Energy Policy 46 (2012) 308–318

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Understanding cross-national trends in high-tech renewable power equipment exports to the United States ☆

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ARTICLE INFO

Article history:
Received 10 October 2011
Accepted 26 March 2012
Available online 21 April 2012

Keywords:
Renewable power
International trade

ABSTRACT

We track US imports of advanced technology wind and solar power-generation equipment from a panel of countries during 1989–2010, and examine the determining factors including country size, sector-specific US FDI outflow, and domestic wind and solar power generation. Differentiating between the core high-tech and the balance of system equipment, we find US imports of both categories have grown at significantly higher rate from the relatively poorer countries, and particularly China and India. Larger countries are found to be exporting significantly more, and US FDI is found to play a significant positive role in the exports of high-tech equipment for the poor countries. For the core wind and solar high-tech equipment, we find domestic renewable power generation of the exporting countries also played a significant positive role.

1. Introduction

The energy sector is by far the single largest contributor of carbon emissions, and worldwide efforts have emphasized the development and deployment of clean energy from renewable sources like wind and solar. There is, however, an ongoing debate about the economic feasibility of these nascent technologies, due to the widespread reliance on government subsidies to develop this sector. Optimists foresee large learning-by-doing effects as average cost declines with cumulative experience (Duke and Kammen, 1999). Pessimists point to the large subsidies these industries receive and argue that purely based on power generated per dollar invested that the returns are quite low (Lesser, 2010). In the United States, the Department of Energy has been heavily criticized for its loan guarantees for the solar firm Solyndra in 2011.[1] Critics have argued that while well intentioned that the government does not have the expertise to "pick winners".

In a world where we have not adopted the first best policies such as a carbon tax for reducing carbon emissions, the developed nations as well as developing countries are stepping up and seeking to produce a larger share of their power from renewable sources. Achieving the "green economy" goals would be cheaper, if the cost of producing renewable power declines. Global international trade is likely to play an important role in accelerating innovation and cost reduction in green technology.

"Clean trade" between developing nations and rich nations is rarely discussed, but in this paper we document the growth in such trade and explore the micro foundations for why developing countries like China and India might have a comparative advantage in certain export goods that are required for producing wind turbines and solar panels. Given that the world is unwilling to price carbon, the green economy's chance to flourish is more likely to take place if international trade lowers the quality-adjusted price of renewable power equipment.

We examine the pattern of exports of advanced technology renewable energy equipment from a panel of developed and developing countries to the US from 1989 through 2010, a period marked by liberalization and rising FDI in developing countries, particularly China and India.[2] We choose the US import market, since the US ranks among the leading nations in terms of both cutting-edge technologies in the field as well as trade and size of the domestic market; thus, products entering the market require quality-conformity. We find that developing countries have eroded the developed countries' shares in the US import market during the last two decades.

In the case of "green energy" trade, the poorer South is emerging as a key provider of cheap equipment for renewable-power

☆ This paper was written while Sawhney was a Visiting Scholar at the UCLA Institute of Environment and the Luskin Center for Innovation. We thank the Luskin Center for research support. We thank two anonymous reviewers for their comments.

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[1] In 2009, Solyndra, a California-based thin-film solar panel maker was awarded a federal loan of $535 million, but in September 2011 the company filed for bankruptcy. "In a Rush to Assist a Solar Company, U.S. Missed Signs", New York Times, page A1, September 23, 2011.

[2] China and India implemented major economic and trade reforms in 1991–1992.

0301-4215/$ - see front matter
http://dx.doi.org/10.1016/j.enpol.2012.03.066

generation to the rich North for its production and consumption of clean energy. If clean energy prices decline then they are more likely to induce a composition shift as nations choose to substitute them for fossil fuel generated electricity (i.e., coal and natural gas). Such a composition shift could significantly reduce national greenhouse gas emissions associated with power generation.

In examining US imports of wind and solar power generation equipment, we distinguish between imports from relatively rich and poor countries, and then compare the trend growth of China and India against the benchmark of these country groups. We test whether sector-specific US FDI and home market size – measured in terms of aggregate economic size and size of renewable electricity production – can explain the observed time trends. We find that domestic renewable power generation played a significant role in the export of core high-tech wind and solar equipment, and for the poor countries US sector-specific FDI has also been a significant determinant of export growth.

Our paper contributes to the growing literature on international technology transfer related to climate change mitigation from the developed to the developing countries (Popp et al., 2009; Driesen and Popp, 2010),[3] and trade in renewable energy technologies (Constantini and Francesco, 2008). Here we consider growing wind-solar power equipment exports to the US as an indicator of clean technology diffusion. The leading sources of renewable energy technology in the world today, especially in wind and solar technology, are the industrialized countries of Germany, Japan, United States and Denmark — where cutting-edge technology is rapidly evolving as evident in their vigorous patenting activity.[4] Among the different renewable energy forms, wind and solar have been the fastest growing power-generation technologies in the last 20 years, with the largest grid-connected installed capacities in countries like the US, China, Germany, Italy, Japan, Spain and India in wind and solar photovoltaic (REN21, 2010). The growth of the renewable power-generation sector has taken place with policy support in all the countries, and with foreign technology-dependence in the emerging economies. Thus the persistent growth of green-technology exports from developing countries signifies the increasing production re-location from the developed countries and the growth of the domestic renewable power sector.

There is a certain irony that trade with developing countries is accelerating the development of the "green economy". The trade and environment literature has studied the conditions such that poor nations would be pollution havens for rich countries as dirty factories could escape tight regulation in rich countries by re-locating to poorer nations (Copeland and Taylor, 2003, 2004). This literature emphasizes that the location of dirty economic activity will be determined by both factor endowments and regulatory intensity.

The rest of the paper is organized as follows: Section 2 gives a brief description of the US imports of wind and solar high-tech power generation equipment during the last two decades; Section 3 outlines the hypotheses and the basic regression specification; Section 4 summarizes the series of regression results; and Section 5 concludes.

2. US imports of wind and solar power generation equipment

For our analysis of US imports of wind and solar power generation equipment, we identify a total of 27 products at 10-digit HTS codes based on energy equipment mapping of the USITC and ICTSD (see the appendix for details of concordance with renewable energy components).[5] The selected equipment in our analysis is a subset of the list of environmental goods being negotiated under the Doha Round of the current WTO negotiations.[6] We classify five of these products as core high-technology equipment and 22 products as balance of system equipment. Among our core high-technology equipment, *wind turbine* is a final product, while *blade* and *hub* are components of wind turbines, and *solar photovoltaic cells* are components of *solar modules*. The balance of system equipment also includes high-technology components (like anemometer, clutch, gearbox, rectifier, etc.) which have multiple-use other than renewable energy production.[7] All the equipment are components of the overall power generation system.

