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Discussion
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Chinese Renewable Energy Technology Exports: The Role of Policy, Innovation and Markets

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Abstract: Chinese companies have become major technology producers, with the largest share of their output exported. This paper examines the development of solar PV and wind energy technology component (WETC) exports from China and the competitive position of the country's renewable energy industry. We also describe the government's renewable energy policy and its success in renewable electricity generation as well as increasing renewable energy innovation and foreign knowledge accumulation, which may drive export performance. We aim at empirically identifying determinants of Chinese solar PV and WETC exports. We estimate an augmented gravity trade model using maximum likelihood estimation. Besides controlling for standard variables derived from the gravity literature, we consider additional explanatory factors by accounting for market, policy and innovation effects steaming from both importing countries and China. We use a panel dataset representing annual bilateral trade flows of 43 countries from the developed and developing world that imported solar PV and WETCs from China between 1996 and 2008.

The analysis shows that while the national market remained small for solar PV, the industry successfully entered foreign markets. The export performance of firms producing WETC increased but remained relatively small while the country developed a large home market. Empirical results indicate that high income countries, with a large renewable energy market and demand side policy support scheme, in terms of incentive tariffs, are increasingly importing solar PV components from China. We show that trade costs have a negative impact on exports of solar PV components but not WETC. Additionally, we find a positive impact of research and development (R&D) appropriation growth, especially from provincial governments in China, but no evidence that bilateral knowledge transfer and indigenous innovation affect exports.

Keywords: China, Gravity model, Trade, Innovation, Policy, Renewable Energy Technologies

JEL Classification: C32, F14, O30, Q42, Q48, Q56

1 Introduction

Since 1990, China's economic growth and export performance has been exceptional. The rapid growth in energy consumption and carbon emissions makes China a decisive player in global climate negotiations. In attempting to create more sustainable growth, China has introduced various policies designed to increase its renewable energy generation capacity and to establish an industrial base for clean technology production. With respect to the latter, China is particularly successful as its clean technology industry experienced a remarkable development. The solar photovoltaic (PV) module producing industry, including companies like Suntech, JA Solar and Yingli, is extremely prosperous with double digit growth rates since 2000 ([REN21, 2011](#), [IEA, 2010](#)). After producing only 3 MW in 2000, China's solar PV panel industry became the largest global producer, making 10,852 MW in 2010, which accounted for 45 percent of world production in 2010 ([Algieri et al., 2011](#), [EPL, 2011](#)). China's wind turbine production also experienced a similar rapid growth. Companies such as Sinovel, Goldwind, Dangfang and Ming Yang increased their production from USD 26 million in 2003 to USD 104 million in 2005, building a supply capacity of 17 gigawatt; some 41 percent of the global market ([Caprotti, 2009](#), [BTMConsult, 2011](#)). At the same time, the Chinese government increased its efforts to close a knowledge gap to developed countries by increasing its research and development (R&D) spending on renewable energies and energy efficiency as well as by introducing numerous policies to support indigenous innovation and attract foreign knowledge. Yet, as this paper will highlight that the local market for renewable energy technologies components in China remained small until recently, with electricity generation from renewable sources contributing only a marginal share to total electricity generation. Consequently, the largest share of solar PV and wind energy equipment production is exported - to only a few high-income countries - and China became the largest exporter of solar PV modules and a major exporter of wind energy technology components (WETC).

Literature describing and examining the dynamics of trade in clean energy technology remains sparse and, with the exception of Algieri et. al ([2011](#)), does not account for development in China. Consequently we contribute to the existing literature in two ways. **First**, our research examines the development of solar PV and wind energy technology component (WETC) exports from China and the competitive position of the

country's renewable energy industry. Furthermore, we describe the government's renewable energy policy and its success in terms of renewable electricity generation and increasing renewable energy innovation and foreign knowledge accumulation in China. **Second**, as in the first study, we empirically identify driving factors of Chinese solar PV and WETC exports. We conduct an *ex-post* econometric study using an augmented gravity model. We use a panel dataset representing annual bilateral trade flows of 43 countries from the developed and developing world that imported solar PV and WETCs from China between 1996 and 2008. Overall our data represents about 90 percent of Chinese exports with respect to both technologies. Besides controlling for standard socioeconomic variables derived from the gravity trade literature, we consider several explanatory factors accounting for market, policy and innovation effects steaming from both importing countries and China. Specifically, we are interested in the effect of renewable energy support schemes and the renewable energy market size in importing countries on export flows from China. Furthermore, the role of Chinese R&D policy, innovation and bilateral technology transfer and the Chinese demand market for solar PV and WETCs is of interest.

We show that China experienced a rapid export growth for both solar PV and wind energy equipment, but that it only runs large export surplus with a few OECD countries. Main results support the descriptive analysis, as income both in importing countries and China are important export determinants. Furthermore, at least for solar PV, the results indicate a strong role for market size and policy setup in importing countries as well as trade costs in terms of tariffs applied to imports from China. The effect of the market size in China for solar PV components and WETCs is in line with the descriptive observation. While the national market remained small for solar PV, the solar PV component industry became particularly successful in targeting foreign markets. On the contrary, while the country developed a large home market for WETC, its export performance in the sector increased but remained relatively small. Additionally, we find a positive impact of R&D appropriation growth, especially from provincial governments in China, but no evidence that bilateral knowledge transfer and indigenous innovation has an effect on Chinese exports of solar PV components and WETC. Hence, our analysis calls for more research on the topic as our innovation measures presumably does not cover other means of

innovation, such as purchasing manufacturing equipment or hiring a skilled foreign trained workforce, and respective supportive policies such as educational investments.

Nevertheless, the results of our study are of interest to policy makers. Among other things, the results suggest that a renewable energy supportive market structure is essential to obtain solar PV technology in an international market. Furthermore, on the one hand, the reduction import tariffs can significantly increase the availability of affordable solar PV technologies from China. Yet, on the other, increasing tariffs along WTO law can also serve as a tool for reducing solar PV component imports from China. Further, the results give a hint that future growth in the Chinese home market for solar PV might eventually decrease the current large export surplus of the sector, as the home market is supplied instead.

The analysis is organized as follows. Section 2 provides a literature overview. Section 3 highlights the development of Chinese exports of renewable energy technology components focusing on solar PV and wind energy technology components (WETC) and - in order to outline supply side mechanisms - brings it in line with efforts undertaken by the central and provincial governments to promote renewable energies in China. Section 4 presents the empirical framework. Section 5 describes data used to estimate determinants of imports of these technologies from China. The results are presented in Section 6 and discussed in Section 7.

2 Related Literature

Literature on innovation, learning and the determinants of export development generally stems from two theoretical traditions. Literature rooted in the Heckscher-Ohlin-Samuelson model and its neo-endowment approach determines trade by the relative factor availability of labor, capital and knowledge. The other theoretical approach, influenced by the Ricardian school, understands technology differences between trading partners as the main determinant of trade between developed countries ([Posner, 1961](#), [Vernon, 1966](#)). Innovation and technology is identified as an important non-price factor positively affecting bilateral trade between countries ([Magnier and Toujas-Bernate, 1994](#), [Verspagen and Wakelin, 1997](#), [Krugman, 1979](#), [Grossman and Helpman, 1991](#), [Eaton and](#)

[Kortum, 2002](#)). The empirical literature outlining the importance of innovation, government policies that encourage domestic R&D, investment and technology diffusion, as well as the levels and similarities of markets is large, but mostly focuses on developed countries. ([Greenhalgh, 1990](#), [Chengang Wang et al., 2010](#), [Levinson, 2009](#), [Papaconstantinou, 1997](#), [Madden et al., 1999](#), [Wakelin, 1998b](#)). With the increasing competitiveness of developing countries' exports, some empirical studies analyze these issues focusing on emerging markets, in particular East Asian economies ([Pamukcu, 2003](#), [Hasan and Raturi, 2001](#), [Madden et al., 1999](#)). Edmonds et. al ([2008](#)) show that China's excessive foreign trade orientation substantially varies between countries due to growth of foreign invested firms and their respective links to home markets. Arguing that government policies play a role in nurturing domestic production capabilities, Rodrik ([2006](#)) and Schott ([2008](#)) suggest that China has developed comparative advantages in highly sophisticated good exports that are not comparable with its development level. Other studies also support the view that foreign direct investment (FDI) and innovation are important drivers for entering export markets. For instance, Zhang and Song ([2000](#)) find evidence that increased levels of FDI positively affect manufacturing export performance, not only through exports generated by foreign affiliates but also by host country industries. In line with the theoretical literature on the importance on innovation and learning for exporting ([Bell and Pavitt, 1993](#), [Westphal, 2002](#)), numerous empirical studies find evidence that innovation activities, technology spillovers through imports, and linkages to multinational companies have a positive effect on Chinese export performance ([Guan and Ma, 2003](#), [Guan et al., 2009](#), [Motohashi and Yuan, 2010](#), [Park and Lippoldt, 2008](#)). Fu and Gong ([2011](#)), for instance, using a panel of Chinese firm-level data, analyze the role of indigenous and foreign innovation efforts in technological upgrading finding that indigenous firms are leading in low- and medium technology industries, while foreign firms lead in the high technology sector. Wignaraja ([2012](#)) identifies that technology transfer from multinationals in combination with systematic investments in and upgrading of minor technological activities as important drivers behind the export success of the automobiles and electronics industry. In the context of the effect of innovation on trade there are two often used measures of innovation that are also used in this study – R&D spending and patents. Empirical evidence finds that increasing R&D

spending might explain the export success of most countries ([Hirsch and Bijaoui, 1985](#), [Buxton et al., 1991](#), [Keesing, 1967](#)) and China ([Zhao and Li, 1997](#)). Yet, R&D spending, reflecting only one input into the innovative process, might be an insufficient measure. Consequently, patent data, reflecting innovative output, is used as a proxy for innovation and technology transfer. Several studies using patent data further support the view that innovation is a decisive element in determining trade flows ([Zeng, 2009](#), [Soete, 1987](#), [Roper and Love, 2002](#), [Wakelin, 1998a](#)). A related approach in this respect centers on the effect of intellectual property rights (IPR) on trade flows. Most empirical studies focus on exports from industrialized nations to a group of developed and developing importer countries. ([Maskus and Penubarti, 1995](#), [Rafiquzzaman, 2002](#), [Smith, 1999, 2001](#)). In the early 2000s, studies began to focus on developing countries' trade flows and the role of IPR rights ([Park and Lippoldt, 2005, 2008](#), [Awokuse and Yin, 2010](#), [Yang and Maskus, 2009](#), [Branstetter et al., 2005](#)). With respect to China, Awokuse and Yin ([2010](#)) present some empirical evidence suggesting that strengthened IPR protection in China significantly affected imports of knowledge intensive products.

