | 1.99              | 9.71      |
| China        | ○             | 1.51                   | 0.20              | 13.08     |
| France       | ○             | 0.54                   | 0.72              | 19.61**   |
| India        | ×             | 1.37                   | 0.82              | 18.45**   |
| Indonesia    | ○             | 1.15                   | 1.09              | 22.62**   |
| Italy        | ○⁺            | 1.49                   | 0.67              | 9.78      |
| Japan        | ○             | 1.31                   | 1.63              | 11.92     |
| Korea        | ○             | 0.87                   | 0.35              | 7.72      |
| Mexico       | ○             | 1.41                   | 0.99              | 10.98     |
| Saudi Arabia | ○             | 0.70                   | 0.76              | 8.04      |
| South Africa | ○⁺            | 0.98                   | 2.59              | 3.58      |
| Turkey       | ×             | 0.86                   | 1.60              | 13.08*    |
| UK           | ×             | 1.09                   | 0.79              | 10.54     |
| USA          | ○             | 0.80                   | 0.51              | 11.13     |

Note: ○ and × represent cointegration and no cointegration, respectively. ** and * denote rejection of the null hypothesis (no serial correlation, homoskedasticity and non-normality) at the 5% and 10% levels, respectively. Superscript + indicates two cointegration vectors.

In the serial correlation test using the $F$-form of the Lagrange Multiplier (LM) test, the null hypothesis of no serial correlation cannot be rejected for all cases at the 10% significance level. Heteroskedasticity is tested using the $F$-form of the LM test, and results show that the null hypothesis of no heteroskedasticity (homoskedasticity) cannot be rejected for all cases at the 10% significance level. Normality of the residuals is tested with the Doornik-Hansen (1994) method. The null hypothesis of normality is rejected for five cases at the 10% significance level; however, non-normality of residuals does not bias the results of
the cointegration estimation (Gonzalo 1994).

The Johansen cointegration procedure is applied to identify the number of cointegrating vectors among the selected variables. The results show one cointegration vector \( r = 1 \) for 10 countries and two cointegration vectors \( r = 2 \) for 3 countries at the 10% significance level (Table 2). The trace tests, for example, show that, of the 13 countries found to be cointegrated, the null hypothesis of no cointegration \( r = 0 \) can be rejected, but fail to reject the null of one cointegration vector \( r = 1 \) at the 10% level for 10 countries.\(^5\) With 3 countries (Canada, Italy and South Africa), on the other hand, the null hypotheses of no cointegration \( r = 0 \) and one cointegration \( r = 1 \) can be rejected, but fail to reject the null of two cointegration vectors \( r = 2 \). For the remaining 4 countries (Argentina, India, Turkey and UK), however, the lower trace statistic fails to reject no cointegration \( r = 0 \) even at the 10% level, indicating that the four variables in those countries are not cointegrated over the sample period.\(^6\) Overall, the results provide evidence to support the hypothesis that CO\(_2\) emissions and measures of economic activity such as trade, income and energy consumption have been closely linked in the majority of the G-20 economies and there is a long-run relationship(s) among them.

The cointegration vectors \( \beta_j \) estimated from equation (3) explain the long-run

\(^5\) The trace test leads to a consistent test procedure, but the maximum eigenvalue test does not (Doornik and Hendry 2001, p. 175); hence, we use the trace statistic to test the null hypothesis.

\(^6\) It is worth mentioning that structural change (break) is an important issue in time-series analysis and affects all inferential procedures related to unit roots and cointegration (Maddala and Kim 1998). In fact, 7 developed countries (except Australia) show that their CO\(_2\) emissions levels tend to increase first, reach a peak and then start declining after a threshold point. For completeness, therefore, we employ the most recent Johansen cointegration technique that allows for structural breaks at known points in time (Johansen et al. 2000). For the United States, Japan and Korea, for example, the plausible structural breaks appear to occur at 1972, 1973 and 1997, respectively, for the CO\(_2\) emissions levels. We find the same results as those derived from the standard Johansen method, indicating that the plausible structural breaks in the series do not affect the long-run relationship among the selected variables for those 7 developed countries. We thank an anonymous referee for raising this issue.
relationships among the selected variables. With the 10 countries in which all four variables are cointegrated with one vector, the first eigenvector ($\beta_1$) of the four eigenvectors is most highly correlated with the stationary part of the process when corrected for the lagged values of the differences. Hence, $\beta_1$ represents the cointegration vector determined by the cointegrated vector autoregression (CVAR) model (Johansen 1988). 7) After normalizing the coefficient of CO$_2$