In selecting the products we will study, we exclude other components such as glass, lead-acid batteries, wires, switches, etc, since even at the 10-digit HTS classification it is difficult to delineate the high-quality products which would be utilized in the wind/solar power generation system. More importantly, it allows us to minimize the inclusion of multiple-use balance of system equipment that are imported for purposes other than renewable electricity generation; and also preclude products where innovation is not high. The total value of US import (from the rest of the world) of our selected renewable energy equipment increased from US$0.8 billion in 1989 to US$9.4 billion in 2010 (constant 2000$), with a higher growth in the core high-tech equipment (see Table 1).

Our choice of 24 countries covers a diverse range of developed and emerging countries exporting the subset of products covered here. These countries together accounted for more than 90% of US imports by value in each of the 27 10-digit HTS products for most of the years during the period considered. The country shares in the US import of the core high-tech products in the start and end points of the period of analysis are depicted in Table 2.

Among the developing countries, the share of China in US imports of core wind and solar energy equipment, including solar panels, cells, and blades have steadily increased, while Japan, Germany, United Kingdom have experienced a substantial erosion in their shares in the US market. India, on the other hand, experienced a more significant growth in wind turbines. The growth of exports from developing countries has been significantly higher than from the developed countries as we show later. It is important to note here that the significantly higher trend growth of US imports in high-tech wind and solar power equipment from the poor countries (and particularly China and India) compared to rich developed countries holds true even when we "deflate" the renewable equipment imports by the total imports from each of these countries.

[3] Much of the focus has been on Clean Development Mechanism (CDM) projects where technology diffusion has occurred without policy prescriptions, being driven instead by firms seeking to lower production costs (Popp, 2011). Inter-country CDM comparisons show that strong economic growth and domestic technological capabilities have been important for countries like China and India, while involvement of foreign partners have been more important for countries like Brazil and Mexico (Dechezleprete et al., 2009).

[4] Overall solar and wind power and hydrogen and fuel cell technologies have witnessed the most substantial increases in patent applications, both in terms of numbers and shares in total alternative energy filings at the European Patent Office and through the Patent Cooperative Treaty (WIPO, 2009).

[5] Harmonized commodity description and coding system for tariff or HTS is maintained by the World Customs Organization and used worldwide for classifying traded commodities. While codes up to 6-digits are set internationally, individual countries are allowed to assign additional 2 or 4 digits for additional subcategories.

[6] In the Doha negotiations, the environmental goods are specified at 6 digit-HS 2002 codes. The equipment analyzed in our paper correspond to 13 of these products under negotiation namely 730820, 841290, 848340, 848360, 850161, 850162, 850163, 850164, 850231, 850300, 850440, 854140, and 902680 (Annex IIA of WTO (2011). Since our 27 products are at a more disaggregated level of 10-digit US HS codes, several disaggregated products often correspond to a single 6-digit good.

[7] This issue has made the negotiations on environmental goods rather challenging, since many of the products have dual-use completely unrelated to environment. See Steenblik (2005).

Table 1
US imports of high-tech wind/solar electricity equipment (in million constant US$, base 2000).

Category of renewable energy equipment	1989	1995	2000	2005	2010
Core high-tech wind/solar equipment	48	121	313	1250	4200
Balance of system equipment	745	2580	3130	3800	5210
Total US import value of 27 wind and solar equipment	793	2701	3443	5050	9410

Core high technology equipment does not include obsolete HS codes after concordance. Since several HTS codes have changed during the period of analysis here, we use the concordance between obsolete and new codes for continuity. See the data appendix for details. However for the core renewable energy equipment the obsolete codes corresponding to the early years are not included. For example, until 1995, wind powered generator sets were included of HTS 8502300000 "other generator sets, not elsewhere specified", and since 1996 a new HTS code of 8502310000 was adopted. Since the obsolete code contained gen sets other than wind-powered, we consider only the newer code under core renewable energy equipment.

Table 2
Country Shares in US Imports (by real value) of High-Tech Core Wind and Solar Equipment, 1989 and 2010.[a]

Country	Blades		Wind turbines		Hub & drive		Solar modules		Solar cells	
	1989	2010	1996[b]	2010	1995[b]	2010	1989	2010	1989	2010
Australia	0.23	0.02	0.00	0.00	0.00	0.51	1.17	0.01	22.29	0.05
Brazil	0.27	24.31	0.00	0.05	10.19	1.76	0.00	0.00	5.30	0.00
Canada	13.06	5.33	0.20	0.69	12.35	10.31	0.16	0.09	0.48	0.07
China	0.97	7.22	0.04	0.39	0.12	12.70	0.04	43.72	0.00	13.75
Denmark	1.13	10.72	95.37	45.92	2.02	1.94	0.00	0.00	0.19	0.00
France	1.29	1.30	0.00	0.01	4.83	0.73	0.00	0.01	0.19	0.04
Germany	31.29	14.37	0.43	7.55	19.48	9.51	0.88	1.87	5.13	24.14
Hong Kong	0.01	0.04	0.00	0.00	0.00	0.02	1.62	0.15	0.29	0.01
India	0.00	9.74	0.00	10.04	0.52	1.13	0.79	0.95	0.00	0.72
Indonesia	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
Italy	2.77	0.61	0.00	2.48	2.58	1.02	0.01	0.02	0.10	0.07
Japan	10.45	3.59	0.23	17.29	18.01	9.64	53.59	10.99	25.14	2.08
Korea, South	0.10	1.37	0.00	0.23	0.45	2.38	0.00	0.42	0.00	2.25
Malaysia	0.00	0.02	0.00	0.00	0.08	0.00	0.00	5.44	31.14	0.03
Mexico	0.12	8.69	0.00	0.06	3.66	35.67	34.74	23.36	7.31	0.31
Netherlands	3.42	0.47	0.00	0.06	0.11	1.12	0.00	0.11	0.01	0.01
Philippines	0.00	0.09	0.00	0.00	0.00	0.00	0.00	5.59	0.00	1.16
Singapore	3.06	0.22	0.00	0.00	0.00	0.17	3.23	0.06	1.23	18.26
Spain	0.67	4.14	0.00	11.41	0.00	2.93	0.00	0.12	0.00	0.07
Sweden	2.71	0.16	0.00	0.00	3.52	0.14	0.00	0.84	0.13	0.28
Switzerland	1.36	0.13	0.00	0.01	5.19	0.24	0.00	0.03	0.05	0.02
Taiwan	2.74	0.15	0.00	0.01	5.76	1.70	1.37	6.13	0.55	35.30
Thailand	0.00	0.04	0.00	0.00	0.00	0.28	0.00	0.00	0.06	0.00
United Kingdom	18.10	5.20	3.65	3.67	7.05	2.55	1.91	0.02	0.25	0.28
Total Share of the 24 countries in the US	93.74	97.92	99.91	99.89	95.94	96.67	99.52	99.92	99.84	98.90

[a] To reflect the country shares at the two end points of our period of analysis — note that the shares are smoothed over two years at each end point (e.g., share for 1989 is the average of the share over 1989 and 1990).