Some studies analyze the role of innovation and government policies in explaining the rapid development of the renewable energy sector in China. De la Tour et al. ([2011](#)) describe the role of innovation and technology transfer of the solar PV industry in China. In a descriptive market study they find that Chinese producers attained their current world position by purchasing manufacturing equipment and by recruiting executives from amongst a skilled Chinese diaspora but that their innovation performance is driven by national policies designed to close the innovative gap in critical areas. Similarly, Wu and Mathews ([2012](#)), ignoring trade, investigate knowledge flows from advanced countries finding that the main foreign knowledge sources for China in the sector are the US, Japan and Germany. They also outline a rising dependence of China on its own knowledge generation, in particular from the public research institutes and universities. With respect to the Chinese wind turbine manufacturing industry Lewis ([2005, 2011](#)) and Ru et. al ([2012](#)) show that public policy plays a key role in the transition of from imitation and cooperation to indigenous innovation. Yet, studies analyzing trade dynamics in clean technology industries are limited, especially with respect to developing countries. Focusing on export flows from developed countries, Constantini and Crespi ([2008](#)) and

Constantinin and Mazzanti ([2012](#)) find that stringent environmental regulation and strong national innovation systems have a significant positive effect on exports of energy technologies. Algieri et al. ([2011](#)) analyze trade dynamics of the global PV industry and describe the competitiveness of major exporting countries. Focusing on US PV exports, they find a relationship between PV exports, foreign income and relative prices, but ignore the role of innovation. Analyzing renewable power equipment exports to the US, Sawhney and Kahn ([2012](#)) find that larger countries export significantly more and that the exporting countries' domestic renewable power generation has a positive significant impact as well. Furthermore, sector specific foreign direct investment from the US to poor exporting countries determines export growth.

In summary, while there is some evidence regarding developed countries' exports in clean energy technologies and the role of innovation and environmental policy for the creation of a clean tech industry, there is little with respect to China. In the present paper we focus on solar PV and wind energy technology component (WETC) exports from China. We link studies on policy effects and innovation in this sector to studies analyzing trade determinants of a new industry. We identify the relationship between Chinese export performance, policy efforts and innovation activities on the supply side within China, as well as drivers on the demand side in importing markets.

3 Chinese exports of solar PV and wind energy components and renewable energy policy in China

International trade is a predominant element of the Chinese economic development. Even though growth rates have slowed since 2007 China has seen several annual growth rates of 10 percent since the 1990s. Trade flows grew even faster after the country was formally admitted to the World Trade Organization (WTO) in 2001 ([Edmonds et al., 2008](#)). The composition of Chinese trade changed as the country moved from a comparative advantage in trade with low technology based processed foods, textiles and manufactured materials in the 1980s and 1990s, to an increasing more technology embodied trade in machinery and equipment ([Yue and Hua, 2002](#)). Using a data set covering bilateral trade relations we find that a similar high-tech components trade

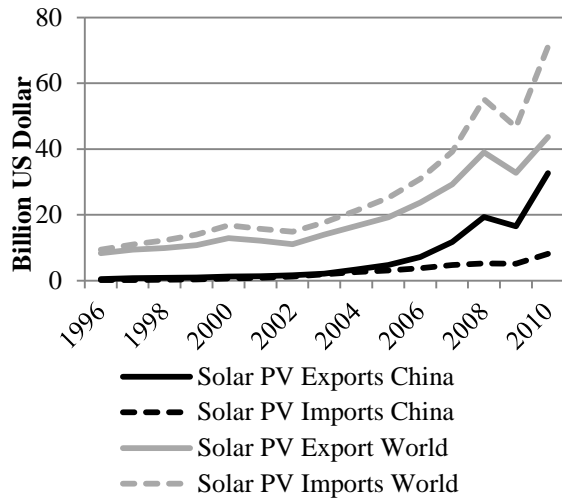
pattern is reflected in the country's exports and imports of renewable energy technology equipment. In this section we describe the export dynamics and the competitive position of the Chinese renewable energy branch. Data was obtained from UN Comtrade (2011) based on relevant Harmonized Commodity and Coding System (HS) codes (Appendix 1).¹ The approach allows for a detailed analysis of technology specific trade flows between countries, but does not permit an assessment with respect to the quality of traded goods ([Hamwey, 2005](#), [Sawhney and Kahn, 2012](#), [Costantini and Crespi, 2008](#)). We also refer to the policy regime supporting renewable energy investment, generation development and innovation in China, in order to identify potential effects of both technology demand and supply side policies on trade in the subsequent empirical analysis.

3.1 Development and diversity of Chinese clean technology trade

Global trade of renewable energy technologies grew only marginally before 2000, but has increased sharply since then ([Costantini and Crespi, 2008](#), [Groba, 2011](#)). Figure 1 highlights that Chinese exports of solar PV components lagged behind this development, but increased sharply after 2006. Since then, Chinese solar PV exports have increased by a factor of 26, reaching approximately USD 32 billion in 2010. The share of Chinese exports across all global exports increased from 5 percent in 1996 to 39 percent in 2010, making China the leading exporter of this technology (Appendix 2). At the same time, imports to China increased by a factor of 12; increasing the Chinese share of global imports from 3 to 9 percent. While China has become an importer of components as well, its global import share remained low and China developed a large export surplus in this sector. A similar, but weaker, development can be observed in WETC trade, where Chinese exports increased by a factor of 12, raising the market share from 2 percent in 2000 to 6 percent in 2010 (Figure 2). In terms of China's trade composition, the share of solar PV equipment exports out of total Chinese exports more than tripled from below 1 percent in 2000 to about 3 percent in 2010. Yet, for wind technology component exports, the share remains significantly lower.

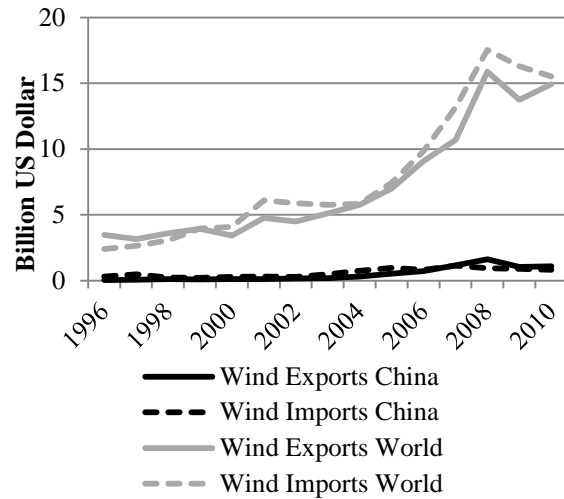
¹ World Integrated Trade Solution: <http://wits.worldbank.org/wits/> Typologies of components relevant to exploit renewable energies are well defined, see: OECD and Eurostat ([1999](#)); Steenblik ([2005, 2006](#)) and Wind ([2008](#)).

Figure 1: Development of Chinese exports and imports of solar PV energy technology components.



Notes: World indicates rest of world without China
 Source: authors' calculations based on UNCTAD Comtrade 2011

Figure 2: Development of Chinese exports and imports of wind energy technology components.



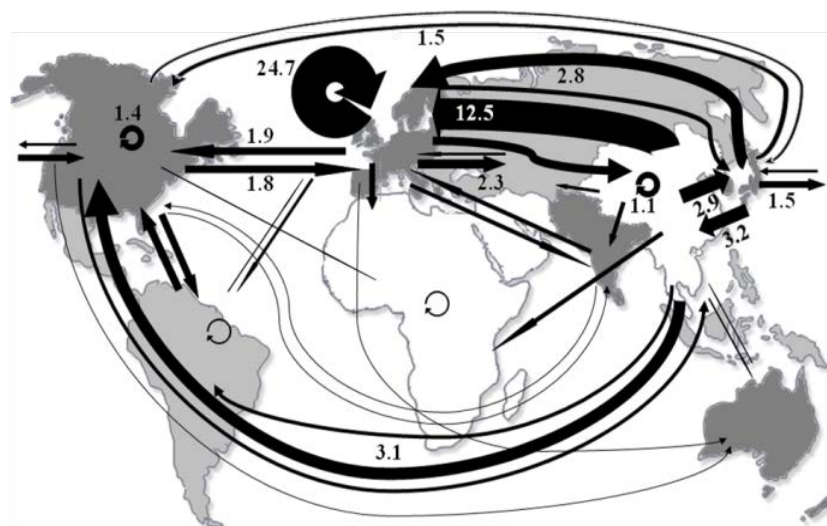
Notes: World indicates rest of world without China
 Source: authors' calculations based on UNCTAD Comtrade 2011

Analyzing sectoral indices of trade related competitiveness, such as relative world market shares (RWS) and relative trade positions (RTP), confirms an increasing export specialization in both technology segments and traces Chinese competitiveness in the international market (Appendix 3). The share of these products in Chinese total exports is generally higher than the global average and has increased sharply since 2000. The RTP indicates that Chinese exporters are better able to penetrate foreign markets than foreign exporters are to penetrate the Chinese market highlighted by an increasing gap between the exports and imports. Overall, the export-import relationship of solar PV and WETC relative to the total export import ratio indicates a clear and increasing relative comparative advantage (RCA) of the sector (Appendix 3). This is in line with earlier finding in the literature showing that China moved to an increasing comparative advantage in machinery and equipment (Yue and Hua, 2002).

Yet, the successful export story in the solar and wind sector is unequally distributed across the importing countries and thus in line with earlier findings of China's excessive

orientation toward foreign trading with high income countries (Rodrik, 2006, Schott, 2008, Edmonds et al., 2008). The major markets importing Chinese solar PV components are OECD countries, which account for 80 percent of respective exports. Countries such as Germany, the US and Italy experienced a two digit, increasing import share of these technologies from China. Other regions contribute little to the Chinese export share, as only marginal volumes are exported to other emerging and developing countries (Figure 3, Appendix 4). Trade with wind energy technology components shows similar pattern of trade relations although OECD countries account for only 50 percent of Chinese exports and there is considerably more regional trade within the East Asian and Pacific region.

Figure 3: Export flow of solar PV technology components 2008 by region in billion US Dollar.



Source: Authors' calculations and illustration based on UN Comtrade 2011 from World Integrated Trade Solution website: <http://wits.worldbank.org/wits/>.

3.2 Renewable energy policy and RE electricity generation in China

Renewable energy policies in OECD countries and China are comparable to some extent as they can be described as a mix of demand and supply driving mechanisms to foster generation and innovation. However, there are also substantial differences. OECD countries largely support renewable energy development through demand generating policies such as feed-in tariffs (FIT), renewable energy portfolios (RPS), and tax

measures. Public spending on renewable energy R&D, on the other hand, has not increased since the 1990's, save for bioenergy ([IEA, 2004](#)). China's national and provincial governments have implemented numerous policies fostering both electricity generation from renewable sources and innovation of respective technologies (Table 1). However, in terms of policy success, differences between increasing investment or electricity generation on the one hand innovation and industrial development on the other are evident.