Table 3. Results of long-run coefficients between CO$_2$ emissions, income, energy consumption and trade openness

| Country         | Income | Trade Openness | Energy Consumption |
|-----------------|--------|----------------|--------------------|
| Australia       | -0.82  | -0.31          | 1.78               |
| Brazil          | 0.31   | 0.66           | 2.34               |
| Canada          | -0.29  | -0.09          | 1.38               |
| China           | -0.20  | -0.16          | 0.75               |
| France          | -5.15  | -2.20          | 0.88               |
| Indonesia       | 4.13   | 1.45           | 3.14               |
| Italy           | -1.13  | -0.27          | 0.27               |
| Japan           | -0.40  | -0.37          | 1.01               |
| Korea           | 1.51   | -0.06          | 0.15               |
| Mexico          | 0.30   | 0.29           | 1.65               |
| Saudi Arabia    | -4.41  | 5.38           | 0.97               |
| South Africa    | 1.91   | 0.77           | 0.12               |
| USA             | -3.36  | -0.23          | 1.87               |

Note: Since the long-run equilibrium relation ($\beta_1$) is normalized to CO$_2$ emissions, coefficients indicate the negative and positive relationships between CO$_2$ emissions and the three variables; for example, in the case of Australia, CO$_2$ emissions have negative relationships with income and openness, but have a positive relationship with energy consumption. For Canada, Italy and South Africa found to have two cointegrating vectors, only the first eigenvector ($\beta_1$) is reported here.

7) Since two cointegrating relationships are found with Canada, Italy and South Africa (Table 2), an identification problem may arise because of the stationarity caused by the linear combination of the two cointegration relations (Harris and Sollis 2003). To solve this problem, we impose restrictions on the cointegration spaces ($\beta$) to identify unique cointegrating vectors. As such, the long-run relationships for the three countries are explained using the relevant long-run coefficients ($\beta_1$ and $\beta_2$).
emissions, for example, the long-run equilibrium relation ($\beta_1$) among the four variables in the U.S. can be represented as the following reduced form (Table 3);

$$CO_2 \text{ emissions} = -3.36Income_t - 0.230\text{openness}_t + 1.87\text{Energy}_t$$  (4)

In equation (4), a negative coefficient of income on CO$_2$ emissions suggests that an increase in income has a favorable effect on environmental quality in the United States. A negative coefficient of openness on CO$_2$ emissions implies that trade liberalization tends to improve environmental quality in the United States. Finally, a positive coefficient of energy consumption on CO$_2$ emissions indicates that an increase in energy consumption results in environmental deterioration.\(^8\)

A possible criticism of our efforts to examine the growth-energy-trade-environment nexus is that the sample size is relatively small for the cointegration analysis, because finite sample analyses could bias the cointegration test towards finding the long-run relationship either too often or too infrequently; our findings should thus be viewed with caution. As Hakkio and Rush (1991) note, however, the power of a cointegration test depends more on the span of the data rather than on the number of observations. Further, their Monte Carlo studies show that increasing the number of observations, particularly using monthly or quarterly data, does not add any robustness to the cointegration results. Combined with our relatively long enough time span (36–47 years) to reflect the long-run relationship among the variables, this should somewhat mitigate our concern with the relatively small sample size and may not undermine the credibility of our findings.

\(^8\) It is important to note that interpreting the coefficients in this relation as long-run elasticities are ambiguous since such an interpretation ignores the dynamics of the system (Lütkepohl 1991). A 1% increase in the U.S. income, for example, may not cause a long-term decline in CO$_2$ emissions by 3.36% because an increase in the U.S. income is likely to have an effect on other variables as well that may interact in the long-run.
IV. Empirical Results