[b] For wind turbines and hub/parts since we consider only the revised HTS codes, hence the initial years correspond to later than 1989.

While there has been drastic loss of market share in the US among the erstwhile leading nations like Denmark, Germany, Japan, United Kingdom, they continue to maintain dominant shares (and in the case of wind-turbines there is a remarkable reversal of Denmark's trend beginning 2008) — reflecting the lead in innovating and high-value products from these countries.

3. US FDI outflow in the selected manufacturing sectors, 1988–2009

The US remains a leading source of outward-FDI in the world (UNCTAD, 2010), and for emerging countries like China and India as well.[8] Since we are interested in tracking the significance of US FDI in the US import of the green energy equipment, we track the investment outflows in four manufacturing sectors.[9] The annual sector-specific US FDI outflows across countries provide insights on how the pattern of investment has changed in the last two decades. For a cross-country time-series analysis, the data on sector-specific US FDI is available only at the 3-digit NAICS (and SIC 2-digit prior to 1999) from US Bureau of Economic Analysis.[10] Thus our analysis here pertains to horizontal FDI, and does not distinguish the portion of vertical FDI within these industries (that would be evident at higher disaggregation of 4-digit SIC, but is not available for our panel). The equipment imports associated with wind and solar power generation come from four manufacturing sectors: primary and fabricated metal (NAICS 331 and 332), machine

[8] Although for China, countries like Hong Kong and Taiwan appear to be the major FDI sources much of this is based on "round-tripping" for tax, financial and other institutional advantages. Similarly for India, Mauritius has long been documented as the largest source of FDI, even though it is due to the routing based on incentive to evade taxes.

[9] Of course US imports of high-technology power equipment from a country are also affected by FDI inflow into the latter from a third country. However, the time-series data on FDI-inflows from the rest of the world, classified by the four manufacturing sectors used here, is not available for all countries.

[10] However, some of the US FDI data by country and industry level are withheld to avoid disclosure of data of certain companies, thus leading to missing data for those years.

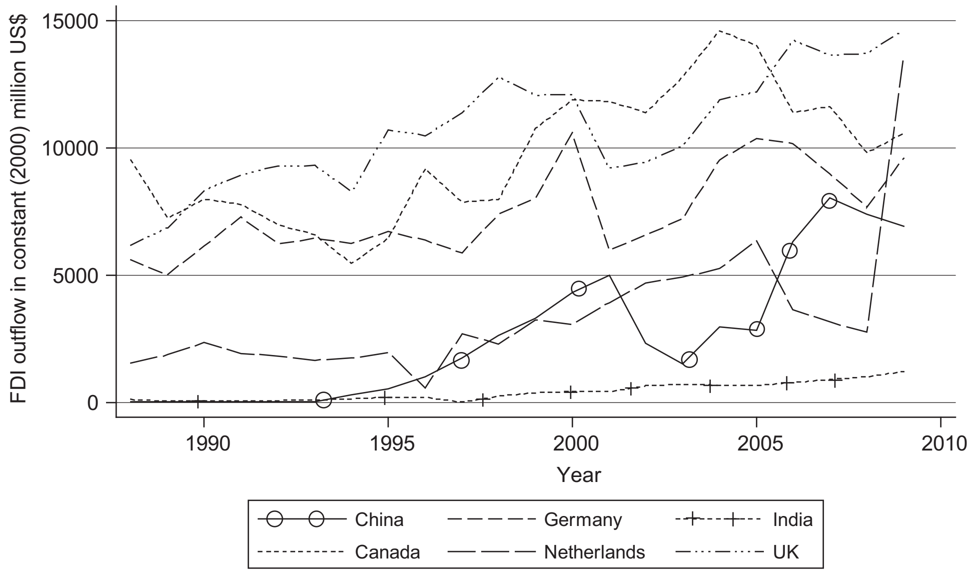

Fig. 1. Actual US FDI outflows in four sectors*, selected countries.

manufacturing (NAICS 333), electrical equipment (NAICS 335), and computer and electronic products (NAICS 334).[11]

Considering the US FDI outflows in these four sectors, the largest recipients continue to be the countries like Canada, Germany, and United Kingdom throughout the period of analysis. While Japan and Italy were among the high recipients in the initial years, they have receded in their ranks. Among the relatively poorer nations Brazil, Malaysia, Mexico, Singapore, Taiwan are among the high recipients of FDI in these manufacturing sectors. While both China and India were among the low recipients among the 24 countries considered, the US FDI flows to China have increased steadily. China now is among the top recipients of US FDI in these four sectors (especially since 2007). Fig. 1 shows that actual US FDI outflows in constant US$ (year 2000) in the four manufacturing sectors to China and India juxtaposed with the highest recipient countries in our panel.

A sector-wise distribution and pattern of US FDI abroad in the twenty-four countries during 1988–2009, indicates that, on the whole, US FDI outflow in the computer and electronic products witnessed the highest annual growth followed by metal and fabricated metal.[12] This pattern is true in both rich and poor countries. The only difference, however, is that US FDI outflow in machine manufacturing to the rich countries show a negative trend, but has been growing in the poor countries. Among our five core renewable equipment, two fall within the ambit of electrical machinery, two within electronic machinery manufacturing sector, and only one within the machine manufacturing sector. The concordance of FDI category (by NAICS codes) with the 10-digit HS codes of traded equipment that we use in our analysis is provided in Table A3 at the end of the paper.

4. Model specification

In order to estimate our trade regressions, we have merged together several different data sets. The US import data is taken from Robert Feenstra's trade database (1989–2006), and supplemented with data from the USITC online database for years 2007 through 2010. The US FDI data is taken from US Bureau of Economic Analysis. Price indices for deflation of import data and FDI are taken from US Bureau of Labour Statistics. Country-specific data on GDP and electricity from wind–solar–biomass–geothermal are from the IMF and World Bank database (see the Data appendix for details).