Table 1: Selection of national and provincial government policies and programs targeting solar PV and wind renewable energy dissemination and innovation in China

<i>Year</i>	<i>Policy</i>	<i>Policy Type and Aim</i>
1986	State High-Tech Development Plan (863 Program)	R&D for Technology Development
1993	Science and Technology Law	Policy Process to support technology development
1996	Brightness Program	Policy Process to increase renewable energy electricity generation
1997	National Basic Research Program (973 Program)	R&D Technology Development
1998	Energy Conservation Law	Policy Process to increase renewable energy electricity generation
2001/2003	Reduced Value Added Tax for RE	Financial Support to increase renewable energy electricity generation
2003(ended)	Wind Power Concession Program	Incentive/Subsidies to increase renewable energy electricity generation
2006/2009	Renewable Energy Law	Policy Process to increase renewable energy electricity generation
2006	National Climate Change Program	Policy Process
2007	Hainan Province Plan for the Construction of Wind Farms	Public Investment to increase renewable energy electricity generation
2007	Shandong Province Energy Fund	Public Investment/ R&D for Technology Development and industrial process
2008	Shandong Province Village Renewable Energy Regulation	Incentive/Subsidies, Regulatory Instruments to increase renewable energy electricity generation
2008	Shandong Province One Million Rooftops Sunshine Plan	Policy Process, Regulatory Investments

Sources: IEA/IRENA ([2012](#)) and REN21 ([2009](#)) *Note:* Policies introduced after 2008 are neglected as they go beyond the time period analyzed in this paper.

Chinese demand side policy to foster investment in renewable energy generation is lagging behind policy implementation in OECD countries and faces several obstacles. The Renewable Energy Law was only introduced in 2006 and respective feed-in tariff

policies were enacted in 2009. (Cherni and Kentish, 2007, Peidong et al., 2009, REN21, 2009, Feng Wang et al., 2010, Xinyu et al., 2011, Hu et al., 2010, Ma et al., 2010). Subsequently, net electricity generation from solar PV sources increased from ten million KWh in 1996 to 150 million KWh in 2008, supplying only a small share of the total electricity generation (EIA 2012). In contrast to Germany, which in 2008 generated 4.4 billion kWh of electricity from solar sources, the local market in China has remained small until 2008 (Figure 4). A different picture appears with respect to wind energy. While only 100 million kWh of electricity was generated from wind energy in 1996, a remarkable increase occurred especially after 2005 (Figure 5).

Figure 4: China solar PV electricity capacity and generation development 1996 – 2010.

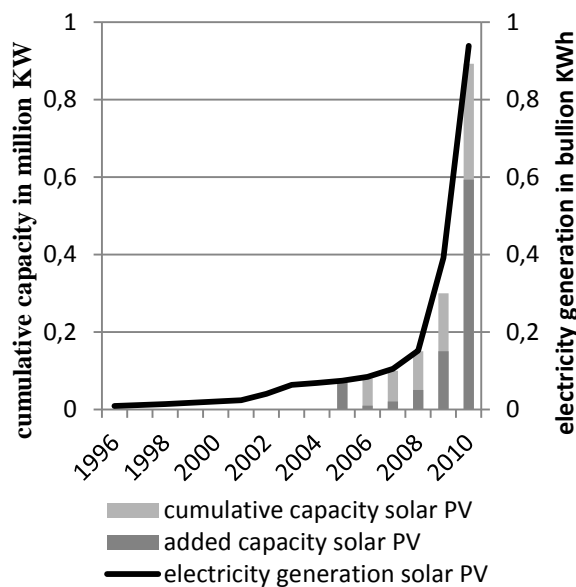
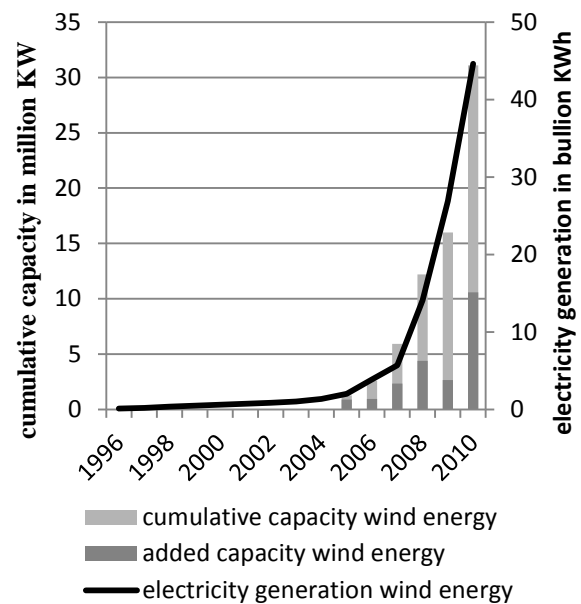


Figure 5: China wind energy electricity capacity and generation development 1996 – 2010.



Notes: Data on capacity development in China is available only for a shorter time period but underlines the highlighted development. Solar PV capacity increased from 0.07 million KW in 2005 to 0.89 million KW in 2010. Wind energy capacity increased from 1.26 million KW in 2005 to 31.1 million KW in 2010. *Sources:* EIA (2011), China Renewable Energy Society (2010)

According to 2012 EIA's international energy statistics, 14 billion KWh of electricity was generated from wind energy sources in 2008. This soared to 73 billion KWh in 2011, making China one of the world's largest electricity producers from wind

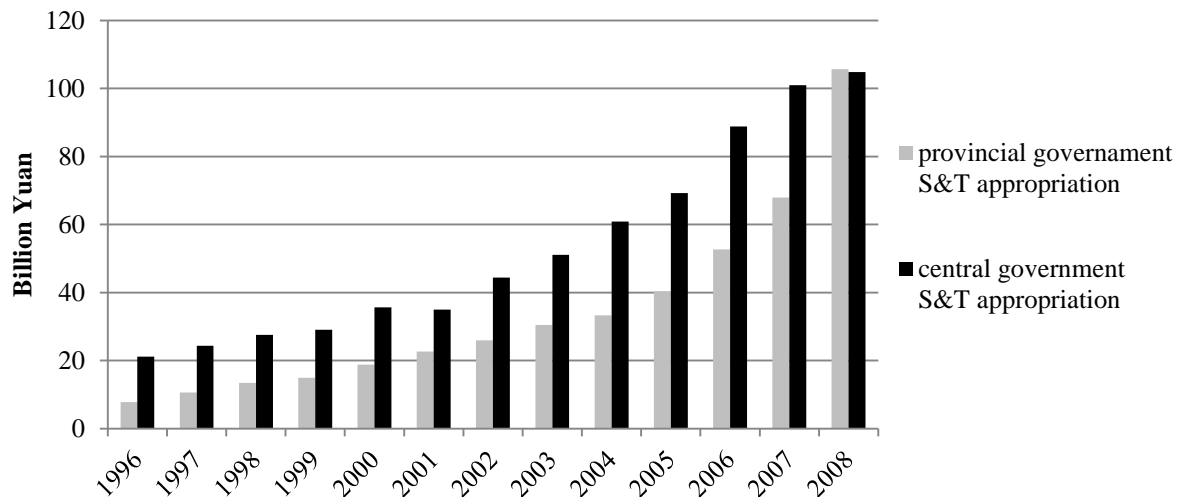
energy. Overall these figures emphasize that that national market for wind energy components in China developed faster until 2008 and is still significantly larger than the market for solar PV components.²

3.3 R&D, innovation and technology transfer in China

With respect to the supply side policies, China, in contrast to OECD countries, substantially increased its public R&D spending in order to improve its technological knowledge base. For instance, China's gross R&D appropriations increased from 30.2 billion Yuan (USD 3.6 billion) in 1996 to 355 billion Yuan (USD 51.8 billion) in 2008 ([World Bank, 2011](#), [MOST, 2011](#)). With respect to clean energy technologies, the *National High-Tech R&D Program* (863 Program) established in 1986 and the *National Basic R&D Program* (973 Program) from 1997, have provided most of the direct funding on technology development ([Tan, 2010](#)). Additionally, in 2006 the Science and Technology National Plan was established giving a top priority to clean energy technologies and environmental protection. It has introduced several measures to stimulate private sector R&D and innovation in China ([Tan, 2010](#)). Programs supporting science and technology (S&T) development have become increasingly important at both the national and regional levels, with provincial government R&D spending recently catching up, reaching a similar magnitude as central government fund provisions. The central government R&D appropriation directed to renewable energy increased from 21.1 billion Yuan (USD 2.5 billion) in 1996 to 104.8 billion Yuan (USD 15.2 billion) in 2008. While local or regional governments spend 7.8 billion Yuan (USD 940 million) in 1996 this amount increased to 105.7 billion Yuan (USD 15.4 billion) in 2008 (Figure 6).

Figure 6: Central and provincial government R&D appropriation directed to renewable energy 1996 - 2008

² Admittedly, the picture changed after 2008 with stongly increasing solar PV capacity and generation development. In 2011 China allready produced 3 billion KWh of solar electricity.

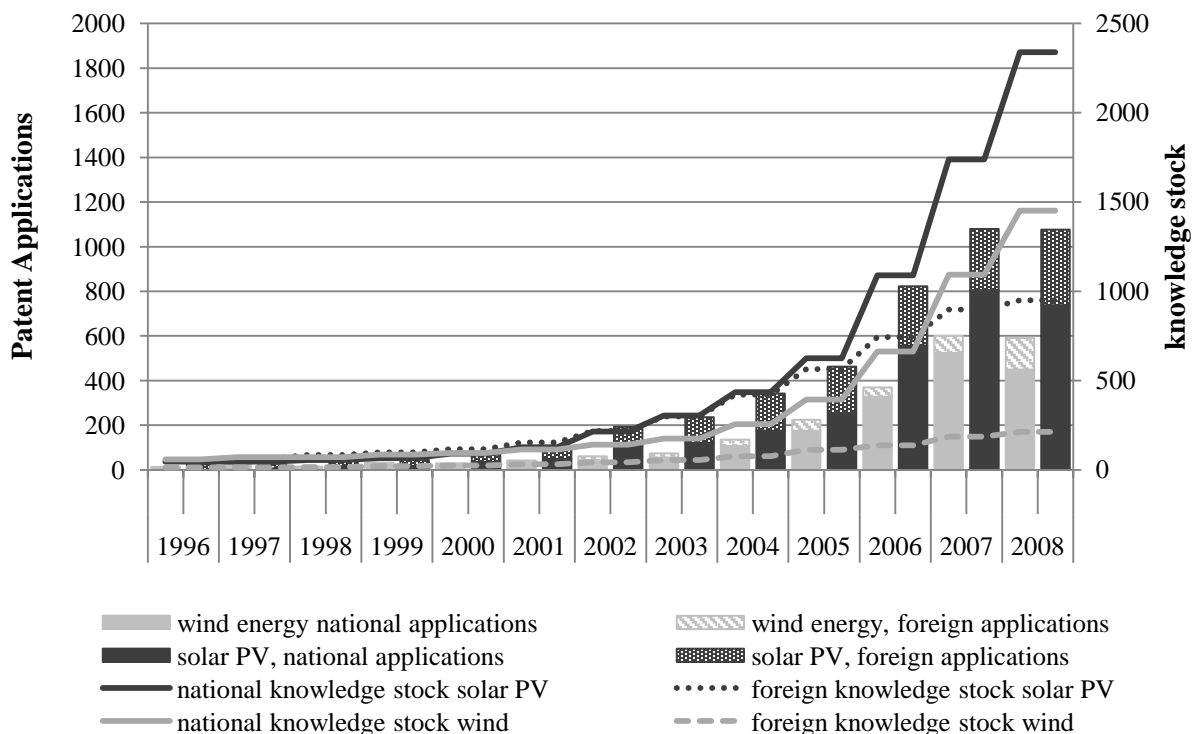


Sources: Tan(2010) and Ministry of Science and Technology (MOST) - China Science & Technology Statistics Data Book