1. Results of long-run analysis

The cointegration vectors ($\beta$) estimated from equation (3) is used to explain the long-run relationship among CO$_2$ emissions, income, energy consumption and openness after normalizing the coefficients of CO$_2$ emissions and rearranging in reduced forms (Table 3). The results show that, of the 13 countries in which all four variables are cointegrated, 8 countries have a negative long-run relationship between CO$_2$ emissions and (per capita) income, indicating that income growth has a favorable effect on environmental quality. For the remaining 5 countries (Korea, Brazil, Indonesia, Mexico and South Africa), on the other hand, CO$_2$ emissions are found to have a positive long-run relationship with income, suggesting that economic growth causes significant environmental degradation. These findings could be explained using the term emission intensity (ratio), which is defined as the ratio of per capita CO$_2$ emissions to per capita income (Baek et al. 2009). Improvement in emission intensity (or decline in the ratio) indicates that CO$_2$ emissions decrease as income of an economy grows over time. This phenomenon can be interpreted to mean that under this circumstance, an economy generally moves beyond the EKC threshold level of income and therefore CO$_2$ emissions decline with higher income per capita; hence, CO$_2$ emissions have a negative relationship with income. Deterioration in emissions intensity (or increase in the ratio), on the other hand, can be interpreted to mean that, since an economy has not reached the EKC turning point, CO$_2$ emissions increases as income rises; hence, CO$_2$ emissions have a positive relationship with income. In fact, of the 8 countries in which CO$_2$ emissions have a negative relationship with per capita income, all countries except for China and Saudi Arabia are found to have crossed the EKC turning points ranging from approximately $19,000 to $22,000 per capita income (in 2005 U.S. dollars) in the 1970s (Figure 1); in other words, the emission intensities of those six countries have significantly improved over the past 35 years (see USA and Canada in Figure 3). Notice that these 6 countries
can be categorized as developed countries on the basis of the World Bank country classification (Table 1). 9) Of the 5 countries in which CO₂ emissions have a

9) According to the World Bank’s main criterion of classifying economies, individual countries are divided based on 2008 gross national income (GNI) per capita as follows: (1) low income (or least developed countries; $995 or less); (2) middle income (or less developed/developing countries; $996~12,195); and (3) high income economies (or industrialized/developed countries; $12,195 or more). From the classification, therefore, G-20 economies can be divided into developing countries ($12,196 or less) and developed countries ($12,196 or more) since they do not include any low income countries; hence, developing countries include Argentina, Brazil, China, India, Indonesia, Mexico, Turkey and South Africa, while developed countries are Australia, Canada, France, Japan, Korea, Italy, Saudi Arabia, UK and USA (Table 1).
positive long-relationship with income, on the other hand, 4 countries are placed in the category of developing countries based on the World Bank’s criterion and appear to have not reached income levels high enough to derive the EKC turning point so that emission level tends to increase with higher income growth (Figure 2); in other words, the emission intensities in those 4 developing countries has improved little over the past 35 years (see Korea and Indonesia in Figure 3).\(^\text{10}\) Overall, these findings provide indirect evidence to support the existence

10) The remaining countries also show the similar patterns. For brevity, however, the figures for those countries are not shown here but will be available upon request.
of the environmental Kuznets curve (EKC) in the sense that as income grows in more advanced (early) stages of economic development, environmental quality starts improving (deteriorating) after (before) a threshold level of income has been crossed.\(^{11}\)

The country that warrants our immediate attention is China, which shows a negative long-run relationship between CO\(_2\) emissions and income, indicating that economic growth appears to reduce the emission level. Give the fact that China has been the largest carbon dioxide emitter since 2006, this finding may be peculiar. However, emission intensity by definition can keep improving as long as the growth rate of real income is faster than that of per capita CO\(_2\) emissions. Indeed, since the beginning of economic reforms and opening-up to international markets in the late 1970s and the early 1980s, China has experienced much faster growth in real income than CO\(_2\) emissions; for example, CO\(_2\) emissions

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\(^{11}\) It should be noted here that empirical studies have typically used a quadratic term of income in their models in order to test for the existence of an EKC. As discussed in the Introduction, however, the main purpose of this study is to examine dynamic inter-relationships among trade, energy consumption, income and CO\(_2\) emissions, rather than a U-shaped relationship only between income and pollution level (i.e., CO\(_2\) emissions). For this reason, we do not incorporate the squared income term in the model; hence, our interpretation here should be viewed as one of possible explanations for the findings.
of China have increased by an average of 4.3% annually since 1978, while real income has grown by an average of 8.5% annually over this period. As a result, the Chinese economy seems to have shown substantial improvement in the emissions intensity for the past 35 years (Figure 4).12)