With products defined at the 10-digit US HTS code, our regression covers the components of wind- and solar-based power generation systems (but some like the wind-powered generator or solar photovoltaic panel and module are final products that are connected to other balance of system equipment). Our basic pooled regression model with country fixed-effects is given by the Eq. (1) below.

$$\begin{aligned}\log(\mathrm{Import}^{\mathrm{US}}_{ijt}) = {} & \alpha_j + D_1 + D_2 + \beta.t + \beta.t{*}D_1 + \beta.t{*}Poor + \beta.t{*}D_1{*}Poor \\ & + \beta.t{*}China{*}D_1 + \beta.t{*}India{*}D_1 + \gamma.\log(FDI_{k,j,t-1}) \\ & + \gamma.\log(FDI_{k,j,t-1})\text{interaction terms} \\ & + \delta\log(GDP_{j,t-1}) + \mu.\log(RenewElec_{j,t-1}){*}D_1 + \epsilon_{ijt},\end{aligned}$$

$$i = 1, \ldots, 27\text{products}; k = 1, \ldots, 4$$
$$\text{sectors}; j = 1, \ldots, 24\text{countries} \in \text{Group} = Rich/Poor \quad (1)$$

where, $Import^{\mathrm{US}}_{\mathrm{ijt}}$ is the US import of product i from country j in year t (t=1989 through 2010), α_j is the fixed effect for country j, D_1 is the dummy for core high-tech product, D_2 is the dummy for manufacturing sector in which product i is manufactured, t is the annual trend corresponding to year 1989 through 2010, *Poor* is the dummy for poor countries (other group of countries being *Rich*). *India* is the dummy for exports from India, *China* is the dummy for exports from China, $FDI_{k,j,\ t-1}$ is the lagged US foreign direct investment in manufacturing sector k (primary/fabricated metal; machine manufacturing; electrical equipment; or electronic products) which produces equipment i) in country j, $GDP_{j,t-1}$ is the lagged gross domestic product in constant US dollars, used as the proxy for economic size, $RenewElec_{j,\ t-1}$ is the lagged renewable electricity production (wind, solar, geothermal & biomass) in country j.

Our country-fixed effects controls for other country-specific determinants of high-technology export growth such as being endowed with a skilled labor force or time invariant government policy. Since we want to compare the export growth rates of

[11] US BEA reports the sector of computer and electronic products separately beginning 1999. For the period 1988–1998, FDI is reported together with the sector of electrical equipment. Thus for continuity in our sector-wise analysis, we consider the FDI in electrical equipment also to be the FDI for electronic products for the years up to 1998.

[12] The decline in electrical sector occurs due to re-classification of computer and electronic products as a separate sector beginning 1999.

China and India against the benchmark of the two groups of country, we include dummies for China and India in trend interactions. We also include a dummy for the product category (core vs balance of system equipment) and a dummy for the industrial sector to which the product belongs (fabricated metal, machinery, electrical, and electronic equipment). The explanatory variables appear with a lag of one year, to allow for the time to translate its impact through capital formation, production and finally export. Thus, each of the variables, namely US FDI in specific manufacturing sector (to which the export product belongs), total domestic output (GDP), and domestic renewable power generation appear with a time lag. To allow for a longer turnaround period for FDI inflow into trade, we also run a variant of the regression model in Eq. (1) with the lag period of FDI increased to 3 years.

In our regressions, we control for country group (*rich/poor*), category of product (core high-tech equipment and balance of system equipment) and cluster by country and year. To control for the countries, we classify our panel of 24 countries into two groups of *rich* and *poor*, using the median real GDP per capita of the panel of countries in 1989 as the dividing line.[13] The US FDI is matched with the industrial classification (at 2 digit SIC/3 digit NAICS) of the product being exported to the US (10 digit HTS code) to better reflect industry-specific impact in the host country.

5. Hypotheses

By estimating Eq. (1), we test three main hypotheses;

H1: Sector-specific US FDI elasticity of high-tech power generation equipment exports is positive.
H2: Larger country size leads to higher high-tech power-generation equipment exports.
H3: Home market effect in terms of wind-solar power is positive for the core high-technology renewable power generation equipment exports.

Following the FDI-trade literature, we expect US FDI to be an important determinant of exports of technology- and skill-intensive goods for both developed and developing countries. Empirics have shown that FDI flows serve as an important channel of technology diffusion, export and economic growth in the host countries (Barrell and Pain, 1997; Blomstrom and Kokko, 1997; Borensztein et al., 1998). More recently, Wang et al. (2007) and Buckley et al. (2002) found that higher FDI in China increased the development of new manufactures, and enhanced export intensities of domestic firms as well as foreign affiliates.[14] Today FDI (in the industrial sector) is considered to be the largest source of private, climate-mitigation relevant financial flows from developed to developing countries (OECD, 2009). Our hypothesis H1 provides a test of the export performance of developing countries in technologically sophisticated equipment to the US as an outcome of technology up-gradation largely as a result of sector-specific US FDI growth to these countries through the last two decades, against the benchmark of richer industrialized countries.[15]

Large countries tend to be large net exporters of goods in monopolistic competitive market set-up (Krugman, 1980), and there this home market effect is stronger in industries with more differentiated products and high transport cost (Hanson and Xiang, 2004). Trade in renewable technologies within the EU based on the gravity model also find higher income levels to be associated with higher trade flows (Constantini and Francesco, 2008). The hypothesis H2 here tests whether countries with larger income are able to export larger amounts of the high-tech manufactured equipment to the US (after controlling for country fixed effects, and inward-FDI).

The period of our analysis also marks the take-off period in the long-term diffusion of wind turbine and solar cell technologies.[16] During the last two decades, the global solar and wind industry grew rapidly. The highest installed capacity of renewable energy, in particular of wind power and solar PV, is the region of European Union followed by the US and Japan, due to the strong government policy initiatives (in 2005 the EU accounted for 74% of the global wind power production (WIPO, 2009: 28)). A growing market for grid-tied wind and solar PV has also emerged in China and India (REN21, 2010). In China, domestic manufacturing of wind turbines and components has matured through the years (spurred by government incentives and local content requirement), and some are optimistic enough to claim that wind power can become competitive with coal-generated power by 2015–2020 (Yu et al., 2009).[17] The growth of domestic wind and solar power equipment sector has been spurred by a range of government support mechanisms including financial/tax incentives, local content requirements, export credit assistance, quality certification and R&D, etc (Lewis and Wiser, 2007) in the developing countries. The significance of government policy support in the growth of the renewable sector in developing countries like China and India is now well-established (Ru et al., 2012; Schmid, forthcoming). The emerging industrialization of the renewable technology in the developing countries has in turn spurred exports. The inclusion of domestic renewable power generation (from wind and solar) as an explanatory variable in regression 6 to some extent controls for the effective renewable support policies enacted by the national governments. Moreover, it serves as a real variable that is comparable across all nations and for which data was available continuously over the time period (two decades. Under H3, we test the significance of the growth of wind- and solar electricity in the home countries (and the underlying policy promotion for renewable energy) in the export of such power-generating equipment to the US.

6. Empirical Results

Table 3 presents the regression results where FDI is lagged by 1 year. As the data on the explanatory variables is

[13] The rich countries include Australia, Canada, Denmark, France, Germany, Hong Kong, Italy, Japan, Netherlands, Sweden, Switzerland, and United Kingdom. The second group of countries below the median income (we call relatively poor countries) includes Brazil, China, India, Indonesia, South Korea, Malaysia, Mexico, Philippines, Singapore, Spain, Taiwan, and Thailand.

[14] The mechanism of technology diffusion work through backward and/or forward linkages of the operations of foreign affiliates in the host country, and becomes evident in plant-level productivity growth and FDI literature (Saggi, 2002, Keller, 2004).

[15] We expect that sector-specific FDI from third countries would positively affect home-country exports to the US. The omission of sector-specific FDI inflows from third countries, would give an upward bias to the estimated elasticity coefficient of US FDI.