Government R&D spending is only one measure of innovative activity and might be insufficient, as it only reflects inputs into the innovative process without measuring the research output. In this research, longer time series data recording China's R&D spending specifically on solar PV and wind energy is not available. Additionally, using government R&D spending neglects R&D efforts by industry as well as the potential role of foreign knowledge. Griliches (1990) and Popp et. al. (2011) highlight that patent data provides meaningful alternative indicators on innovation and technology transfer as they focus on inventive process output and provide information on the origin of the invention, the technology and the applicant. In China, IPR rights were strengthened by major amendments to the Chinese patent law in 1995 and 2001 to set appropriate incentives for innovation and to attract foreign knowledge toward China (Hu and Jefferson, 2009, Sun, 2003). Some studies analyze the development of innovation, technology transfer and patenting showing that the increased propensity to patent by foreigners in China is driven by Chinese patenting and by other foreign inventors patenting in China (Hu and Mathews, 2008, Hu, 2010). Furthermore, the literature overview in Section 2 highlighted that government policies supporting innovation and technology transfer are key elements in explaining trade flows and the rapid development of the solar PV and wind energy industry in China. Building upon this literature, we expect that both R&D spending and foreign and national knowledge are related to respective technology exports. Following

the classification by Johnston et. al (2010), based on the International Patent Classification (IPC) system and Dechezleprêtre (2010, 2011) to differentiate between foreign and national knowledge, we obtain solar PV and wind energy patent data from the European Patent Office’s Worldwide Patent Statistical database (EPO, 2010). Similar to Hu and Mathews (2008), Hu and Jefferson (2009) and Wu and Mathews (2012), but for solar PV and wind energy technologies, the data show that patenting activity began to surge in the early 2000s (Figure 7) ³.

Figure 7: Foreign and national patent applications and knowledge stock for solar PV and wind energy technology in China



Sources: Patent Applications authors' calculations based on EPO PATSTAT 2010 Note: Number of patent applications in fractional counts to avoid duplications, knowledge stock calculation is based on a depreciation rate of 0.15.

³ See also Section 4.1 and Appendix 5 for a more detailed outline of this approach. In order to avoid duplicates the number of patent families is counted. Knowledge stock is calculated using a depreciation rate of 0.15. The number of total patent applications has been cross checked with the Chinese State Intellectual Property Office (SIPO).

The total number of patents applied for both technologies by foreign and Chinese inventors increased rapidly. With respect to solar PV innovation, the data show that 88 percent of patents applied for in China in 1996 were invented by foreigners. This figure decreased to 48 percent in 2000 and 31 percent in 2008. Innovation and foreign technology transfer in wind energy technology experienced a similar development, although foreign knowledge in terms of patent applications initially played a smaller role in 1996 accounting for only 32 percent in 1996 and 24 percent in 2008. The subsequent increasing gap between national and foreign knowledge is in line with findings highlighting a shift from imitation and cooperation to indigenous innovation.

4 Empirical framework: gravity model for trade analysis

Section 3.1 described the development and structure solar PV and WETC trade highlighting that the majority of Chinese exports is imported by high income OECD countries. In fact, approximately 70 percent of Chinese solar photovoltaic (PV) component exports in 2008 were imported by six countries: Germany, the US, Japan, Korea, Italy, and Spain. The empirical trade flow analysis to identify determinants of trade generally adopts a gravity model. Accounting for the different potential drivers, such as those highlighted in Sections 3.2 and 3.3 and further described in Section 5, that go beyond standard trade determining variables, we adopt an augmented gravity model as follows:

$$X_{ijt} = \beta_0 \left(\frac{Y_{it}^{\beta_1} Y_{jt}^{\beta_2} Z_{ijt}^{\beta_n}}{D_{ij}^{\beta_3}} \right) \eta_{ijt} \quad (1)$$

where X_{ijt} is the dependent variable describing specific technology export flows between destination country i and exporting country j , i.e. China, as a function proportional to economic mass (Y), a suite of additional explanatory variables (Z) and inversely proportional to trade costs such as distance (D). Based on work of Tinbergen (1962), the model gives a generally successful empirical performance and its theoretical foundations are strong (Anderson, 1979, Bergstrand, 1985, 1989, Feenstra et al., 2001, Jug and Mirza, 2005, Anderson and van Wincoop, 2003). The generally utilized empirical specification of the gravity model reads as follows:

$$\ln X_{jit} = \beta_0 + \beta \ln Y_{it} + \beta \ln Y_{jt} - \beta \ln D_{ji} + \beta_4 \ln Z_{ijt} + \eta_{ijt} \quad (2)$$

$$\text{with:} \quad \eta_{ijt} = \delta_{it} + \alpha_i + \varepsilon_{ijt}$$

A similar specification is adopted in earlier work identifying the determinants of Chinese trade ([Edmonds et al., 2008](#), [Rodrik, 2006](#)). Using panel data facilitates the recognition of how relevant variables evolve over time as well as identifying time or country specific effects. Proper estimation of this model when small sectoral trade flows are analyzed, as done in this study, requires taking several issues regarding econometric specification and panel data characteristics into consideration. Standard ordinary least square estimation (OLS) yields biased coefficients as the framework is subject to unobserved heterogeneity ([Hsiao, 2003](#)). A common remedy is the employment of random or fixed effects α_i . While the fixed effects estimator controls for time constant unobserved heterogeneity between countries, the random effect estimation assumes exogeneity and imposes no correlation between individual effects and the regressors. This assumption is likely to be invalid, yielding inconsistent estimates as various country specific characteristics that influence import and export behavior are neglected. Using Hausman tests, we show that the null hypothesis of zero correlation between unobserved effects and the dependent variable is rejected; implying that fixed effect estimation is advisable. Additionally, the results LR, LM and F-tests confirm that unobserved heterogeneity is present, indicating that individual effects α_i and country specific time trends δ_t are required. By including these time-invariant and time-variant importing country specific effects we not only control for heterogeneity but also for multilateral trade resistance between China and its trading partners ([Anderson and van Wincoop, 2003](#), [Baldwin and Taglioni, 2006](#)). A remedy is that interesting time invariant variables such as distances are dropped from estimation.

4.1 Frequent zero trade flows and overdispersion

A major source of inconsistency arises under the presence of zero trade flows and log-transformation in the gravity equation under OLS estimation. As the log of zero is not defined, information is lost rendering biased estimates and a loss in efficiency. Zero trade flows, however, are quite common when analyzing bilateral trade data and are frequent

in datasets of sector specific trade flows. Frankel (1997) outlines several widely applied approaches ranging from omitting zero trade flows to replacing them with arbitrarily small numbers or adding one when taking logs. However, each of these approaches suffers from arbitrary data modification and might be subject to sample selection biases as the zeros are not randomly distributed (Westerlund and Wilhelmsson, 2008).

A robust alternative drawing attention in literature is the Poisson pseudo-maximum likelihood estimator (PPML), proposed by Santos Silva and Tenreyro (2006). This level-log retains the dependent variable in levels while right hand side variables remain logarithmized. Therefore, the zero problem is solved and the estimated gravity equation is given as:

$$X_{jit} = \beta_0 + \beta \ln Y_{it} + \beta \ln Y_{jt} - \beta \ln D_{ji} + \beta_4 \ln Z_{ijt} + \delta_{it} + \alpha_i + \varepsilon_{ijt} \quad (3)$$

Santos Silva and Tenreyro (2006) and Winkelmann (2008) argue that Poisson estimation of non-count data is robust against potentially remaining heteroskedasticity and measurement errors in the log transformed right hand side variables thus being more adequate than models assuming homoskedasticity. However, Poisson estimation poses another problem. A violation of the equidispersion condition in the Poisson model not guaranteeing the proportionality condition $E(Y/X) = Var(Y/X)$, does not allow for adequate estimation (Wooldridge, 2002). In our data we find an increasing ratio of the variance to the conditional mean. Hence overdispersion is present, which requires Negative Binominal Regression Model (NBREG) to properly estimate coefficients while allowing the inclusion of zero trade flows (Cameron and Trivedi, 2005, Amiti and Freund, 2010).⁴ But negative binominal models controlling for unobserved heterogeneity through country specific dummies yields consistent maximum likelihood estimates only under strict assumptions as the number of incidental parameters is increasing with sample size (Amity and Freund, 2010, Guimaraes, 2008). Chamberlain (1980) and Mundlak (1978)

⁴In this case, we conducted a likelihood ratio test on the Poisson and the negative binominal distribution on each cross-section section. The test rejects the null hypothesis of equivalence pointing toward overdispersion.

provide an alternative to fixed effects by including averages of time-varying country specific explanatory variables.⁵ We adopt this approach to properly control for present fixed effects such that:

$$\overline{\alpha_i^{Y_{it}; Y_{jt}; Z_{ijt}}} = \frac{1}{t} \sum_{t=1}^t (Y_{it}; Y_{jt}; Z_{ijt}) \quad \text{for } i = 1, 2, \dots, N \quad (4)$$

4.2 China: respecting individual non-variant time series variables and multicollinearity

Standard gravity model studies usually analyze a panel of bilateral trade between multiple importer and exporter countries. In our case we aim at determining drivers of trade between multiple importing countries and only one exporting country. By introducing control variables for Chinese economic development, policy effects and innovation, as specified in the following section, we include variables that vary over time but not across individuals. In this study, these variables are highly but not perfectly correlated potentially causing statistical problems such as high standard errors even under joint significance, implausible coefficient magnitudes and signs ([Green, 2002](#)). In order to reduce multicollinearity issues, control variables for China enter the regression in differences.⁶

4.3 Final model specification

We estimate the Fixed Effects OLS model, the PPML as well as the NBREG models. Even though Santos Silva and Tenreyro ([2006](#)) outline that Poisson estimation of non-count data is robust against remaining heteroskedasticity, we expect the NBREG model to yield consistent and efficient estimates as overdispersion is controlled for ([Wooldridge,](#)

⁵ See also Wooldridge (2010), for an empirical applications see Bergstrand, Egger, Larch (2011)

⁶ An alternative to this approach is estimation in first differences. However, this poses several other problems as first differencing neglects zero trade flows or introduces infinite growth rates with zero observations early in the period analyzed. Furthermore, the interpretation of policy dummy control variables changes from the effect of the existence of these policies to the effect of the introduction of these policies.