Of the 13 countries in which all four variables are cointegrated, 8 countries

12) Unlike China, over the past three decades Saudi Arabia has experienced a constant decrease in income and fluctuations in CO₂ emissions with an increasing trend. For this reason, it is found that CO₂ emissions seem to have a negative relationship with income for Saudi Arabia.
show a negative long-run relationship between CO\(_2\) emissions and openness, indicating that trade liberalization tends to improve environmental quality (Table 3). Besides, 7 out of the 8 countries belong to the category of developed countries as the World Bank classifies. The finding thus, by and large, supports the *gains-from-trade hypothesis* mostly for developed countries; with trade induced income growth, industrialized countries tend to be more willing and able to channel resources into environmental protection through the enforcement of environmental regulations and the investment on cleaner production technologies, thereby improving environmental quality. For the remaining 5 countries in which 4 countries (Brazil, Indonesia, Mexico and South Africa) fall into the category of developing countries, on the other hand, CO\(_2\) emissions are found to have a positive long-run relationship with openness, suggesting that air pollution tends to worsen with a higher degree of openness. This result generally supports the *pollution haven hypothesis (PHH)* for developing countries. Specifically, when confronted with international competition, developing countries have strong incentives to set environmental standards below their efficiency levels in order to attract foreign investment and multinational firms, particularly those engaged in highly polluting activities. Under this circumstance, as developed countries create demand for tighter environment protection, trade liberalization leads to move more rapid growth of dirty industries from developed economies to developing world, thereby deteriorating environmental quality.

Finally, all 13 countries found to be cointegrated are shown to have a positive long-run relationship between CO\(_2\) emissions and energy consumption, indicating that air pollution tends to increase as a country’s energy consumption increases (Table 3). This suggests that over the past four decades energy consumption has been a significant detrimental effect on environmental quality, regardless of the development stages of individual countries. This result thus could be interpreted to support the contention that among various greenhouse gases, CO\(_2\) emissions through the combustion of fossil fuels (e.g., coal, petroleum and natural gas) seems to be the major contributor of global warming.\(^{13}\)
Table 4. Results of weakly exogenous tests

| Country        | Weakly exogenous ($H_0: \alpha_i = 0$) | CO$_2$ Emissions | Income | Trade Openness | Energy Consumption |
|----------------|----------------------------------------|------------------|--------|----------------|--------------------|
| Australia      |                                        | 7.01             | 1.94   | 6.81**         | 1.38               |
|                |                                        | [0.01]           | [0.16] | [0.01]         | [0.24]             |
| Brazil         |                                        | 0.09             | 0.65   | 10.45**        | 0.36               |
|                |                                        | [0.77]           | [0.42] | [0.00]         | [0.55]             |
| Canada         |                                        | 21.05**          | 0.61   | 0.09           | 9.34**             |
|                |                                        | [0.00]           | [0.74] | [0.96]         | [0.01]             |
| China          |                                        | 0.98             | 0.07   | 6.51**         | 0.11               |
|                |                                        | [0.32]           | [0.79] | [0.01]         | [0.75]             |
| France         |                                        | 6.36             | 16.79**| 0.03           | 7.64**             |
|                |                                        | [0.01]           | [0.00] | [0.86]         | [0.01]             |
| Indonesia      |                                        | 0.64             | 8.99** | 4.80**         | 0.55               |
|                |                                        | [0.42]           | [0.00] | [0.03]         | [0.46]             |
| Italy          |                                        | 8.98             | 2.94   | 1.31           | 6.04**             |
|                |                                        | [0.01]           | [0.23] | [0.52]         | [0.05]             |
| Japan          |                                        | 31.08**          | 34.93**| 0.48           | 36.98**            |
|                |                                        | [0.00]           | [0.00] | [0.48]         | [0.00]             |
| Korea          |                                        | 3.95**           | 0.65   | 0.56           | 3.34               |
|                |                                        | [0.05]           | [0.42] | [0.46]         | [0.07]             |
| Mexico         |                                        | 4.55**           | 0.13   | 4.23**         | 2.86**             |
|                |                                        | [0.03]           | [0.71] | [0.04]         | [0.09]             |
| Saudi Arabia   |                                        | 6.18**           | 10.05**| 0.19           | 9.48**             |
|                |                                        | [0.01]           | [0.00] | [0.66]         | [9.47]             |
| South Africa   |                                        | 0.77             | 13.47**| 6.17**         | 1.74               |
|                |                                        | [0.68]           | [0.00] | [0.05]         | [0.42]             |
| USA            |                                        | 3.98             | 0.16   | 1.18           | 0.39               |
|                |                                        | [0.05]           | [0.69] | [0.28]         | [0.53]             |

Note: ** and * denote rejection of the null hypothesis of weak exogenous at the 5% and 10% levels, respectively. Values are the likelihood ratio (LR) test statistics based on $x^2$ distribution. Parentheses are $p$-values.

