World Trade Flows in Photovoltaic Cells: A Gravity Approach Including Bilateral Tariff Rates

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Abstract

This paper investigates the determinants of world trade flows in one of the principal environmental goods, photovoltaic cells, focusing on the period of growing trade of this industry between 2000 and 2004, with the emphasis on the effects of bilateral tariffs. Cross-section analysis based on the gravity model including bilateral tariffs as one of the trade costs demonstrates the systematic effects of bilateral tariff rates as well as distance effect and APEC bloc effect on the bilateral trade flows in the photovoltaic cells sector among 51 countries in each year between 2000 and 2004. Result of the panel analysis based on a fixed effect model of the gravity equation by allowing trading-pair heterogeneity using the data of 2000-2004 consolidates the significant effect of bilateral tariff rates on the trade flows, and demonstrates the globalization effect on trade growth in this sector. As for the pattern of bilateral trade of this sector, the cross-section analysis shows that the bilateral trade flows are larger for the country-pairs with similar GDP per capita by exchanging various varieties of the differentiated products, which can be explained by the monopolistic competition model. Results of the gravity analysis for photovoltaic cells suggest the effectiveness of the current efforts of APEC and the WTO for tariff reduction on various kinds of environmental goods for expanding bilateral trade flows of those goods among the covered countries of either developed or newly industrialized countries, which would lead to environmental protection through worldwide diffusion of those goods.

Keywords: Trade Liberalization of Environmental Goods, Trade in Photovoltaic Cells, Gravity Model, Tariff Rates, Monopolistic Competition, Globalization

Ⅰ. Introduction

This paper examines the determinants of the world trade network between 2000 and 2004 focusing on one of the principal environmental goods, photovoltaic cells, with emphasis on the effects of import tariffs. The importance of trade liberalization in environmental goods has been discussed since the end of the Uruguay Round in the World Trade Organization (WTO); and Paragraph 31 (iii) of the Doha Ministerial Declaration in 2001 considers the reduction or elimination of tariffs and non-

tariff barriers to trade in environmental goods and services to pursue win-win-win results for trade, economic development and the environment. Members of the WTO have been working to liberalize trade in goods and services that can benefit by protecting the environment, and the talks for this kind of trade liberalization take place in "Special Sessions" of the Trade and Environment Committee of the WTO. On the other hand, in 2012, Asia-Pacific Economic Cooperation (APEC) put together a list of 54 environmental goods and affirmed their commitment to reduce applied tariff rates to five percent or less on these environmental goods by the end of 2015. Recently, on 8 July 2014 at the WTO, fourteen WTO members launched plurilateral negotiations of the trade liberalization for Environmental Goods. What is important is that their talks will build on the APEC list of 54 environmental goods.[1)]

The purpose of this paper is to investigate how the tariff barriers affected trade growth in one of the important environmental goods, photovoltaic cells, in order to evaluate the effectiveness of current efforts for tariff reduction in environmental goods in APEC and the WTO. Based on the gravity model estimation including tariff rates as one of the trade costs, rigorous investigation is made about the effects of tariffs as well as the other determinants on trade for the sector of photovoltaic cells among 51 countries, including APEC countries, European countries, and the newly industrialized countries.[2)] It seems that the tariff reduction has been playing an important role in the growth of world trade since World War Ⅱ, together with income growth, transport cost declines, and other factors. For example, the empirical results of Baier and Bersgtrand (2001) suggest that income growth explains about 67%, tariff reductions about 25%, and transport cost declines about 8% of average world trade growth between the 1950s and 1980s, using the gravity model estimation.

This paper is organized as follows. Section Ⅱ provides the movement of world tariff reduction of photovoltaic cells from the late 1990s, and shows how the trade of photovoltaic cells increased with the tariff reduction. Section Ⅲ presents the analytical model and equations used in the empirical study of the photovoltaic cells sector, and the last part of section Ⅲ discusses the characteristics of data used in the econometric analysis. Section Ⅳ investigates the estimation results of both cross-section analysis and panel analysis to clarify the main findings for the world trade of photovoltaic cells in the first half of the 2000s when the trade of photovoltaic cells increased just after the tariff removal in the developed countries and the tariff reduction of developing countries. In Section Ⅴ, the conclusion of this paper is presented.

Ⅱ. World Trade and Tariffs of Photovoltaic Cells

The world trade and tariffs of photovoltaic cells are classified in HS 854140, and this HS code is included in the list of environmental goods of both the WTO and APEC as the principal item in the category of renewable energy. The content of HS code 854140 is photosensitive semiconductor devices, including both photovoltaic cells whether or not assembled in modules or made up into panels and light emitting diodes. In order to sort out photovoltaic cells by excluding light emitting diodes, we have to investigate more detailed trade data than provided by the six digit HS. As the HS code of those disaggregated data depends on the countries, we collected the detailed data for photovoltaic cells by examining trade data of each of 51 countries included in the analysis. According to the description in the APEC list of environmental goods, ANNEX C of APEC (2012),

the environmental benefit of photovoltaic cells is to generate electricity in an environmentally benign manner (with no emissions, noise or heat generated).