2002). Including the variables of interest that will be described in the subsequent section and respecting estimation issues outlined above our final estimation model is described as follows:

$$\begin{aligned}
X_{i\ China\ t} = & \beta_0 + \beta_1 \ln Y_{it} + \beta_2 P_{it} + \beta_3 \ln M_{it} + \beta_4 \ln I_{i\ China\ t} + \beta_5 \Delta \ln Y_{China\ t} \\
& + \beta_6 \Delta \ln P_{China\ t} + \beta_7 \Delta \ln I_{China\ t} - \beta_8 \ln T_{i\ China\ t} - \beta_9 \ln D_{i\ China} \\
& + \delta_{it} + \alpha_i + \varepsilon_{ijt}
\end{aligned} \tag{6}$$

and according to (4) with:

$$\alpha_i = \beta_0 \ln \bar{Y}_i + \beta_{11} \ln \bar{T}_i + \beta_{12} \ln \bar{I}_i + \beta_{13} \ln \bar{M}_i + \beta_{14} \bar{P}_i$$

where β_0 is a constant term, $\ln Y_{it}$ and $\Delta \ln Y_{China\ t}$ represent the economic mass of importing countries and the respective growth in China; Z_{ijt} from (3) has been replaced by a suit of binary variables representing policies in importing countries that promote renewable energy utilization (P_{it}), market size of renewable energy equipment in terms of electricity generated from either solar PV or wind energy ($\ln M_{i,s,t}$), importing country stock of knowledge available in China ($\ln I_{i\ China\ t}$) and controls for growth in R&D appropriation policy ($\Delta \ln P_{China\ t}$) and technology specific knowledge stock in China ($\Delta \ln I_{China\ t}$) as described in Section; D_{ij} representing trading costs in (3) is divided into distance between China and the importing country ($\ln D_{i\ China}$) and effectively applied tariffs of the importing country on imports from China ($\ln T_{i\ China\ t}$). Finally, δ_{it} represent country specific trends and α_i represent country fixed effects canceling out unobserved heterogeneity, thus reducing endogeneity. Consequently, an independent idiosyncratic error ε_{ijt} remains. In the NB estimation specification these country specific effects are approximated using the Chamberlain-Mundlak approach of mean differencing. Both, fixed effect and country specific time trends play a key role when controlling for heterogeneity as discussed earlier.

5 Trade determining variables and data

The gravity model is implemented using annual data of panel of 43 importing countries for the period 1996-2008 accounting for 90 percent of solar PV and wind energy technology component exports from China in 2008. Although, we would like to extend the analysis to incorporate more recent developments, the availability of data permits us to focus only on the period from 1996 to 2008.

5.1 Socioeconomic variables

Economics mass in gravity trade studies is generally control for by using socioeconomic country characteristics such as income and population. The standard gravity literature points out that a country's income is positively related to the bilateral trade volume⁷. Furthermore, according to the environmental Kuznets curve theorem, demand preferences for environmental products increase with income ([Dinda, 2004](#)). Therefore, we expect income per capita to positively affect imports of solar PV and wind energy technology components. Following Frankel ([1997](#)), we include GDP per capita as explanatory variable in order to control for the relationship between higher income and increasing trade flows of more capital intensive products such as those analyzed here. Another mass variables used in the literature is the area of importing countries which is expected to positively affect trade. In our context, country size in terms of area can also be seen as a proxy for renewable energy potential. Data for each of the variables is obtained from the World Development Indicator (WDI) and the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII).

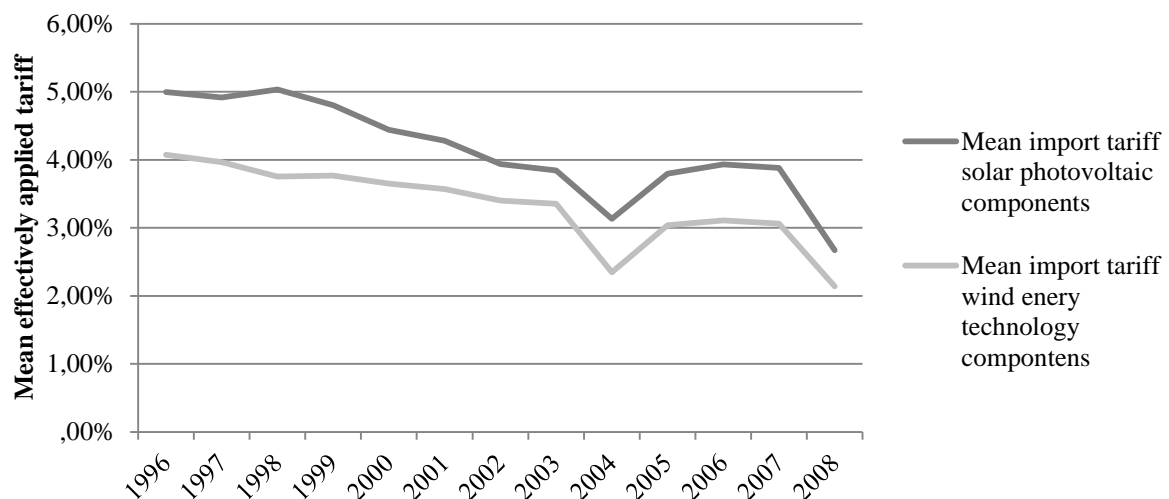
5.2 Trade costs and trade barriers

Trade costs play a significant role in determining trade flows between countries. Hence we include distance between economic centers, which is expected to negatively affect trade as additional costs are induced, and the actual level of trade barriers measured in terms of tariffs effectively applied on Chinese solar PV and wind energy components by

⁷ For an extensive discussion on standard determinants of bilateral trade see Frankel ([1997](#)) and Balassa ([Balassa, 1969](#)).

importing countries. As data on nontariff barriers to be introduced in a cross-country study, this variable serves as standard proxy for the level of trade restrictions.⁸ We expect that higher import duties will reduce imports as higher costs are associated. Figure 8 shows that the mean import tariff applied on import of WETC from China is lower than tariffs imposed on solar PV components. Mean import tariffs for both technology segments have been decreasing in the past decade, suggesting that this reduction is in line with increasing imports.

Figure 8: Mean effectively applied tariffs on imports of solar photovoltaic and wind energy technology components from China



Note: based on the sample of 43 importing countries. Source: authors' calculations based on UNCTAD TRAINS database

The dent of below 1 percent in 2004 is explained by using the tariff applied by the EU to obtain tariffs by EU member countries which do not report individual tariff levels. Yet, the accession of several Central and Eastern European countries to the European

⁸ Several studies outline the importance of non-tariff barriers to trade with environmental goods such as those analysed here. Alavi (2007) shows that non-tariff barriers such as local content, tied in aid and a lack of standards for certification and approval of projects are major barriers for wind energy technology trade. Fliess and Kim (2008) highlight that environmental industry cost-raising factors pose greater problems due to limited resources of small and medium sized companies that are commonly active in the sector.

Union in 2004 raised the mean tariff applied due slower adoptions of EU level import tariffs. This could lead to mixed results as imports were increasing at the same time. However, introducing tariff barriers into the analysis allows us to understand potential effects of increasing tariffs, which were discussed in the US and the EU in early 2012. Data for technology specific import duties in importing countries are obtained from the UN TRAINS databank using the respective HS classifications (Appendix 1).

5.3 Market size and policies promoting renewable energies

In order to capture the market size for renewable energy technology components in importing countries & China, we use the amount of electricity generated (in Million KWh) from solar PV and wind energy. We assume that a large amount of electricity generation from each source corresponds to a high demand of, and thus a large market for, each of the respective technologies components. Consequently, imports are expected to be higher in countries that generate relatively more solar PV and wind energy electricity.⁹ Data is obtained from the EIA ([2012](#)) International Energy Statistics. We also include support policy schemes promoting renewable energies utilization in importing country to control for policy type and market structure to some extent. The importance of these supply side policies for electricity generation and innovation is emphasized in the literature ([Popp et al., 2011](#), [IEA, 2004](#), [Johnstone et al., 2010](#)). Constantini and Crespi ([2008](#)) outline the role of environmental regulation on trade with energy technology components. Yet, the effect that specific renewable energy policies have on trade has not been assessed. We introduce dummy variables for (1) incentive tariffs, (2) obligations and (3) tax measures. Time of enactment information is collected from the IEA/IRENA (2011) Global Renewable Energy Policies and Measures Database. Incentive tariffs are summarized as guaranteed price systems, feed-in tariffs and bidding systems promoting the use of renewable energies. Obligations require suppliers to provide a specific production

⁹ A potential limitation on the feasibility of this variable is the issues of endogeneity as increasing renewable energy generation can also be caused by increased imports of respective technologies. However, this is a feasible way of measuring regulatory output. Nevertheless, we have conduct robustness checks with this variable lagged by one period and results remain robust. Therefore, we assume that endogeneity is not a problem.

quantity or percentage from renewable sources through portfolio standards, quota systems or targets. Tax measures summarize different policies, such as production and investment tax credits and property tax exemptions favoring renewable energy utilization. Table 2 displays the enactment of these policy types in the countries analyzed. Policy enactment is considerably skewed over time as some countries introduced these policies early while others lagged behind. Interestingly, countries that have an especially high share of component imports from China, such as Germany and the US, also have relatively large markets, measured as electricity generation from renewable sources, and introduced such policies early in the 1990s while those that only trade marginally with China implemented respective policies only after the turn of the century. However, policy strength and policy design are of each of the three policies are different across countries. Therefore, a caveat of the analysis is that we cannot measure those differences as only data on policy enactment is available.