13) It should be pointed out that we did not consider other factors such as country’s energy efficiency and energy production technology that may significantly affect CO$_2$ emissions levels in our analysis; hence, this conclusion also should be viewed with caution.
2. Results of testing for weak exogeneity: identifying driving variables

In order to examine the causal effects of trade, energy consumption and income on the environment, the test of long-run weak exogeneity is implemented by restricting the speed-of-adjustment parameter \( (\alpha) \) to zero in the model. This test examines the absence of long-run levels of feedback due to exogeneity (Johansen and Juselius 1992). A weakly exogenous variable is thought to be a driving variable that pushes the other variables away from adjusting to long-run equilibrium, but is not influenced by the other variables in the model. The results show that, of the 13 countries in which all four variables are cointegrated, the income and openness are weakly exogenous at the 10% significance level mostly for the developed member countries. Of the 8 developed member countries, for example, the null hypothesis of weak exogeneity cannot be rejected for income and/or openness at the 10% level in the majority of cases (12 out of the 16 cases), while the null hypothesis can be rejected for CO\(_2\) emissions and energy consumption in almost all cases (except energy consumption for Australia and USA) (Table 4). This finding indicates that, for the developed member countries, income and/or trade openness are generally the driving variables in the system; they significantly affect CO\(_2\) emissions and energy consumption in the long-run, but are not influenced by CO\(_2\) emissions and energy consumption. In other words, changes in income and/or trade openness would cause changes in CO\(_2\) emissions and energy consumption. This further suggests that, since environmental quality is a normal good, economic growth induced by trade liberalization allows for the possibility that people in developed countries demand for a clean environment, which in turn pushes firms to shift towards clearer techniques of production, thereby contributing to the environmental quality improvement. In addition, this finding supports the so-called conservation hypothesis associated with the relationship between energy consumption and economic growth/openness; that is, since economic growth induced by trade liberalization causes an increase in energy consumption, the policy of conserving energy consumption may be implemented with little or no adverse effect on economic growth and expansion of trade.
Of the 5 developing countries in which all four variables are cointegrated, on the other hand, the null hypothesis of weak exogeneity cannot be rejected for CO₂ emissions and energy consumption at the 10% level in almost all cases (8 out of the 10 cases). These results indicate that, for the developing member countries, CO₂ emissions and energy consumption are generally weakly exogenous to the long-run parameters in the system; hence, these two variables do not adjust to deviations from any equilibrium state defined by the cointegration relation. In other words, any shock in CO₂ emissions and energy consumption would cause fluctuations in income and trade openness. This finding further suggests that as high regulation countries (i.e., developed economies) implement tighter environmental regulations, multinational firms, particularly those engaged in highly polluting activities, tend to relocate to developing countries with lower environmental standards, which in turn worsen environmental quality with an increase in openness. This further supports the so-called growth hypothesis; that is, since energy consumption stimulates economic growth/trade, restrictions on the use of energy may adversely affect economic growth in developing countries, while increase in energy may contribute to economic growth.

V. Concluding Remarks

While numerous studies have analyzed the relationship between environmental quality, income growth and energy consumption, relatively little attention has been paid to the environmental consequences of trade liberalization. We examine the dynamic effects of trade, income, energy consumption on CO₂ emissions for G-20 economies in a cointegration framework. To achieve this goal, the Johansen multivariate cointegration method is used.

The results of the cointegration analysis show that there is a long-run relationship (s) between environmental quality and measures of economic activity; that is, CO₂ emissions, trade openness, income and energy consumption have been closely linked in the G-20 economies over the past 40 years. The results of long-run coefficients show that CO₂ emissions have a negative relationship with income
and trade for the developed G-20 members and have a positive relationship between the two variables for the developing member countries; that is, trade liberalization and income growth play a positive role in improving environmental quality for the developed member countries, while they have detrimental impacts on environmental quality in the developing member economies. It is also found that CO₂ emissions have a positive relationship with energy consumption for most G-20 members; that is, energy consumption generally worsen environmental quality for both the developed and developing economies, providing empirical evidence that CO₂ emissions through the combustion of fossil fuels may be the major contributor of global warming. Finally, the weak exogeneity tests show that, for the developed countries, income and/or trade openness are found to be weakly exogenous in the system, indicating that changes in degree of trade openness and income growth lead to corresponding changes in the rates of growth in emission and energy consumption. For the developing countries, on the other hand, CO₂ emissions and/or energy consumption are found to be weakly exogenous, suggesting that any shocks in emission and energy consumption result in corresponding fluctuations in income growth and trade openness.
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