[16] According to Jacobson and Lauber (2006) the take-off period of such tech-diffusion began in the 1990s.

[17] At the same time that China is ramping up its renewable power generation, 81% of China's power is generated using coal. China is sharply increasing its imports of coal and this has raised international coal prices. An unintended consequence of this is to nudge other nations to substitute away from coal to cleaner fuels (Wolak and Morse, 2010). Today, wind provides only a small share of China's total electricity. For details see http://www.esi.nus.edu.sg/portal/Portals/0/18032011/China_He_Gang.pdf.

Table 3
Log($Import^{US}$) regressions with country fixed-effects.

	1	2	3	4	5	6
Trend	0.0532***	0.0337***	0.0534***	0.0436***	0.0566***	0.0406***
	[0.0045]	[0.0080]	[0.0045]	[0.0092]	[0.0044]	[0.0112]
Trend* D_1	0.0855***	0.0851***	0.0843***	0.0867***	0.0844***	0.0676***
	[0.0120]	[0.0135]	[0.0118]	[0.0135]	[0.0127]	[0.0132]
Trend *Poor*	0.0410***	0.0149	0.0165*	0.0187	0.0290**	0.0242*
	[0.0097]	[0.0123]	[0.0097]	[0.0126]	[0.0128]	[0.0144]
Trend* *Poor** D_1	0.0214*	0.0273	0.0111	0.0114	0.0199	0.0095
	[0.0112]	[0.0236]	[0.0121]	[0.0239]	[0.0157]	[0.0272]
Trend**China*			0.1739***	0.0670***	0.1535***	0.0414
			[0.0130]	[0.0242]	[0.0182]	[0.0361]
Trend**China** D_1			−0.0145	0.0027	−0.0329	−0.0201
			[0.0174]	[0.0200]	[0.0211]	[0.0226]
Trend**India*			0.0881***	0.0262	0.0786***	0.0096
			[0.0145]	[0.0203]	[0.0178]	[0.0258]
Trend**India** D_1			0.1236***	0.1104***	0.1163***	0.0855***
			[0.0166]	[0.0170]	[0.0205]	[0.0209]
Log(FDI_{t-1})		0.3237***		0.3233***		0.2598***
		[0.0577]		[0.0577]		[0.0562]
log(FDI_{t-1})* D_1		−0.3716***		−0.3529***		−0.4755***
		[0.0550]		[0.0554]		[0.0640]
log(FDI_{t-1})**Poor*		0.2306***		0.2050***		0.2496***
		[0.0751]		[0.0770]		[0.0877]
log(FDI_{t-1})**Poor** D_1		−0.0686		−0.0535		−0.0013
		[0.0460]		[0.0451]		[0.0543]
Log(GDP_{t-1})		0.6641**		0.2081		0.464
		[0.2812]		[0.3567]		[0.4742]
Log($RenewElec_{t-1}$)* D_1						0.2600***
						[0.0338]
D_1	−1.4058***	1.1766***	−1.3861***	1.0247***	−1.2953***	−3.6794***
	[0.1487]	[0.3801]	[0.1453]	[0.3831]	[0.1593]	[0.7316]
D_2	0.1623***	0.0186	0.1563***	0.0231	−0.0065	−0.0859**
	[0.0432]	[0.0386]	[0.0429]	[0.0389]	[0.0433]	[0.0390]
Constant	12.0696***	1.4292	12.0693***	7.3094	12.5900***	4.7262
	[0.1294]	[3.5581]	[0.1258]	[4.5324]	[0.1328]	[6.1341]
Observations	9155	9155	9155	9155	7744	7744
R^2	0.2632	0.2959	0.2721	0.2983	0.2722	0.2978

The omitted category is the balance of system equipment from relatively rich countries (i.e. countries with greater than median GDP per capita in constant US$). Balance of system products include – towers, speed changers, gears, clutches, generators, rectifiers, inverters and anemometers, D_1=dummy for core high-tech products which include – blades, hub, wind turbines, solar modules and solar cells. D_2=dummy for manufacturing sector in which product *i* is manufactured, Figures in parentheses give the standard errors of the estimated coefficients.

*** Indicates significant at 1%.

** Significant at 5%

* Significant at 10%. The standard errors are clustered by country/year.

incomplete (due to Taiwan and Singapore) for our entire panel of countries (and years), we run our regressions (and test the hypotheses) in a staggered manner as we include additional explanatory variables that are not available for all countries.[18] Regressions 1 through 4 cover all 24 countries, while regressions 5–6 cover 22 countries.

Based on the results reported in columns, we find that the time trend growth in core high-tech equipment exports from the rich countries is substantially higher than that in the balance of system equipment (for e.g., 13.8% and 5.3%, respectively, in regression 1).[19] The poor countries experienced a higher trend growth rate (20.1% and 9.42% in core and balance of system equipment, respectively, in regression 1) than the rich countries in both categories of equipment.[20] All the regressions indicate that rich and poor nations enjoyed a faster trend growth in the core high-tech renewable power generation equipment than the non-core high-tech equipment.

Controlling for the US FDI in specific manufacturing sector and home market size (real GDP), we find that the trend growth rates reduce somewhat for both groups of countries and product categories. The trend growth rates dropped to 3.37% and 11.88% per year in the balance of system and core high-tech equipment, respectively, for both the rich and poor countries (see regression 2). Country size is found to be highly significant with elasticity of export at 0.66 (regression 2). The elasticity of US FDI is found to be positive for poor countries in both core and balance of system equipment exports; however for rich countries the elasticity is positive only for balance of system equipment but negative for the core renewable equipment (regression 2).[21]

[18] Taiwan and Singapore are not included in regressions 5 and 6. Taiwan gets dropped since data on renewable electricity generation is missing, while Singapore gets dropped since the computed renewable power generation from wind/solar is zero. Since both Taiwan and Singapore are in the category of poor, our benchmark with poor countries changes in these regressions compared to the benchmark of poor country results reported in columns 1–4.

[19] Since the omitted category is the balance of system equipment from the rich countries, the trend for core high tech equipment is (5.32+8.55) =13.87. Similarly, the trend for balance of system equipment from poor countries is (5.32+4.1) =9.3, and trend for core high tech equipment from poor countries is (5.32+4.1+8.55+2.1)=20.07, all significant.

[20] The significantly higher trend growth of the poor countries relative to rich developed countries holds true even when we de-scale the renewable equipment imports by the total imports from each of these countries.