Table 2: Years of renewable energy policy enactment in the sample of 43 countries from 1996 - 2008

(1)	FR, AT, SE BE, CH, DE, DK, ES, GB, GR, IE, IT, LU, PT, US			AR, CZ, NO		KR	BR, CA, HU, LT	BG, EE, NL	MT, SI	SK, TR	CY, IN		
(2)	AT, AU, ES, KR, IT BE, CH, NL DK, FI, NZ				FR, DE, CZ, JP, GB, IE, LU, TR NO, SE	BR				RO	IN		PL
(3)	FR, AT, DK BE, CA, FI, GR, IE, IT, KR, LU, NL, SE, TR, US			AR, CZ, PL DE, NO, PT	ES, GB, IN MX		SK	BR, CY	ZA	MT			
	1996 ^a	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008

Notes: Each row represents a renewable energy supportive policy type implemented in the respective country: (1) Incentive Tariffs (2) obligations (3) tax measures. (a) Policies implemented in 1996 or before. *Countries (ISO):* AR Argentina, AT Austria, AU Australia, BE Belgium, BG Bulgaria, BR Brazil, CA Canada, CH Switzerland, CY Cyprus, CZ Czech Republic, DE Germany, DK Denmark, EE Estonia, ES Spain, FI Finland, FR France, GB United Kingdom, GR Greece, HU Hungary, ID Indonesia, IE Ireland, IN India, IS Iceland, IT Italy, JP Japan, KR Korea, LT Lithuania, LU Luxembourg, LV Latvia, MT Malta, MX Mexico, NL Netherlands, NO Norway, NZ New Zealand, PL Poland, PT Portugal, RO Romania, RU Russia, SE Sweden, SI Slovenia, SK Slovak Republic, TR Turkey, US United States, ZA South Africa; *Sources:* IEA/IRENA (2011) Global Renewable Energy Policies and Measures Database; REN21 (2011) Renewables 2011 Global Status Report.

Section 3 highlighted that supply side policy in China has been lagging behind the development in other countries and that the electricity generated from solar PV remained low until 2008, while that of wind energy increased substantially after 2005. Along econometric issues presented in Section 4 we include electricity generation growth from solar PV and wind energy sources in China as a control for environmental regulation or market size and its effect on determining exports. We believe, that an increasing national market might be paralleled by the development of an industry that can also increasingly target international markets as observed in Germany for instance. Yet, on the contrary, a growing national market for solar PV and wind energy components in China could also negatively affect exports as increased national demand for components could be satisfied through national production. In order to test the potential impact we include the lagged growth of solar and wind electricity generation to allow inertia in industry development.

5.4 R&D, knowledge and technology transfer

The literature overview shows that R&D, knowledge adoption capabilities, technology transfer and innovation play an important role in facilitating bilateral trade. In Section 3.2 we show that R&D appropriations in China at the national and provincial level directed at renewable energies increased substantially. We expect increased spending, considered to be a technology push policy, to have a positive trade effect. Section 3.3 points out that patent applications in China surged after 2000, both in total patents and, in particular, patents on solar PV and wind energy technologies. Using patent data the interest of this analysis is twofold. First, we want to identify the role foreign knowledge plays in explaining Chinese exports and whether or not China exports clean technologies to countries that have previously transferred knowledge to China. Second, we aim at understanding the role of Chinese inventiveness in the process of enabling the country to access new markets.

Following the innovation and knowledge spillover literature we introduce two variables to estimate the effect of innovation and knowledge transfer in green technologies.

First, the knowledge stock variable based on patents by inventors from each importing country applied for protection in China is used as a proxy for available foreign knowledge. We expect transfers of knowledge in these sectors to have a positive impact

on imports, as both technology design and production knowledge might have been exported through patents in order to secure future profits in a growing market or for gaining production cost advantages. This expectation is strengthened by a descriptive analysis which, however, also highlights differences between technologies. Countries that contributed most to solar PV technology specific foreign knowledge in China are also among the top ten importers of solar PV components from China. A slightly different picture emerges when looking at technology transfer and imports of wind energy technology components. The market is much smaller and emerging markets, such as India and Indonesia, are among the top ten importers even though they have only marginally transferred knowledge to China (Table 3).

Table 3: Top 10 countries in terms of technology transfer to China and solar energy component imports from China

Technology Transfer Stock to China⁽¹⁾					Imports Technology Components from China				
	1996	2000	2004	2008	<i>(Mio US \$)</i>	1996	2000	2004	2008
Solar PV technology									
Japan	22.2	57.2	261.7	558.5	Spain	3	6	18	4200
United States	10.9	29.3	74.7	159.2	Germany	23	67	388	3700
Germany	2.8	9.1	28.1	84.0	United States	199	382	863	2300
Korea	1.8	5.7	18.3	65.3	Japan	115	388	700	1400
Netherlands	0.5	0.8	4.2	11.8	Korea	6	36	220	1100
France	0.3	1.7	4.5	6.9	Italy	8	15	62	884
Switzerland	4.8	5.1	4.3	6.3	Netherlands	6	26	145	847
Australia	0.4	1.3	4.2	5.1	India	0	7	46	543
United Kingdom	1.7	2.0	3.7	4.5	Belgium	0	5	37	459
Italy	0.1	0.4	3.4	3.7	France	18	51	82	363
Wind energy technology									
United States	4.1	4.4	13.0	57.9	United States	2	26	74	352
Germany	1.0	3.8	12.7	37.3	India	0	0	2	230
Japan	3.0	5.8	18.5	30.3	Japan	8	15	45	183
Denmark	0.0	1.7	10.1	20.8	Indonesia	2	11	18	63
Spain	0.0	0.1	1.4	13.3	Korea	1	0	10	42
Korea	0.1	1.9	3.9	6.6	Germany	0	3	12	31
United Kingdom	0.5	0.4	3.3	4.9	Turkey	0	1	7	28
France	0.2	0.3	0.5	4.5	Italy	0	1	7	26
Italy	0.2	0.2	1.3	3.8	Australia	1	5	5	22
Canada	0.0	0.0	1.7	3.6	Canada	1	1	8	21

Notes: (1) Knowledge stock based on fractional patent counts and a depreciation rate of 0.15, initial knowledge stock based on 1980. Sources: OECD/EPO Patstat Database, UNCTAD Comtrade Database, Authors calculation.

Second, we identify the role of the development of Chinese innovations by introducing the national knowledge stock growth based on patent applications by Chinese in China. Contrary to using only annual patent applications counts, the knowledge stock approach accounts for previous knowledge, which is important to determine innovation success. We expect that increasing national knowledge stock has a positive effect on Chinese exports, as would be in line with the literature outlined above.

More detailed information on these two variables is presented in Appendix 1. Growth in R&D appropriation and knowledge stock in China are lagged by one period to account for technology transition inertia from innovation to market readiness. Using both an innovation input measure in terms of R&D spending and an output measure in terms of patents, might pose difficulties due to multicollinearity. Yet, we use both controls only lagged once which is likely to reduce this problem as R&D spending in one period will not immediately affect research output in that period but only in later periods. Additionally, endogeneity is avoided.

6 Results

The subsequent tables present results for different estimation models on total exports (Table 4), solar PV (Table 5) and wind energy technology component exports (WETC) (Table 6) from China to the sample of 43 importing countries. Estimation results on total exports highlight that the model is correctly specified. These results serve as benchmark for show coefficient size and effects of general trade determining variables also used in the remaining sectoral trade estimations and corresponding model specifications. In terms of total exports, the log-likelihood indicates that the Fixed Effects Ordinary Least Square (FE) estimation is preferred over Poisson (PPML) and negative binomial estimation (NB) as zero trade flows and overdispersion are not present. In the FE estimation 95% of variance are explained by the selected predictors. In this specification a one percent increase in per capita income in importing countries has a trade increasing effect of 3.7 percent. Distance and area are omitted due to fixed effects estimation which drops time-invariant controls. While GDP per capita has a comparable coefficient, the NB specification using the Chamberlain-Mundlak fixed effects approach indicates that a

doubling of distance has a trade decreasing effect of 95 percent, while the area of importing countries has a trade increasing effect as expected. Furthermore, in the FE specification, a one percent increase of Chinese income per capita growth increases exports by 3 percent. The results indicate that the model is calibrated correctly, as the standard control variables have the expected sign and significance and are thus in line with earlier findings ([Edmonds et al., 2008](#)).

Table 4: Preliminary Total imports from China estimation results

	(1) FE	(2) PPML	(3) NB
GDP per capita _{it} ,ln	3.74*** (0.69)	1.95*** (0.65)	3.81*** (0.30)
distance _{i-china} ,ln			-0.95*** (0.15)
area _i ,ln			0.31*** (0.03)
import tariff _{it china s} ,ln	-0.07 (0.05)	-0.00 (0.05)	-0.02 (0.02)
Δ GDP per capita _{China t} ,ln	3.00*** (0.88)	1.77*** (0.63)	0.75* (0.40)
Constant	-23.67*** (6.68)		0.55 (1.94)
country fixed effects	Yes	yes	Chamberlain/ Mundlak
country trend	Yes	yes	yes
N	516	516	516
r2	0.956		
Wald chi2		46.03	16,471.70
P		0.47	0.00
Ll	67.06	-20,974,077	-6,528.22

The first three columns of Table 5 present the same model specification as in Table 4 for solar PV exports from China. Compared to the results estimating total trade, size and significance level of coefficients differ in magnitude to some degree but major features of the gravity model are confirmed throughout the analysis. The fixed effects (FE) model in Specification (1) does not adequately taking into account zero trade flows, which represent 14 percent of the observations. Thus, it is likely to be inconsistent as it is based on manipulated data of the dependent variables ($\ln+1$). The alternative estimation

procedure (PPML) in Specification (2) is also likely to be biased even though it controls for zero trade flows and heteroskedasticity as data is characterized by considerable overdispersion. The log likelihood values indicate that the model fit improves considerably when using NB instead of PPML.

The baseline model is likely to be subject to an omitted variable bias. Consequently, Specifications (4)-(6) extend the baseline model by introducing control variables capturing market size for solar PV components, renewable energy policy support schemes in importing countries and technology specific knowledge transfer from importing countries to China. Specifications (7)-(16) additionally introduce controls for policy development in China in terms of R&D appropriation growth and national knowledge stock development as well as renewable energy market development in China. To the extent that there might be multicollinearity between R&D efforts and the knowledge stock in China, we estimate these variables separately in Specifications (11)-(16). Most coefficients are robust across different model specifications.

The preferred NB model shows that a one percent increase in importing country per capita income yields an increase of solar PV component imports of 4.5 percent (Specification 3) to 3.6 percent (Specification 16). As suggested by theory, distance has a significant negative impact on trade in the baseline model outlining that a doubling of distance decreases trade by 137 percent in Specification 3. Yet, including further controls reduces this effect considerably and the coefficient becomes insignificant. The coefficient on technology specific import tariffs is negative and significant in Specifications (6), (9), (13) and (15) Yet, a one percent increase in tariffs decreases trade only by 0.05 percent.

The strongly significant coefficient on solar PV electricity generation in destination markets indicates that a one percent increase in market size in importing countries is estimated to increase respective imports from China between 2.76 percent (Specification 6) and 1.8 percent (Specification 9).