Table 1 provides the MFN applied tariff rates in photovoltaic cells in the countries with at least one non-zero tariff rate during 1998 and 2005, included in the gravity analysis. The tariff barriers were removed in the late 1990s in many countries including countries such as Australia, USA, and EU members, and also in the newly developed countries such as South Korea, Philippines, Taiwan and Thailand. The countries which joined EU in 2004 such as Cyprus, Czech Republic, Hungary, Malta, and Slovakia had removed tariffs a few years earlier than their entry to EU. The countries which still had high tariff rates in photovoltaic cells in the first half of 2000s are Brazil, Chile, China, India, Peru, and Russia, although China removed its tariff on photovoltaic cells in 2002.

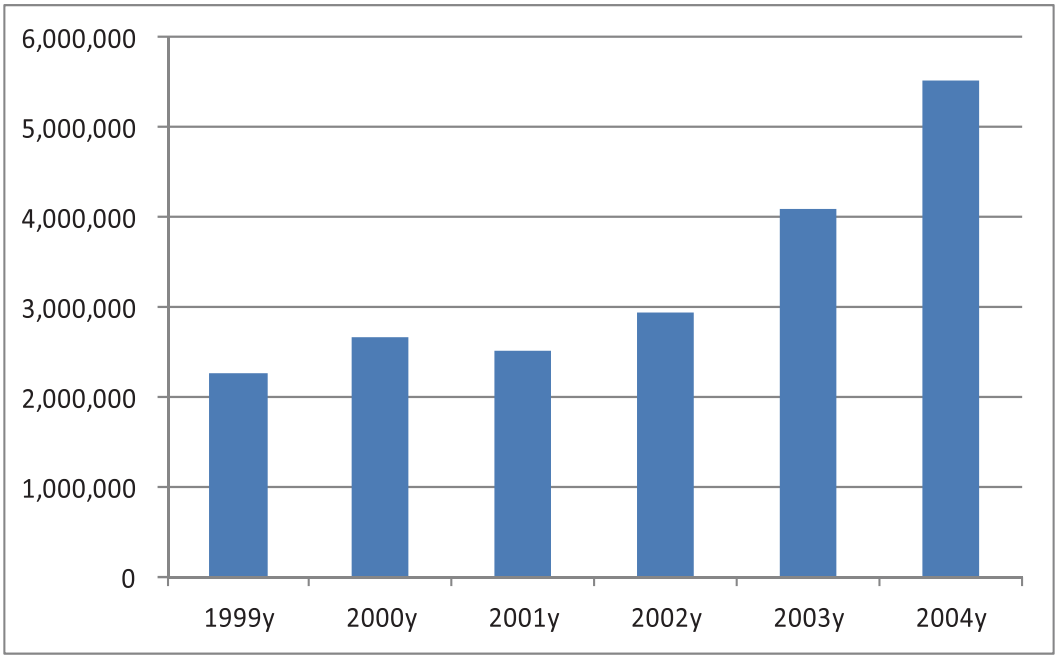
Figure 1 shows the world trade in photovoltaic cells from 1999 to 2004 by aggregating the total export value to the world from 51 countries included in this analysis. We can confirm that the trade value in this environmental good increased in the early 2000s in various countries in accordance with the worldwide trade liberalization. The years 2000–2004 were selected in this analysis for the following reasons. The estimation of the gravity equation for 1999 was not satisfactory because of too few observations of trade pairs in the photovoltaic cells sector, and after 2005, it is difficult to identify the influence of bilateral tariffs as India, a significant country, removed tariffs on photovoltaic cells in 2005.

Table 1 MFN Applied Tariffs for Photovoltaic Cells (Average), 1998–2005

(%)

Year	1998y	1999y	2000y	2001y	2002y	2003y	2004y	2005y
Australia	1.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brazil	10.18	9.50	9.22	7.50	6.89	3.78	3.67	4.44
Chile	11.00	10.00	9.00	0.00	7.00	0.00	6.00	6.00
China	10.00	10.00	10.00	10.00	0.00	0.00	0.00	0.00
Cyprus	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Czech Republic	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
European Union	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hungary	5.00	5.00	5.00	5.00	0.00	0.00	0.00	0.00
India	20.00	15.00	16.50	15.00	15.00	15.00	10.00	0.00
Indonesia	2.50	2.50	0.00	0.00	0.00	0.00	0.00	0.00
South Korea	2.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Malta	10.46	10.46	11.05	8.00	8.00	0.00	0.00	0.00
Peru	12.00	12.00	12.00	8.00	8.00	8.00	8.00	8.00
Philippines	3.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
Russia	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Slovakia	1.60	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Taiwan	0.28	0.21	0.00	0.00	0.00	0.00	0.00	0.00
Thailand	35.00	35.00	0.00	0.00	0.00	0.00	0.00	0.00
USA	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: WTO, Tariff Download Facility
Note: The selected countries are those with at least one non-zero tariff rate between 1998 and 2005.



Source: Data by Global Trade Atlas.