[21] Based on the omitted category, elasticity of sector-specific US FDI is 0.32 for balance of system equipment from rich countries, and (0.3237−0.3716)=−0.04 for core high tech equipment from rich countries. While for poor countries, the elasticity is (0.3237+0.2306)=0.554 in balance of system equipment, and

In regressions 3 of Table 3, we separate out the trend growth rates of China and India. We find that the trend growth in exports from the poor countries continues to be significantly higher than that of the rich countries. Both China and India exhibit substantially higher trend growth rates than the rich and poor countries; however, there is asymmetry in their growth dynamics.[22] China exhibits a much higher trend growth than India in the balance of system equipment (24.38% compared to 15.8% per year), while India exhibits a higher trend growth than China in the core balance of system equipment (37.7% compared to 32.8% per year in regression 3). Controlling for FDI and real GDP (regression column 4), we again find that the trend growth rates decline significantly for all countries and for both categories of equipment. Moreover, the drop in the trend growth is relatively larger in the balance of system equipment than in the core high-tech equipment (comparing column 4 with column 3). In particular, the trend growth rates of Chinese exports reduce significantly from 24.38% to12.93% per year in balance of system equipment, and from 32.8% to 21.6% per year in core equipment (comparing regression 3 and 4). For India, accounting for FDI and economy size, the trend growth of balance of system equipment exports reduces drastically from 15.8% to 4.36% per year; while trend growth of core equipment exports dip from 37.7% to 29.7% per year (comparing regression 3 and 4). This suggests that the FDI is more significant for the export of balance of system equipment than the core equipment for all the countries.

The results from regressions 1–4 suggest that the US FDI has been an important determinant of imports of the balance of system equipment from both rich and poor countries, and particularly for the emerging economies of China and India. The estimates of elasticity of US FDI is seen to be significantly positive for the balance of system equipment (0.32 for rich countries, and 0.55 for poor countries in regression 2; and 0.32 for the rich and 0.52 for poor countries in regression 4); but negative for the rich countries in the core equipment. For the poor countries, however, the FDI elasticity is significantly positive for core equipment exports too (0.18 and 0.17 in regression 2 and 4, respectively).

In regression 5, Table 3, the trend growth rates estimation covering 22 countries for which we have complete data on FDI, GDP, and renewable power generation, show the same pattern as before (regression 3) across rich and poor nations as well as China and India. Controlling for US FDI, GDP and the wind–solar electricity generation (regression column 6), we find that for China, the trend growth declines more substantially in the balance of system equipment from 21.9% to 6.48% per year (comparing regression 5 and 6, respectively) and that of core equipment declines from 30.35% to 13.24%. Similar pattern of trend growth decline is noticed for India, with a more pronounced fall in the trend of balance of system equipment from 16.42% to 6.48% per year, and relatively less so in the core high-tech equipment from 38.48% to 23.54% per year (comparing regression 5 and 6, respectively).

The elasticity of US FDI is found to be significantly positive for poor countries, and greater for the balance of system equipment (0.50, regression 6). For the rich countries however, the FDI elasticity of exports is significantly positive for the balance of system equipment (0.26, regression 6) but negative for the core equipment (−0.21, regression 6). For domestic renewable electricity, the elasticity is significantly positive at 0.26, but overall economic size is no longer significant.

From the above sets of regressions in Table 3, three clear consistent results emerge concerning our hypotheses H1, H2 and H3:

H1: Sector-specific US FDI is a significant factor in export growth of the poor countries.

H2: Country size has a positive effect on exports of high-tech power-generation equipment (although not always individually significant, it is jointly significant together with other control variables).

H3: Home market effect in terms of wind–solar power sector has been a significant factor in the export of the core high-technology equipment to the US (more pronounced in rich countries and China).

In the appendix, in Table A1 we have reported the results of similar regressions but with FDI lagged by 3 years to allow for deeper impact of FDI in the host countries. The regressions in Table A1 are based on a somewhat smaller dataset compared to Table 3, as we lose some observations due to missing FDI data for earlier years. The qualitative results on trend growth rates across countries and core versus balance of system equipment are the same; both country size and domestic renewable power generation are found to have significant positive roles in the growth of exports to the US. However, we find with a longer lag, US FDI is no longer significant in the US import of the balance of system equipment from rich and poor countries. For core equipment imports, however, FDI elasticity is estimated to be significantly positive for the poor countries (0.045, in regression 6 of Table A1), but significantly negative for the rich countries. This is similar to the result from Table 3 where for the core equipment, the FDI elasticity was estimated to be significantly positive only for the poor countries (0.034 in regression 6, Table 3). Combining Tables 3 and A1 results, we infer that US FDI (particularly, electrical equipment and electronic equipment) did play a significant positive role in the poor countries and helped relocate manufacturing of high-technology renewable energy equipment in the developing countries. Thus our qualified H1 reads: Sector-specific US FDI is a significant factor in export growth of the poor countries, *especially for the core renewable energy equipment*.

We recognize that US FDI is unlikely to be randomly assigned across nation/year/industries and could be correlated with the error term in Eq. (1).[23] Foreign investors will invest their scarce resources in those projects that yield a high risk adjusted rate of return. Recall that we lag US FDI one year in the regressions. While we do not believe that exports in year t cause US FDI in year t-1 to grow, there could be omitted third factors causing both. As noted earlier, the growth and maturity of the renewable energy industry in the developed countries (and more recent growth in developing countries) has been driven by government support policies. If foreign investors believe that a developing nation's government will become actively involved in subsidizing green tech in the following year, then they may start to increase their FDI. Such complementarities between government policy and private capital are likely to help the

(*footnote continued*)
(0.3237+0.2306−0.3716)=0.51 in core high-tech equipment, all statistically significant.

[22] The significantly higher trend growth of US imports in high-tech wind and solar power equipment from the poor countries (and particularly China and India) compared to rich developed countries holds true even when we measure imports relative to the total imports from these countries. These results are available on request.

[23] Our renewable energy variable (as measured by electricity produced from wind/ solar/ biomass and geothermal) is less subject to concerns about endogeneity since it is determined by domestic electricity tariff policies, and climate-change mitigation measures for capacity installation in renewable energy production.

Table A1
Log($Import^{US}$) regressions with country fixed-effects (FDI lagged by 3 years).