1 **Table 5:** Estimation results for imports of solar photovoltaic components from China

	<i>Baseline</i>			<i>Market and Policies in i</i>			<i>Full Model</i>								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(11)	(12)	(13)	(14)	(15)	(16)
	FE	PPML	NBREG	FE	PPML	NBREG	FE	PPML	NBREG	FE	PPML	NBREG	FE	PPML	NBREG
GDP per capita _{it} , ln	2.27 (1.89)	1.09 (1.50)	4.50*** (0.60)	2.84 (2.01)	-0.02 (0.99)	4.54*** (0.61)	3.02 (1.91)	1.31* (0.79)	3.41*** (0.72)	2.88 (1.92)	1.48* (0.82)	4.69*** (0.74)	2.91 (1.84)	1.65* (0.86)	3.61*** (0.72)
distance _{i-china} , ln			-1.37*** (0.27)			-0.30 (0.30)			-0.05 (0.33)			-0.17 (0.32)			-0.30 (0.33)
area _i , ln			0.70*** (0.05)			0.55*** (0.08)			0.51*** (0.08)			0.51*** (0.08)			0.53*** (0.08)
import tariff _{it china s} , ln	-0.05 (0.07)	0.03 (0.04)	-0.01 (0.02)	-0.07 (0.07)	0.01 (0.03)	-0.04** (0.02)	-0.07 (0.08)	0.00 (0.03)	-0.06*** (0.02)	-0.07 (0.07)	0.01 (0.03)	-0.05** (0.02)	-0.06 (0.07)	0.01 (0.03)	-0.05*** (0.02)
Δ GDP per capita _{China t} , ln	6.10 (3.95)	-0.73 (2.03)	1.42* (0.74)	5.80 (3.86)	1.33 (1.48)	1.74** (0.88)	3.56 (4.19)	1.05 (1.15)	1.74 (1.53)	3.63 (4.12)	-0.31 (1.35)	0.79 (1.51)	5.71 (3.84)	1.30 (1.42)	2.20* (1.33)
electricity gen _{it s} , ln				2.28*** (0.46)	0.40*** (0.14)	2.76*** (0.43)	2.34*** (0.36)	0.26** (0.13)	1.83*** (0.42)	2.33*** (0.35)	0.27** (0.12)	2.04*** (0.40)	2.27*** (0.34)	0.32** (0.14)	1.91*** (0.42)
tax measures _{it}				0.30 (0.29)	-0.36* (0.19)	-0.02 (0.12)	-0.04 (0.27)	-0.23 (0.21)	0.00 (0.13)	-0.03 (0.26)	-0.26 (0.21)	0.10 (0.13)	-0.00 (0.27)	-0.30 (0.21)	-0.06 (0.13)
incentive tariffs _{it}				0.72 (0.46)	0.36* (0.21)	0.28** (0.12)	0.55 (0.45)	0.41** (0.16)	0.33*** (0.13)	0.55 (0.45)	0.42*** (0.16)	0.36*** (0.13)	0.57 (0.45)	0.38** (0.18)	0.30** (0.12)
obligations _{it}				-0.50* (0.27)	-0.37*** (0.10)	-0.11 (0.10)	-0.49* (0.25)	-0.21** (0.09)	-0.10 (0.10)	-0.47* (0.26)	-0.29*** (0.10)	-0.12 (0.10)	-0.45* (0.24)	-0.31*** (0.09)	-0.07 (0.10)
Tech Transfer _{i china s t-1} , ln				-0.09* (0.05)	-0.09 (0.07)	-0.01 (0.02)	-0.12** (0.05)	-0.07 (0.06)	-0.01 (0.02)	-0.12** (0.05)	-0.07 (0.06)	-0.01 (0.02)	-0.12** (0.05)	-0.08 (0.07)	-0.02 (0.02)
Δ electricity gen _{s China t-1} , ln							-3.98 (8.08)	2.58* (1.32)	2.32 (2.97)	-3.91 (8.03)	-0.59 (2.29)	1.54 (2.93)	0.75 (5.80)	1.69* (0.98)	1.30 (2.64)
Δ ST central _{China t-1} , ln							0.55 (0.85)	0.48* (0.25)	0.44 (0.34)	0.71 (0.67)	0.13 (0.10)	0.06 (0.32)			
Δ ST local _{China t-1} , ln							-0.84 (0.77)	0.68*** (0.26)	0.75*** (0.27)	-0.92 (0.90)	0.47 (0.31)	0.70*** (0.27)			
Δ KnowStock _{s China t-1} , ln							0.28 (0.93)	-0.70** (0.28)	-0.53** (0.25)				0.44 (0.82)	-0.30 (0.27)	-0.13 (0.23)
constant	-17.48 (18.19)		-3.11 (2.66)	-23.50 (19.35)		0.66 (2.70)	-25.05 (18.34)		-2.07 (3.23)	-23.67 (18.53)		-0.28 (3.04)	-24.25 (17.77)		-0.26 (3.25)
country fixed effects ⁽²⁾	yes	yes	Mundlak	yes	yes	Mundlak	yes	yes	Mundlak	yes	yes	Mundlak	yes	yes	Mundlak
country trend	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
N	516	516	516	516	516	516	473	473	473	473	473	473	473	473	473
r2	0.851			0.859			0.857			0.857			0.857		
Wald chi2 ⁽¹⁾		2,335.50	7,952.45		4,229.11	7,474.40		5,701.87	8,167.70		4,814.84	7,815.82		3,551.34	7,738.09
ll	-666.4	-755,229	-4,140.9	-652.2	-632,071	-4,145.7	-570.29	-526,751	-3,822.9	-570.44	-550,796	-3,833.8	-570.99	-559,522	-3,828.1

Note: *** p<0.01, ** p<0.05, * p<0.1 denote significance level at 1%, 5% and 10%. Cluster robust standard errors in parenthesis. FE Fixed Effects OLS Regression, PPML Poisson Pseudo Maximum Likelihood Regression, NBREG Negative Binominal Regression. (1) Wald χ^2 p values not reported, all significant. (2) Mundlak/Chamberlain approach for fixed effects in NBREG model.

With respect to demand push policies in importing countries, incentive tariffs, implemented to incentivize renewable electricity generation, are estimated to increase solar PV imports from China between 34 percent and 43 percent (Specification 16 and 6).¹⁰ Other policies such as tax measures and obligations have no statistically significant impact when focusing on NB estimation. Controlling for time trends, the growth of the market for solar PV components in China in terms of solar PV electricity generation has no significant effect. This result however is not surprising as the Chinese market remained very small as outlined above.

The country specific technology transfer and thus foreign knowledge in China, measured as patent-based knowledge stock, has no significant impact on bilateral exports. One reason behind this could be that once technology in terms of patents is transferred to China from one country the product produced with that knowledge or containing this knowledge can be exported to all countries and not just that specific country where the innovation originated. Additionally, national knowledge stock, also based on patent data, remains ambiguous ranging from a negative 0.5 percent significant impact of a one percent change in specification (9) to a non-significant effect in specification (16). With respect to Chinese renewable energy R&D policy a one percent increase in provincial government R&D appropriation growth ranges from 0.7 percent (column 13) to 0.75 percent (column 9) and is significant at the one percent level. Central government S&T appropriation growth on the other hand, showing high but lower growth rates than provincial government R&D spending, has no significant impact. These results however should be treated with caution for two reasons. First, the true amount of S&T appropriations allocated to research in solar PV remains unclear and is only approximated in this study. Second, as we have to use growth rates as an explanatory variable and are controlling for time effects at the same time a large amount of explanatory power is lost due to differencing or is captured by controlled time trends.

Table 6 presents results on WETC exports. As export flows are much smaller the number of zero trade flows increases to 37 percent while overdispersion is still present. The sample size is reduced because of all zero outcomes of the dependent variable for

¹⁰ Results from calculating $e^{\text{estimated coefficient} - 1}$.

some countries. Negative binomial (NB) estimation in Specification (3), (6), (9), (13) and (16) is still preferred. Results indicate that especially high per capita income countries import WETCs from China – namely, a one percent increase in per capita income increases imports from China between 9.1 percent in the baseline model (Specification 3) to around 7.7 percent in the full model specification (Specification 9,13 and 16). The distance between economic centers of China and the importing country is negative for all specifications indicating a trade decreasing effect for a doubling of distance ranging from 199% percent to 50 percent. Yet, again as for solar PV exports the coefficient is only significant for specifications not including additional control variables of innovation and R&D in China. Tariffs on WETC imports from China surprisingly have a positive significant impact on trade flows as a one percent increase in effectively applied tariffs increases trade flows by 0.05%. Thus, this result stays in contrast to the standard belief of liberalization leading to increased trade and might be explained by the small sector analyzed here, the dominance of the international market by only a few companies and the fact that more is exported to emerging markets such as India and Indonesia that apply higher tariffs.

A large market for WETC, approximated by wind electricity generation in importing countries has a negative impact but is only significant at the 5% level. Namely, a one percent increase in wind electricity generation decreases imports from China by 0.7 percent in Specification (6) to 0.5 percent in Specification (9). This result is surprising as a positive impact was expected. Yet, the existence of a strong wind energy industry in markets with large wind energy electricity generation, such as Denmark, Germany and the US, might explain this finding as demand is rather satisfied by local production. Yet, this finding is in line with the effect renewable energy support policies in importing countries have on trade flows as they are also only weakly significant if at all. Incentive tariffs, for instance, have a statistically weak significant impact increasing trade flows by 55 percent in Specification (6). Yet, the results are insignificant if we additionally control for exporting country characteristics of China using NB estimation in Specification (9), (13) and (16). Chinese market growth for WETC in terms of electricity generation has a significant trade decreasing effect as a one percent increase decreases Chinese exports between 2.1 percent in Specification (9) and 1.3 percent in Specification (16).