Figure 1　Photovoltaic cells exports of 51 countries (1,000 US $)

Ⅲ. Analytical Framework and Data

This section presents the methodological base of this research on world trade in the photovoltaic cells sector, and the data used for the set of variables. The gravity model is used for the analysis, which Bayoumi and Eichengreen (1997) described as the workhorse for empirical studies of the pattern of trade. Also, Rauch (1999) expressed the gravity equation as the standard empirical framework used to predict how countries match up in international trade.[3)]

The traditional form of the gravity model can be expressed as equation (1), according to Bergstrand and Egger (2010).

$$\ln PX_{ij} = \beta_0 + \beta_1 \ln GDP_i + \beta_2 \ln GDP_j + \sum_{m=3}^{M} \beta_m \ln(Z_{ij}^m) + \varepsilon_{ij} \qquad (1)$$

where PX_{ij} is the value (in current prices) of the merchandise trade flow from exporter i to importer j, GDP_i (GDP_j) is the level of nominal gross domestic product in country i (country j) Z_{ij}^m, (m = 3, ..., M) is a set of observables to which bilateral trade barriers are related, including the bilateral physical distance between the economic centers of countries i and j, and ε_{ij} is a disturbance term, with expected signs for coefficients $\beta_1 > 0, \beta_2 > 0, and\ \beta_m < 0$. ln refers to the natural logarithm.

A statistical overview in Cheng and Wall (2005) clarifies various forms of the gravity model to estimate bilateral trade flows, using both cross-section and panel analysis. By starting with a general model (GM) shown in equation (2) with no restrictions on the parameters, the standard single-year

cross-section model (CS), a pooled-cross-section model (PCS), and a fixed effects model (FE) are introduced with some specific restrictions on the parameters. The following overview of the four types of the gravity model is quoted from Cheng and Wall (2005).

$$\text{General Model (GM): } \ln X_{ijt} = \alpha_0 + \alpha_t + \alpha_{ij} + \beta'_{ijt} Z_{ijt} + \varepsilon_{ijt} \qquad t = 1,...,T \tag{2}$$

where X_{ijt} is exports from country i to country j in year t, $Z_{ijt} = [z_{1t}, z_{2t}, \cdots]$ is the $1 \times k$ vector of gravity explanatory variables. The intercept has three parts: one common to all years and country pairs, α_0, one specific to year t and common to all pairs, α_t, and one specific to the country pairs and common to all years, α_{ij}. The disturbance term, ε_{ijt} is assumed to be normally distributed with zero mean and constant variance for all observations, and the disturbances are pairwise uncorrelated.

The standard single-year cross-section model imposes the restrictions that the slopes and intercepts are the same across country pairs, that is $\alpha_{ij} = 0$, and $\beta_{ijt} = \beta_t$ as specified in equation (3).

$$\text{Cross-Section Model (CS): } \ln X_{ijt} = \alpha_0 + \alpha_t + \beta'_t Z_{ijt} + \varepsilon_{ijt} \qquad t = 1,...,T \tag{3}$$

where α_0 and α_t cannot be separated.

The pooled-cross-section model imposes the restriction on the general model that the parameter vector is the same for all t, although it normally allows the intercepts to differ over time, and takes the form of equation (4).

$$\text{Pooled Cross-Section Model (PCS): } \ln X_{ijt} = \alpha_0 + \alpha_t + \beta' Z_{ijt} + \varepsilon_{ijt} \qquad t = 1,...,T \tag{4}$$

In the following fixed effect model, the restriction that the country-pair intercept terms equal zero is removed, and this model can be estimated using least squares with dummy variables for each of the country pairs. In this specification, the explanatory variables such as distance and common language are eliminated, because they are fixed over time, even though they are not collinear with the country-specific effects.

$$\text{Fixed Effect Model (FE): } \ln X_{ijt} = \alpha_0 + \alpha_t + \alpha_{ij} + \beta' Z_{ijt} + \varepsilon_{ijt} \qquad t = 1,...,T \tag{5}$$

This model is also considered to be the preferred method in Feenstra (2004), in order to take account of the unobserved bilateral price indexes, multilateral resistance, termed by Anderson and van Wincoop (2003) in the theoretical explanation of the gravity model under the usual assumptions in horizontal differentiation models using CES utility function.

In Ⅲ-1, the estimation model of cross-section analysis is presented, in Ⅲ-2, the specifications for panel analysis are developed, and in Ⅲ-3, an explanation of the data is presented.

Ⅲ-1 Specifications of Cross-Section Analysis

Bergstrand and Egger (2010) point out two aspects of equation (1). Firstly, actual bilateral trade flows can be explained quite well by this specific and simple log-linear equation, and secondly,

bilateral trade flows are strongly influenced by economic trade frictions (or trade costs). They show that trade frictions have two forms, one being natural trade costs and the other unnatural (or policy-based) trade costs. Natural trade costs are made of transport costs and other related costs such as time, contract enforcement costs, costs associated with the use of different currencies, legal and regulatory costs, and local distribution costs. On the other hand, unnatural trade costs can be decomposed into tariffs, taxes on goods crossing international borders, and nontariff barriers on international trade.

In this paper, tariff rates of the photovoltaic cells sector are explicitly included, as well as distance between two pair countries, and dummy variables for common language and APEC bloc to take into account the effects relating to trade costs in equation (1). According to the gravity estimation for manufacturing trade by Ando and Kimura (2013), in order to take into account the effect of differences in factor endowments on bilateral trade, the difference in GDP per capita between two countries is introduced. The coefficient will be positive if the difference in factor endowments is the important determinant for trade increase of the photovoltaic cells sector as Heckscher-Ohlin Model predicts, and it will be negative if the similarity of pattern of factor endowment is important for trade increase in this sector as predicted by the new trade theory based on monopolistic competition with differentiated products.[4] The following equation (6) will be estimated for the cross-section analysis.