	1	2	3	4	5	6
Trend	0.0556***	0.0266***	0.0554***	0.0479***	0.0570***	0.0394***
	[0.0045]	[0.0081]	[0.0045]	[0.0081]	[0.0045]	[0.0102]
Trend* D_1	0.0789***	0.0842***	0.0802***	0.0873***	0.0860***	0.0760***
	[0.0117]	[0.0127]	[0.0116]	[0.0126]	[0.0125]	[0.0122]
Trend *Poor*	0.0493***	0.0165	0.0274***	0.0218*	0.0441***	0.0317**
	[0.0096]	[0.0114]	[0.0093]	[0.0115]	[0.0120]	[0.0133]
Trend* *Poor** D_1	0.0186	0.0022	0.0115	-0.0076	0.0189	0.0025
	[0.0114]	[0.0154]	[0.0125]	[0.0159]	[0.0166]	[0.0187]
Trend**China*			0.1641***	0.1519***	0.1529***	0.1135***
			[0.0145]	[0.0207]	[0.0177]	[0.0328]
Trend**China** D_1			−0.0097	−0.018	−0.0256	−0.0421**
			[0.0167]	[0.0169]	[0.0205]	[0.0198]
Trend**India*			0.1060***	0.0984***	0.0803***	0.0615**
			[0.0219]	[0.0229]	[0.0235]	[0.0271]
Trend**India** D_1			0.1241***	0.1380***	0.1173***	0.1231***
			[0.0211]	[0.0211]	[0.0235]	[0.0245]
Log(FDI_{t-3})		−0.0204		−0.019		−0.0352
		[0.0249]		[0.0245]		[0.0239]
log(FDI_{t-3})* D_1		−0.0708		−0.0662		−0.1730***
		[0.0622]		[0.0618]		[0.0622]
log(FDI_{t-3})**Poor*		0.0232		−0.0234		−0.0838
		[0.0432]		[0.0422]		[0.0523]
log(FDI_{t-3})**Poor** D_1		0.1765**		0.2268***		0.3371***
		[0.0852]		[0.0835]		[0.0990]
Log(GDP_{t-1})		1.3354***		0.3656		0.9105**
		[0.2879]		[0.3056]		[0.4332]
Log($RenewElec_{t-1}$)* D_1						0.1940***
						[0.0346]
D_1	−1.2743***	−1.2132***	−1.2928***	−1.2680***	−1.2923***	−5.2065***
	[0.1430]	[0.1579]	[0.1415]	[0.1561]	[0.1535]	[0.7334]
D_2	0.1507***	0.1481***	0.1491***	0.1497***	−0.0076	−0.0046
	[0.0424]	[0.0424]	[0.0422]	[0.0422]	[0.0424]	[0.0424]
Constant	12.0067***	−5.0807	11.9922***	7.3308*	12.5112***	0.6744
	[0.1244]	[3.6874]	[0.1220]	[3.9015]	[0.1279]	[5.6496]
Observations	8933	8933	8933	8933	7609	7609
R^2	0.2793	0.2822	0.2864	0.2874	0.2868	0.2923

The omitted category is the balance of system equipment from relatively rich countries (i.e. countries with greater than median GDP per capita in constant US$). Balance of system products include – towers, speed changers, gears, clutches, generators, rectifiers, inverters and anemometers, D_1=dummy for core high-tech products which include – blades, hub, wind turbines, solar modules and solar cells., D_2=dummy for manufacturing sector in which product *i* is manufactured, Figures in parentheses give the standard errors of the estimated coefficients.

*** Indicates significant at 1%.

** Significant at 5%.

* Significant at 10%. The standard errors are clustered by country/year.

industry to grow. In this case, our OLS estimates are likely to overstate the causal effects of US FDI because the coefficient on US FDI will partially reflect the unobserved increased effort by the exporting nation's government to promote green tech. In the absence of identifying a credible instrumental variable for US FDI by nation/year/industry category, we are cautious about giving our correlation estimates a causal interpretation.[24] Future research should seek to study the likely synergies between export nation's renewables promotion policies and attracting FDI inflows.

7. Conclusion

The import of core-high tech wind and solar power generation equipment has grown faster than other high technology equipment in the US during the past two decades. The growth of imports from poorer countries have outpaced (though from far lower base) that from rich countries. Distinguishing between the "core" renewable energy equipment and balance-of-system equipment, the latter including goods with multiple-use (other than renewable energy generation), we find that China has exhibited much higher trend growth in the export of balance of system equipment than India, while India exhibited higher trend growth in the core high-tech renewable energy equipment exports. Although richer countries like Germany, Japan, Denmark, Canada, continue to be major exporters of these high-tech equipment into the US, their import market shares (by value) have been eroded considerably.

We find that country size is an important correlate of exports of the high-tech balance of system equipment to the US; and home market effect in terms of wind–solar power generation has played a significant positive role in the export of core renewable energy equipment from both rich and poor countries. The US FDI elasticity for exports of high technology renewable energy equipment to the US is found to be significantly positive for poor countries.

Our analysis provides a stark comparison between countries, and the significance of overall macro trends in the export of renewable power generation equipment to the US. The rapid growth of exports from the emerging countries in the high-tech equipment and their share displacement of the rich industrialized

[24] We have also estimated Eq. (1) and included nation/year fixed effects. In these regression results, that are available on request, we estimate a FDI elasticity of 46. By including nation/year fixed effects, the FDI coefficient is identified by within nation/year variation in FDI across the four FDI industry categories. This finding indicates that the FDI results cannot simply be a proxy for government macro energy policy because the nation/year fixed effects control for such policies.

countries in the US import market suggest that technology adoption in the relatively poor countries has been notably high over the last two decades.

This paper's empirical work has focused on national exports to the United States by industry/year. At the industry level, however, we cannot distinguish whether multinational affiliates or domestic firms were the source of exports from the different countries; nor the extent of imported inputs embodied in the exports.[25] In a developing country such as China, its exports have a high foreign-content. This is especially the case for exports from foreign invested firms (Koopman et al., 2008). Our analysis does not capture the embodied imports (which fall under distinct and diverse product/HS classifications) in the specific product exports that we consider. However, given the overall nature of the products in our sample, from our results we can conclude that developing countries are rapidly emerging as the "green havens" producing technologically advanced renewable energy equipment.

Greater international trade and participation of Asian economies in renewable power equipment production has likely played a significant role in reducing the cost of such equipment. For example, the average solar PV module price has reduced from $4.66/W (per Watt) in 2004 to $2.01/W in 2010, is expected to further drop to $1.49/W by 2015.[26] Access to cheap imports from China has offered U.S consumers a great increase in consumer surplus (Weinstein and Broda, 2008). In the case of renewables equipment, declines in these products' prices offer externality benefits. The role of international trade in mitigating environmental externalities merits future research.

While our study highlighted the role of inward-FDI in the high-technology climate-mitigation industry for the developing countries, alternative means of technology access is increasingly evident within the industry. For instance, the firms from developing countries like China and India have engaged in acquisition of component-specialist firms in a bid to access technology, apart from licensing technology or entering into joint-ventures: the Indian wind turbine manufacturer Suzlon acquired Hansen Transmissions of Belgium (gearbox specialist) in 2006–2007, and purchased RE Power of Germany (wind turbine manufacturer) in 2009, while the Chinese wind turbine manufacturer Goldwind acquired Vensys Energy of Germany (specialist in gearless wind turbines) in 2008.[27] Future research with firm-level data could attempt to explore this alternative channel of technology diffusion and its role in the growth of trade in the renewable energy industry.

Appendix. Data Appendix

Data source: We have built the data from four sources. The data on US imports is taken from Robert Feenstra's trade database (1989–2006), supplemented with data directly from the USITC online database for years 2007 through 2010. The FDI data is taken from US Bureau of Economic Analysis. Country-specific data on GDP, and electricity from renewable sources, are from the World Bank database. Price indices have been taken for deflation of import data taken from US Bureau of Labour Statistics (see Appendix Table A1).