$$\ln PX_{ij} = \beta_0 + \beta_1 \ln GDP_i + \beta_2 \ln GDP_j + \beta_3 \ln GDPPC_{ij} + \beta_4 \ln DIST_{ij} + \beta_5 \ln(1 + TAR_{ij}) + \beta_6 CL_{ij} + \beta_7 AP_{ij} + \varepsilon_{ij} \quad (6)$$

where $\ln PX_{ij}$ is log of exports of photovoltaic cells from country i to country j, $\ln GDP_i$ and $\ln GDP_j$ are log of GDP of country i and country j respectively, $\ln GDPPC_{ij}$ is log of the absolute value of the difference in GDP per capita between country i and country j, $\ln DIST_{ij}$ is log of the geographical distance between capitals of country i and country j, $\ln(1 + TAR_{ij})$ is log of bilateral tariff rates for photovoltaic cells, CL_{ij} is a dummy variable taking unity if an official language is common to both countries and zero otherwise, and AP_{ij} is a dummy variable with unity if both of exporting country and importing country are members of APEC. We estimate the gravity equation for photovoltaic cells trade among 51 countries, including developed and newly industrialized countries, for each of 5 years from 2000 to 2004, by OLS according to equation (6). The expected signs in equation (6) are as follows: $\beta_1 > 0$, $\beta_2 > 0$, $\beta_4 < 0$, $\beta_5 < 0$, $\beta_6 > 0$, $\beta_7 > 0$. The sign of the absolute value of the difference in GDP per capita between country i and country j, β_3, depends on the characteristics of the goods as already mentioned. In order to examine the effects of the combination of the explanatory variables, four types of specifications are estimated selecting some of the variables, as shown in Table 4.

Ⅲ-2　Specifications of Panel Analysis

As Bergstrand and Egger (2010) state, researchers have turned more to panel data to estimate the effects of each determinant of the gravity equation in order to avoid unobservable heterogeneity across country pairs.

According to Cheng and Walls (2005), we estimate a specification with a country-pair

fixed effect and a time effect, by introducing dummy variables for each of the country pairs and time dummy variables. The dependent variable $\ln RX_{ij}$ is log of real exports of photovoltaic cells from country i to country j, and independent variables are log of real GDP of exporting country i, ($\ln RGDP_i$), log of real GDP of importing country j, ($\ln RGDP_j$), and log of tariff rates of photovoltaic cells in the import of country j from country i, $\ln(1 + TAR_{ij})$.

$$\ln RX_{ijt} = \alpha_{ij} + \alpha_t + \beta_1 \ln(RGDP_{it}) + \beta_2 \ln(RGDP_{jt}) + \beta_3 \ln(1 + TAR_{ijt}) + \varepsilon_{ijt} \quad (7)$$

where α_{ij} is the specific country-pair effect between the trading partners. The country-pair intercepts include the effects of all omitted variables that are cross-sectionally specific but remain constant over time, such as distance and common language.

We also estimate the following equation of the PCS model by OLS with time dummies, to compare the estimation results with the Fixed Effects model.

$$\begin{aligned}\ln RX_{ijt} = {} & \alpha_0 + \alpha_t + \beta_1 \ln(RGDP_{it}) + \beta_2 \ln(RGDP_{jt}) + \beta_3 \ln(1 + TAR_{ijt}) \\ & + \beta_4 \ln(DIST_{ij}) + \beta_5 AP_{ij} + \beta_6 CL_{ij} + \varepsilon_{ijt}\end{aligned} \quad (8)$$

where $\ln RX_{ijt}$ is log of real exports of photovoltaic cells as dependent variable, α_0 denotes the part of the intercept common to all years and trading pairs, α_t is the year-specific effect common to all trading pairs, $\ln RGDP_i$ is log of real GDP of importing country j, $\ln RGDP_j$ is log of real GDP of importing country j, TAR_{ij} is tariff rates of photovoltaic cells, $\ln DIST_{ij}$ is log of distance between country i and country j, AP_{ij} is a dummy variable with 1 if both countries are members of APEC and 0 otherwise, and CL_{ij} is a dummy variable if both countries share a common official language. Explanatory variables other than $\ln RGDP_i$ and $\ln RGDP_j$ take the same form as in equation (6).

Ⅲ-3 Data

The data used for the estimation are described briefly as follows. The nominal bilateral trade values of the sector of photovoltaic cells (in 1,000 US dollars) for 51 trading countries are taken from the Global Trade Atlas online data, providing customs trade data reported by the government of each country. The data of each country are examined in order to exclude the data for light emitting diodes from HS 854140 data. In cross-section analysis, zero trade flows are excluded, and in panel analysis, these are excluded from the data set if all of the five years' data are zero. The data source of bilateral tariffs of photovoltaic cells in all five years for each country is the WTO Tariff Download Facility.

Nominal GDP (in 1,000 US dollars), real GDP (in 1,000 US dollars), and nominal GDP per capita (in 1,000 US dollars) are taken from the World Bank's World Development Indicators. Trade data of photovoltaic cells are scaled by GDP deflators to generate real trade flows for the panel analysis. The data of bilateral distance between capitals of the pair countries (in kilometers) and common official language are from the CEPII (Centre d'Etude Prospectives d'Informations Internationales) database. Data of GDP and GDP per capita for Taiwan are from the JETRO database originally from Directorate-General of Budget, Accounting and Statistics, Executive Yuan, Republic of China (Taiwan).

Table 2　List of countries in the analysis

APEC	Europe	Other countries
Australia	Austria	Brazil
Canada	Belgium	India
Chile	Bulgaria	South Africa
China	Croatia	Turkey
Hong Kong	Cyprus	
Indonesia	Czech Republic	
Japan	Denmark	
South Korea	Estonia	
Malaysia	Finland	
Mexico	France	
New Zealand	Germany	
Peru	Greece	
Philippines	Hungary	
Russia	Ireland	
Singapore	Lithuania	
Taiwan	Malta	
Thailand	Italy	
USA	Norway	
Vietnam	Netherlands	
	Poland	
	Portugal	
	Romania	
	Slovakia	
	Slovenia	
	Spain	
	Sweden	
	Switzerland	
	UK	

The list of 51 countries included in this analysis is shown in Table 2. All APEC countries except Brunei Darussalam and Papua New Guinea are included, along with 28 European countries, and Brazil, India, South Africa, and Turkey, which are significant newly industrialized countries.

Table 3(a) and 3(b) presents the descriptive statistics of the variables used in cross-section analysis and panel analysis respectively. As the zero trade flows are excluded from trade data in cross-section analysis, it is clear from the trade enlargement of the sector of photovoltaic cells from 2000 to 2004 that the observations of non-zero trade are increasing year by year. In panel analysis, the trade flows of the country-pairs with at least one non-zero trade in the five years' data are included, as indicated earlier.

Ⅳ. Empirical Results

This section presents estimation results of the gravity analysis for the sector of photovoltaic cells. In Ⅳ-1, the results of cross-section analysis are presented and in Ⅳ-2, those of panel analysis are reported.

Table 3

Table 3(a) Descriptive Statistics(Cross Section)

		ln(EXPORTij)	ln(GDPi)	ln(DGDPPCij)	ln(DIST)	ln(1+TARIFFij)	APECij	CLij
2000	Observations	899	899	899	899	899	899	899
	Mean	4.799	19.812	9.109	8.190	0.013	0.176	0.133
	Std.Dev.	2.563	1.534	1.222	1.135	0.039	0.381	0.340
	Max	12.107	23.054	10.519	11.700	0.182	1	1
	Min	0.693	15.191	3.176	4.088	0.000	0	0
2001	Observations	951	951	951	951	951	951	951
	Mean	4.851	19.777	9.074	8.214	0.012	0.198	0.126
	Std.Dev.	2.549	1.430	1.174	1.131	0.036	0.398	0.332
	Max	12.177	23.087	10.514	11.700	0.182	1	1
	Min	0.077	15.181	2.853	4.088	0.000	0	0
2002	Observations	1027	1027	1027	1027	1027	1027	1027
	Mean	4.772	19.848	9.171	8.189	0.010	0.187	0.124
	Std.Dev.	2.610	1.401	1.206	1.141	0.034	0.390	0.329
	Max	12.554	23.119	10.641	11.700	0.182	1	1
	Min	0.693	15.273	2.256	4.088	0.000	0	0
2003	Observations	1075	1075	1075	1075	1075	1075	1075
	Mean	4.854	19.964	9.363	8.195	0.009	0.173	0.126
	Std.Dev.	2.644	1.447	1.135	1.141	0.034	0.378	0.332
	Max	12.806	23.167	10.793	11.700	0.182	1	1
	Min	0.693	15.449	3.546	4.088	0.000	0	0
2004	Observations	1126	1126	1126	1126	1126	1126	1126
	Mean	5.108	20.074	9.459	8.206	0.008	0.164	0.123
	Std.Dev.	2.677	1.395	1.100	1.143	0.032	0.371	0.329
	Max	13.103	23.231	10.918	11.700	0.182	1	1
	Min	0.693	15.546	3.757	4.088	0.000	0	0

Table 3(b) Descriptive Statistics (Panel)

	ln(Real EXPORTij)	ln(Real GDPi)	ln(1+TARIFFij)
Observations	7775	7775	7775
Mean	3.149	19.787	0.011
Std.Dev.	3.131	1.448	0.036
Max	13.160	23.263	0.182
Min	−1.068	15.544	0.000

Ⅳ-1 Estimation Results for Cross-Section Analysis

Table 4 shows the results in the cross-section analysis for the estimation of equation (6) using OLS for the sector of photovoltaic cells. In this table, the results of the four cases are shown with different specifications, for each of five years. Case 1 and case 2 are estimated for the comparison of the results with and without tariffs as the explanatory variable. Case 3 is the specification including all the variables, and case 4 excludes only the difference of GDP per capita between country pairs because of its comparatively low statistical significance. Adjusted R-squared is highest in case 3 in the results of all years with the values between 0.332 and 0.361. Those are low as compared to the estimation results of the gravity analysis with entire trade or manufacturing trade as independent variable. In the results of gravity analysis for transport equipment and electric machinery sector in Ando and Kimura (2013), adjusted R-squared is shown with the values between 0.5 and 0.6 in many cases. Because this analysis focuses only one item of photovoltaic cells sector, adjusted R-squared is even lower. In case 4, all the coefficients are statistically significant at the 1% level except that of bilateral tariff rates in 2002, which is significant at the 5% level.