[25] Since intermediate inputs often fall within other product classification (like imports of silicon wafers used in solar cell manufacturing), country net import at the 10-digit HTS would not accurately reflect the embodied imported inputs. The value-added on imported inputs are best reflected at the plant-level export analysis.

[26] "Global Solar PV Module Market - Downward Trend in Module Prices to Continue through 2015" http://www.marketresearch.com/

[27] Goldwind began as a licensee of Vensys Energy in 2003.

Table A2
Summary Statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Log(*Import*)	9155	13.34421	2.681616	7.040245	20.75951
Log(*FDI*)	9428	6.392317	1.498658	−0.157	9.522493
Log(*GDP*)	9428	13.17078	1.046298	10.56402	15.4644
Log(*RenewElec*)	7957	22.02226	2.212534	13.81551	25.38671

Commodity trade data

We use general imports (i.e., imports as they come off the dock in the US) reported in US$, and convert these to constant US 2000$ using the US Import Price Index for all commodities except petroleum (year 2000 = 100). The 10-digit HTS classification has been revised several times over the time-period of our analysis, and some of our high-tech core products have different codes over time. To address this, we have used the concordance of old obsolete HTS codes with new HTS codes from Pierce and Schott (2009). For example, code 8502300000 for "other generator sets" included wind-powered generators until 1995, but since 1996 a new code of 8502310000 was adopted exclusively for "wind-powered generators". The details of the obsolete codes for each of the 27 products are listed in Table A2.

US FDI data

USBEA data by country by industry (by SIC classification for 1988–1998 and by NAICS classification 1999–2009) for the 22 year period 1988–2009. The data in million US dollars is converted to constant US 2000$ million using the Export Price Index.

Country-specific factors (world bank database and IMF)

GDP per capita and GDP

The gross domestic product per capita and GDP (both at constant 2000 US$) are taken from the World Bank database. However, since the data for Taiwan is not available in the World Bank database, we have used the IMF database in for the current US dollar values of these variables. Using Taiwan's GDP deflator (IMF database) we compute the constant US$ values of annual GDP and GDP per capita (base year 2000).

RenewElec

We calculate the annual electricity production from wind, solar, geothermal, and biomass sources of each country as the residual of the total electricity production *less* electricity generated from coal, hydro, oil, and natural gas.

Our final data panel is unbalanced with missing data on sector-specific US FDI, as well as electricity from renewable sources. According to the US BEA, some of the US FDI data by country and industry level are withheld to avoid disclosure of data of certain companies. For Taiwan we do not have data on renewable energy, while for Singapore electricity generated from wind/solar/biomass/geothermal is zero.

The table below gives the summary statistics of the data and Table A3 gives the list of 27 products (by 10-digit HTS codes) covered in our analysis, and the concordance with the FDI sector classification (by NAICS 3-digit codes).

Table A3
List of 10-digit HTS Codes of Wind and Solar Energy Equipment and Concordance with NAICS Codes.

	HTS 10-digit	Obsolete HS codes	HTS code description	Component	FDI category
1	7308200000		Tower and lattice masts of iron and steel	Tower	1 (Primary & fabricated metal-NAICS 331, 332)
2	8412909080		Parts of engines and motors, nesoi	Blades	2 (Machine manufacturing–NAICS 333)
3	8483405010		Fixed ratio speed changers	Gearbox	2 (Machine manufacturing–NAICS 333)
4	8483405050		Multiple and variable ratio speed changers	Gearbox	2 (Machine manufacturing–NAICS 333)
5	8483407000		Speed changers, nesoi	Gearbox	2 (Machine manufacturing–NAICS 333)
6	8483408000		Ball and roller screws	Gearbox	2 (Machine manufacturing–NAICS 333)
7	8483409000		Gears, except transmission elements	Gearbox	2 (Machine manufacturing–NAICS 333)
8	8483604040	84836040000 (until 2000)	Clutches and universal joints, clutches	Coupling, shafts	2 (Machine manufacturing–NAICS 333)
9	8483604080	84836040000 (until 2000)	Clutches and universal joints, univ. Joints	Coupling, shafts	2 (Machine manufacturing–NAICS 333)
10	8483608000		Shaft couplings, except universal joints	Coupling, shafts	2 (Machine manufacturing–NAICS 333)
11	8501610000		AC generators, power output ≤ 75 KVA	Generator	3 (Electrical equipment–NAICS 335)
12	8501620000		AC generators, > 75 but ≤ 375 KVA	Generator	3 (Electrical equipment–NAICS 335)
13	8501630000		AC generators, > 375 but ≤ 750 KVA	Generator	3 (Electrical equipment–NAICS 335)
14	8501640020		AC generators, > 750 but ≤ 1000 KVA	Generator	3 (Electrical equipment–NAICS 335)
15	8501640030		AC generators, > 1000 but ≤ 4000 KVA	Generator	3 (Electrical equipment–NAICS 335)
16	8501640050		AC generators, > 4000 KVA output	Generator	3 (Electrical equipment–NAICS 335)
17	8502310000	8502300000 (till 1995)	Other generating sets, wind powered (was under "other electric generating sets, nesoi" till 1995)	Wind Generator	3 (Electrical equipment–NAICS 335)
18	8503009545	8503006040 (until 1993), 8503008540 (1994)	Parts of generators, other than commutators	Hub, drive, parts	3 (Electrical equipment–NAICS 335)
19	8504409510	(until 1996) 8504408004,	Power supplies (rectifier), output < 50 W	Rectifier	4 (Computer & electronic products–NAICS 334)
20	8504409520	8504408008, 8504408010,	Power supplies (rectifier), > 50 W but < 150 W	Rectifier	4 (Computer & electronic products–NAICS 334)
21	8504409530	8504408015, 8504408025,	Power supplies (rectifier), > 150 W but < 500 W	Rectifier	4 (Computer & electronic products–NAICS 334)
22	8504409540	8504408040,	Power supplies (rectifier), > 500 W	Rectifier	4 (Computer & electronic products–NAICS 334)
23	8504409570	8504408060,	Inverters (static converters)	Inverter	4 (Computer & electronic products –NAICS 334)
24	8504409580	8504409001, 8504409007, 8504409012, 8504409018, 8504409025, 8504409040, 8504409060	Inverters (static converters), nesoi	Inverter	4 (Computer & electronic products–NAICS 334)
25	8541406020		Solar cells, assembled into modules or panels	PV panel/ module	4 (Computer & electronic products–NAICS 334)
26	8541406030		Solar cells, not made into panels or modules	PV cells	4 (Computer & electronic products–NAICS 334)
27	9026804000		Heat meters and anemometers	Anemometer	4 (Computer & electronic products–NAICS 334)

Source: Based on HTS code identified for renewable energy equipment in USITC (2005, 2009), and Wind (2009).

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