Table4　Estimation Results (Cross-Section Analysis)

	Equation(4) 2000				Equation(4) 2001				Equation(4) 2002			
	case1	case2	case3	case4	case1	case2	case3	case4	case1	case2	case3	case4
Constant	−18.048 ***	−18.206 ***	−17.284 ***	−18.316 ***	−19.090 ***	−19.321 ***	−18.780 ***	−19.521 ***	−20.697 ***	−20.678 ***	−19.838 ***	−20.705 ***
	(−12.484)	(−12.577)	(−12.338)	(−14.037)	(−13.673)	(−13.787)	(−13.886)	(−15.315)	(−14.746)	(−14.688)	(−14.528)	(−15.950)
ln(GDP$_i$)	0.756 ***	0.756 ***	0.739 ***	0.730 ***	0.807 ***	0.809 ***	0.809 ***	0.803 ***	0.824 ***	0.823 ***	0.808 ***	0.804 ***
	(14.665)	(14.728)	(15.047)	(14.776)	(16.145)	(16.213)	(16.786)	(16.583)	(16.322)	(16.244)	(16.547)	(16.334)
ln(GDP$_j$)	0.668 ***	0.665 ***	0.638 ***	0.638 ***	0.662 ***	0.666 ***	0.649 ***	0.647 ***	0.738 ***	0.732 ***	0.700 ***	0.700 ***
	(14.158)	(14.117)	(14.139)	(14.018)	(14.267)	(14.354)	(14.469)	(14.371)	(16.153)	(15.997)	(15.627)	(15.548)
ln(GDPPC$_{ij}$)	−0.158 ***	−0.146 **	−0.143 **		−0.121 **	−0.110 **	−0.107 *		−0.145 ***	−0.137 ***	−0.114 **	
	(−2.624)	(−2.396)	(−2.412)		(−2.024)	(−1.821)	(−1.834)		(−2.758)	(−2.574)	(−2.277)	
ln(DIST$_{ij}$)	−0.450 ***	−0.431 ***	−0.484 ***	−0.494 ***	−0.468 ***	−0.456 ***	−0.529 ***	−0.540 ***	−0.483 ***	−0.474 ***	−0.532 ***	−0.544 ***
	(−7.183)	(−6.858)	(−7.864)	(−8.035)	(−7.678)	(−7.488)	(−8.760)	(−8.993)	(−8.236)	(−8.098)	(−9.136)	(−9.430)
ln(1+Tariff$_{ij}$)		−5.842 ***	−5.290 ***	−5.591 ***		−6.063 ***	−5.386 ***	−5.584 ***		−4.496 **	−3.971 **	−4.245 **
		(−3.278)	(−2.896)	(−3.078)		(−3.321)	(−2.896)	(−3.099)		(−2.373)	(−2.097)	(−2.249)
CLij			1.004 ***	1.063 ***			1.125 ***	1.152 ***			1.287 ***	1.323 ***
			(4.666)	(5.070)			(5.673)	(5.851)			(6.504)	(6.724)
APj			1.268 ***	1.227 ***			1.058 ***	1.040 ***			1.062 ***	1.049 ***
			(5.649)	(5.523)			(5.541)	(5.486)			(5.507)	(5.468)
Adjusted R^2	0.274	0.281	0.345	0.341	0.292	0.298	0.345	0.355	0.297	0.300	0.361	0.359
Observations	899	899	899	899	951	951	951	951	1027	1027	1027	1027

	Equation(4) 2003				Equation(4) 2004			
	case1	case2	case3	case4	case1	case2	case3	case4
Constant	−17.871 ***	−18.156 ***	−17.216 ***	−18.853 ***	−19.887 ***	−19.991 ***	−19.239 ***	−20.882 ***
	(−11.778)	(−11.972)	(−11.842)	(−13.969)	(−13.454)	(−13.618)	(−13.358)	(−15.463)
ln(GDP$_i$)	0.763 ***	0.765 ***	0.753 ***	0.757 ***	0.826 ***	0.825 ***	0.808 ***	0.809 ***
	(14.393)	(14.472)	(14.684)	(14.642)	(16.153)	(16.210)	(16.173)	(16.036)
ln(GDP$_j$)	0.681 ***	0.688 ***	0.652 ***	0.662 ***	0.708 ***	0.712 ***	0.689 ***	0.696 ***
	(14.668)	(14.835)	(14.336)	(14.556)	(15.862)	(15.979)	(15.614)	(15.685)
ln(GDPPC$_{ij}$)	−0.202 ***	−0.191 ***	−0.168 ***		−0.194 ***	−0.192 ***	−0.174 ***	
	(−3.519)	(−3.344)	(−3.085)		(−3.326)	(−3.300)	(−3.027)	
ln(DIST$_{ij}$)	−0.484 ***	−0.476 ***	−0.547 ***	−0.574 ***	−0.483 ***	−0.443 ***	−0.496 ***	−0.517 ***
	(−8.091)	(−7.969)	(−9.271)	(−9.833)	(−7.793)	(−7.607)	(−8.495)	(−8.903)
ln(1+Tariff$_{ij}$)		−6.927 ***	−6.474 ***	−6.738 ***		−7.616 ***	−7.343 ***	−7.399 ***
		(−4.106)	(−3.670)	(−3.811)		(−4.521)	(−4.198)	(−4.169)
CLij			0.756 ***	0.806 ***			0.673 ***	0.698 ***
			(3.558)	(3.863)			(3.293)	(3.419)
APj			1.501 ***	1.495 ***			1.285 ***	1.291 ***
			(7.555)	(7.542)			(6.618)	(6.685)
Adjusted R^2	0.276	0.283	0.345	0.341	0.281	0.289	0.332	0.327
Observations	1075	1075	1075	1075	1126	1126	1126	1126

Note: t values are in parentheses .
***: significant at the 1% level; ** at 5% level; * at 10% level.

The main findings of cross-section analysis of each of five years can be summarized as follows. At first, the coefficient estimates for GDPs in both exporting and importing countries are positive and statistically significant at the 1% level, and the former is bigger than the latter in all the cases for all the years. The coefficients of GDPs in exporting countries take values in the range of 0.73–0.82, and those in importing countries are in the range of 0.64–0.71, suggesting that an increase in a country's GDP will lead to a less-than proportional increase in its imports and exports.

The coefficients of the difference between two countries' GDP per capita are always negative and significant at the 1% level in the more recent years of 2003 and 2004, and significant at the 5 % level in 2000 and 2002. Also, the absolute values of these coefficients are bigger in 2003 and 2004 than those of the earlier years, with 0.168 and 0.174 respectively in case 3. This suggests that trade is accelerated between countries with similar patterns of factor endowment, reflecting that trade in the sector of photovoltaic cells can be explained by a new trade theory based on monopolistic competition with differentiated goods, and contradicts the prediction of the traditional Heckscher-Ohlin theory of trade. Furthermore, this tendency is strengthened in 2003 and 2004.

The coefficients for distance are negative as expected and statistically significant in all cases for all years. If we focus on the estimates in case 4, the absolute values of these coefficients are relatively small in 2000 with 0.49, but after 2001 those absolute values tended to increase, with nearly 0.54 in 2001 and 2002, 0.57 in 2003, suggesting that the country pairs with a shorter distance tended to increase trade more than in 2000. In 2004, however, the effect of the distance on trade decreased slightly to 0.52 in case 4.

The coefficients for bilateral tariff rates are negative as expected and statistically significant at the 1% level except those in 2002, which are negative and statistically significant at the 5% level. Also, the absolute value of the coefficient in 2002 is smallest with 4.245 in case 4, but this increased to 6.738 and 7.399 in 2003 and 2004 respectively. Hayakawa (2011) shows that the absolute value of the estimate of the coefficient of bilateral tariff rate in the analysis of manufacturing trade is nearly 4, which can be considered a reasonable size considering the theoretical model of the gravity equation based on the horizontal differentiation using CES utility function.[5)] Since the adjusted R-squared is higher in case 2 as compared to case 1 for all years, the importance of bilateral tariff rate in the specification of the gravity equation for the sector of photovoltaic cells can be clarified.

The coefficient of the dummy variable for common official language in the photovoltaic cells is statistically significant in all cases of all years. If we focus on case 4, the coefficient value increased until 2002, with 1.063 in 2000, 1.152 in 2001, and 1.323 in 2002. On the other hand, the coefficient reduced after 2003, with 0.806 in 2003 and 0.698 in 2004. Contrary to the results for the dummy variable for common official language, the effects of the dummy variable for the APEC bloc are higher in 2003 and 2004 with 1.495 and 1.291 respectively, as compared to this effect in 2001 and 2002 with 1.040 and 1.049 respectively, in case 4. The coefficient estimate for 2004, 1.291 suggests that on average, two APEC members trade photovoltaic cells about 3.3 times as much as other country pairs. Surprisingly, this estimate of 1.29 is the same value estimated by Frankel (1997) for the APEC bloc dummy variable in the gravity model for 1992, including the effects of prospective trading blocs shown in Table 4–3 of Frankel (1997).

Ⅳ-2 Estimation Results for Panel Analysis

Table 5 reports the estimation results of the panel analysis of the gravity equation for the trade of photovoltaic cells among 51 countries. The regression results for the fixed effects model according to equation (7) are shown in the first column and those for the pooled cross-section model estimated according to equation (8) are shown in the second column. In panel analysis, the variables of exports and GDP are in real values instead of nominal values used in the cross-section model. The fixed effect model is preferable to pooled cross-section model as explained in section Ⅲ, but pooled cross-section model is also estimated to verify the robustness of the results for cross-section analysis of each year.

Regarding the estimation results for the fixed effects model of equation (7), adjusted R-squared is highest in this analysis with 0.754, and the signs of the coefficient of the exporting country's real GDP and bilateral tariff rates are as expected and are statistically significant. The negative coefficient on the importing country's real GDP is not as expected, although it is not statistically different from zero. In the fixed effects model, by allowing for trading-pair heterogeneity,

Table 5　Estimation Results (Panel Analysis)

	Fixed Effects		Pooled Cross-Section	
	2000-2004		2000-2004	
Constant	-24.662	***	-25.790	***
	(-4.002)		(-43.949)	
$\ln(GDP_i)$	1.558	***	1.005	***
	(5.898)		(49.967)	
$\ln(GDP_j)$	-0.165		0.727	***
	(-1.423)		(37.594)	
$\ln(DIST_{ij})$			-0.693	***
			(-26.132)	
$\ln(1+Tariff_{ij})$	-4.973	***	-6.304	***
	(-3.659)		(-36.604)	
CL_{ij}			1.281	***
			(13.827)	
AP_{ij}			1.331	***
			(16.344)	
Time Dummies				
2001	0.132	***	0.117	
	(13.145)		(1.307)	
2002	0.264	***	0.214	**
	(11.881)		(2.388)	
2003	0.380	***	0.341	***
	(11.522)		(3.799)	
2004	0.627	***	0.569	***
	(13.098)		(6.332)	
Country Pair	YES		—	
Adjusted R^2	0.7544		0.363	
Observations	7775		7775	

Note: t values are in parentheses .
***: significant at the 1% level; ** at 5% level; * at 10% level.

the estimated coefficient for bilateral tariff rates, in absolute value, is smaller than that in the pooled cross-section model, representing the value of 4.97 consistent with the results in Hayakawa (2011). On the other hand, the estimated coefficient of real GDP of exporting country and the estimated role of globalization in the fixed effects model are bigger than in the pooled cross-section model. An increase in a country's real GDP by 1% leads to increasing its exports by 1.5%, and globalization effect shown by year dummies has increased the real volume of trade by 63% between 2000 and 2004, according to the definition of Cheng and Wall (2005).

For the results of the pooled cross-section model, the signs of all the coefficients of the included explanatory variables are as expected and are statistically significant, except the time dummy of 2001. According to the estimates of the pooled cross-section model, the following major findings can be clarified. Firstly, an increase in a country's real GDP leads to an approximately proportional increase in its real exports, and less than proportional increase in its real imports. Secondly, the estimated coefficient for bilateral tariff rates is −6.304 showing a strong effect. Thirdly, the estimated coefficient on the log of distance is −0.693, which means that when the distance between two countries is increased by 1.0 percent, trade between them falls by about 0.69 percent. Fourthly, regarding the estimate of the coefficients on the dummy variables, that for a common language is 1.28, which implies that two countries sharing an official linguistic link tend to trade 3.6 times as much as two otherwise similar countries and the estimated coefficient on the dummy for the APEC bloc is 1.33, which implies that two of the APEC countries trade 3.8 times as much as two otherwise similar countries.[6] Accordingly, the effects of common official language and APEC bloc can be thought to be quite similar. Lastly, the year dummies are statistically significant except in 2001, and this implies the common trend toward greater real trading volumes, independent of the sizes of the economies. As Cheng and Wall (2005) define these year dummies as an indicator of the extent of globalization, globalization seems to be an important factor for trade growth of photovoltaic cells.

Ⅴ. Conclusions

This paper investigated the importance of reduction of bilateral tariff rates on trade of one of the representative environmental industries for renewable energy, the sector of photovoltaic cells, in order to assess efforts for tariff reduction for environmental goods among APEC countries and the WTO. Three potential contributions of the study can be clarified as follows. Firstly, the bilateral trade flow data in the sector of photovoltaic cells have been sorted using detailed data among 51 countries, as well as the bilateral tariff rates of photovoltaic cells from WTO data. Secondly, the gravity model has been shown very useful in estimating trade flows in the photovoltaic cells sector by using cross-section data, including difference between per capita income of exporting and importing countries, as well as bilateral tariff rates. Bilateral tariff rates systematically affected the trade flows in all the years between 2000 and 2004, and the trade flows of photovoltaic cells are supposed to be explained by the new trade theory based on monopolistic competition with differentiated goods, since the country pairs with less difference of GDP per capita trade more actively, allowing the difference of GDP capita to be a proxy of difference of factor endowment. Thirdly, using the fixed effect model with panel data by allowing trading-pair heterogeneity, this study showed the strong systematic effect of bilateral

tariff rates on the trade flows, and also the trade increase in the photovoltaic cells sector resulting from the globalization effect.

Although many countries abolished tariffs on photovoltaic cells in the end of the 1990s, the results of this analysis shows that the remaining tariffs in BRICs countries and Chile were clear trade impediments in the first half of the 2000s in this sector. The analysis suggests that further tariff reductions are important to activate trade flows of environmental goods among the covered countries, whether developed or newly industrialized countries. The current efforts of tariff reduction of various kinds of environmental goods with different environmental purposes in APEC and WTO are important for trade increase and environmental protection through worldwide diffusion of those goods.

Further research estimating the determinants of trade flows of various environmental goods is required to consolidate the effects of bilateral tariff rates in those goods. In particular, a gravity analysis of environmental goods having similar purposes as photovoltaic cells for electricity generation from renewable resources, such as electric generating sets for wind-power (HS850231), would be necessary for comparing results with those derived from the analysis for photovoltaic cells.

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Notes

1) The author has been published the papers on the empirical analysis using gravity model for trade in environmental goods, emphasizing the importance of trade of environmental goods on environmental protection. See Matsumura (2014a), (2014b), (2015), and (2016).
2) The selected countries are indicated in Table 2.
3) Baier and Bergstrand (2001) review how the researchers have expressed the intrinsic qualities of the gravity model in international trade.
4) Bergstrand (1989) introduces generalized gravity equation based on factor-proportions theory and monopolistic competition theory.
5) Theoretically, the coefficient of bilateral tariff rate in the gravity equation can be shown as 1- σ, where σ is elasticity of substitution among varieties. Concerning the value of σ, Hayakawa (2011) refers the value in the range of 5 to 10 concluded by Anderson and van Wincoop (2004).
6) The exponential of 1.28 is equal to 3.60, and the exponential of 1.33 is equal to 3.78.

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