1 **Table 6:** Preliminary estimation for imports of wind energy technology components from China

	Baseline			Market and Policies in <i>i</i>			Full Model								
	(1) FE	(2) Poisson	(3) NBREG	(4) FE	(5) Poisson	(6) NBREG	(7) FE	(8) Poisson	(9) NBREG	(11) FE	(12) Poisson	(13) NBREG	(14) FE	(15) Poisson	(16) NBREG
GDP per capita _{it} , <i>ln</i>	8.60*** (3.12)	4.81* (2.75)	9.13*** (1.06)	8.18*** (3.12)	3.35*** (1.03)	8.46*** (0.97)	10.2*** (3.79)	2.69 (1.88)	7.76*** (1.37)	10.60*** (3.77)	2.87 (2.31)	7.89*** (1.05)	9.78** (3.87)	2.73 (1.68)	7.65*** (1.36)
distance _{i-china} , <i>ln</i>			-1.99*** (0.20)			-0.91*** (0.32)			-0.53 (0.37)			-0.51 (0.35)			-0.50 (0.36)
area _i , <i>ln</i>			0.81*** (0.08)			0.52*** (0.13)			0.42*** (0.14)			0.41*** (0.14)			0.41*** (0.14)
import tariff _{it china s} , <i>ln</i>	-0.02 (0.05)	0.04* (0.02)	0.06*** (0.01)	-0.02 (0.06)	0.05* (0.02)	0.05*** (0.01)	-0.02 (0.06)	0.05** (0.02)	0.03*** (0.01)	-0.02 (0.06)	0.05** (0.02)	0.03*** (0.01)	-0.02 (0.06)	0.05** (0.02)	0.03*** (0.01)
Δ GDP per capita _{China t} , <i>ln</i>	19.22** (9.06)	-0.86 (4.46)	-2.26 (2.05)	18.39** (8.75)	-1.20 (4.12)	-1.19 (2.17)	23.99** (10.35)	-4.18 (2.59)	7.57** (3.14)	27.28** (10.67)	-4.29 (2.71)	7.45** (3.08)	20.19* (10.56)	-3.74 (4.05)	6.80** (2.77)
electricity gen _{it s} , <i>ln</i>				-0.19 (0.84)	-0.30 (0.22)	-0.72*** (0.21)	-0.06 (0.76)	-0.53* (0.31)	-0.54** (0.25)	0.17 (0.77)	-0.51* (0.30)	-0.52** (0.25)	-0.04 (0.76)	-0.53* (0.28)	-0.56** (0.24)
tax measures _{it}				-0.56 (0.50)	-1.13* (0.60)	0.33 (0.30)	-0.24 (0.36)	-1.07** (0.47)	0.40 (0.34)	-0.33 (0.35)	-1.11** (0.53)	0.42 (0.32)	-0.28 (0.38)	-1.06** (0.51)	0.41 (0.35)
incentive tariffs _{it}				0.83 (0.58)	0.67 (0.42)	0.44* (0.25)	0.88 (0.62)	0.69* (0.40)	0.42 (0.28)	0.87 (0.62)	0.70* (0.42)	0.41 (0.28)	0.88 (0.62)	0.69* (0.40)	0.44 (0.28)
obligations _{it}				0.40 (0.60)	0.05 (0.28)	0.37 (0.27)	-0.10 (0.57)	0.16 (0.28)	0.13 (0.31)	-0.13 (0.57)	0.14 (0.26)	0.13 (0.31)	-0.09 (0.58)	0.16 (0.29)	0.13 (0.31)
Tech Transfer _{i china s t-1} , <i>ln</i>				-0.03 (0.08)	0.17*** (0.04)	0.04 (0.04)	0.07 (0.07)	0.18*** (0.03)	0.06 (0.04)	0.07 (0.07)	0.17*** (0.03)	0.07 (0.04)	0.08 (0.07)	0.18*** (0.03)	0.06 (0.04)
Δ electricity gen _{s China t-1} , <i>ln</i>							-4.79*** (1.85)	0.62 (1.70)	-2.09** (0.93)	-4.16** (1.80)	0.99 (0.90)	-1.92*** (0.72)	-3.01** (1.35)	0.35 (0.75)	-1.26*** (0.43)
Δ ST central _{China t-1} , <i>ln</i>							0.62 (0.84)	-0.09 (0.55)	0.48 (0.45)	0.31 (0.83)	-0.17 (0.43)	0.44 (0.43)			
Δ ST local _{China t-1} , <i>ln</i>							2.58 (1.85)	-0.32 (1.63)	0.87 (1.05)	2.60 (1.85)	-0.66 (0.90)	0.69 (0.83)			
Δ KnowStock _{s China t-1} , <i>ln</i>							1.96* (1.11)	0.62 (1.58)	0.23 (0.90)				1.75 (1.09)	0.75 (0.94)	-0.31 (0.73)
constant	-82.9*** (29.98)		4.90 (3.13)	-79.1*** (30.12)		-2,706.67	-98.7*** (36.79)		18.48*** (4.66)	-103*** (36.58)		18.95*** (4.21)	-94.16** (37.59)		18.80*** (4.65)
country fixed effects	yes	yes	Mundlak	yes	yes	Mundlak	yes	yes	Mundlak	yes	yes	Mundlak	yes	yes	Mundlak
country trend	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
N	516	492	492	516	492	492	473	451	451	473	451	451	473	451	451
r2	0.742			0.747			0.760			0.758			0.757		
Wald chi2		800.73	2,608.43		295 Mio.	2492.54		2,617.64	2,639.07		2,420.90	2,648.36		1,804.07	2,631.53
ll	-894.61	-200,893	-2,713	-890.13	-166,694	-2706.67	-782.99	-158,310	-2,545.09	-784.78	-158,699	-2,545.13	-785.24	-158,398	-2,545.79

Note: *** p<0.01, ** p<0.05, * p<0.1 denote significance level at 1%, 5% and 10%. Cluster robust standard errors in parenthesis. FE Fixed Effects OLS Regression, PPML Poisson Pseudo Maximum Likelihood Regression, NBREG Negative Binominal Regression. (1) Wald χ^2 p values not reported, all significant. (2) Mundlak/Chamberlain approach for fixed effects in NBREG model.

This result highlights that increasing national demand might be satisfied with Chinese production that potentially reduces exports. Thus, it is in line with the finding for the market size variable in importing countries.

Country specific technology transfer and national knowledge stock on wind energy technology – similar to the solar PV result in Table 5– have no significant impact on trade flows in a NB estimation framework. Differently, to the results in Table 5 – R&D appropriations of both central and provincial governments have no significant effect on exports.

7 Discussion and Conclusion

The export performance of China with respect to solar PV and wind energy technology components (WETC) has been exceptional since 2005. Our research aimed at outlining this development and examining the drivers behind it. We show that China runs large exports surpluses with only a few developed countries in both technology sectors and that it gained a considerable comparative advantage. Our findings are in line with more general trade studies outlining that China has developed comparative advantages in highly sophisticated good exports that do not necessarily corresponding to its level of development ([Rodrik, 2006](#), [Schott, 2008](#)). We show that China trades only marginally with other emerging markets and developing countries – especially with respect to solar PV technology components.

This empirical study is the first attempt at estimating the driving factors of Chinese solar PV and wind energy components exports. The few existing studies in this field are limited to descriptive studies trade development and policy performance and innovation. We conduct an *ex-post* econometric study using an augmented gravity model and a panel dataset of 43 countries from the developed and developing world that imported solar PV and WETCs from China between 1996 and 2008. In addition to controlling for standard socioeconomic variables derived from the gravity trade literature, we consider several explanatory factors accounting for market, policy and innovation effects steaming from both importing countries and China. Specifically, we are interested in the effect of renewable energy support schemes and the renewable energy market size in importing countries on export flows from China. Furthermore, the role of Chinese R&D policy,

innovation and bilateral technology transfer as well as the Chinese demand market for solar PV and WETCs is of interest.

The results highlight that importing country per capita income has a significant positive effect on solar PV and WETC imports from China. The growth of Chinese per capita income also has a significant effect on exports. This is in line with the general trade literature showing that trade increases with country income. It also supports the environmental Kuznets curve hypothesis arguing that demand for (and supply of) environmental goods increases with income. Additionally, the area of importing countries, seen as a proxy for economic mass and also for renewable energy potential, has a significant effect.

With respect to trade costs we find that distance has no significant effect but that high import tariffs have a negative effect on solar PV imports, as higher costs are associated. This result is insightful from the perspective that reduced tariffs are likely to increase the availability of this technology in the global market, in particular for developing countries. Results on tariffs applied to WETC imports, however, are surprising as higher tariffs are associated with higher imports. However, this can be explained by several factors. First, WETC exports from China are extremely small compared to exports of solar PV components. Second, a larger share of exports is imported by developing countries, especially the East Asian economies and India, which apply higher tariffs. Thus, the result might be driven by the small size of the sector analyzed.

The results also highlight that market size in importing countries is very important for understanding trade flows of solar PV components but not decisive for determining WETC exports. Strong development of electricity generation as an indicator for market size increases imports of components to satisfy demand. The results for wind energy technologies are different as a large market in terms of electricity generation in importing countries reduces imports of wind energy components. A possible explanation for this finding is that countries with a large amount of generation, such as the USA, Denmark and Germany, have a strong, competitive wind turbine industry themselves and are thus not as reliant on technology imports. Additionally, countries with a smaller market, such as India and Indonesia import relatively more – compared to the solar PV market analysis. Growth of the wind energy market in terms of electricity generation in China has a

negative impact on respective exports, while that of solar PV did not. This is in contrast to Sawhney and Kahn (2012) who suggest that solar PV exports to the US are determined by the exporting country market size. However, the descriptive analysis also highlighted while the national market remained small in terms of solar PV electricity generation, the solar PV component industry became particularly successful in targeting foreign markets. On the contrary, while the country developed a large home market for electricity generated from wind energy, its export performance in the sector increased but remained relatively small. In terms of policy this is interesting as it suggests that a future growth of the home market for solar PV in China might eventually decrease the currently large export surplus of the sector as rather the home market will be supplied. However, more research is required in this respect.

We also show that the policy structure supporting renewable energy dissemination in importing countries has some effect at least on solar PV component imports from China. Differentiating between incentive tariffs, obligations and tax measures, we find that countries with an incentive tariff scheme in place are importing significantly more solar PV components than countries that have only implemented tax measures and obligations. This makes sense insofar as feed-in tariffs are considered to be a very effective policy instrument for increasing generation from solar PV. However, these results should be interpreted cautiously for several reasons. First, we only test the effect of policy existence, as available data does not allow controlling for policy strength and policy design across countries. Second, numerous countries have simultaneously implemented policy designed to strengthen renewable energy dissemination, but we only test for selected policies neglecting this policy mix.

The paper also aims at identifying the effect of the Chinese R&D policy and innovation as well as the role of foreign knowledge as potential drivers for exports. Results are ambiguous but not in contrast to findings in the literature. We use data on central and provincial government S&T appropriations that have been identified in earlier literature as being directed to R&D on renewable energy.

We find that only provincial R&D spending growth has a positive effect on Chinese solar PV exports, while central government R&D spending seems to have no empirically significant effect. We see several reasons for this finding. First, provincial government

R&D spending experienced greater growth rates than that from the central government. Second, while central government S&T appropriations for renewable energies are linked to public institutions and universities, and thus the provision of public goods or basic research, this link is not so clear for provincial government appropriations, which are likely to be directed to specific technologies and projects. Also, indirectly explaining the insignificance of central government R&D appropriation, investment support for manufacturing through, among other, R&D policies has not been sufficiently tied to innovation incentives ([Grau et al., 2012](#)). However, these results however should be treated cautiously for two reasons. First, the true amount of S&T appropriations allocated to research in solar PV and wind energy remains unclear and is only approximated in this study. Second, as we have to use growth rates as an explanatory variable and are controlling for time effects a large amount of explanatory power can be lost due to differencing or is captured by controlled time trends.

We use technology specific patent data to obtain national and foreign knowledge stock in China in order to test the role of innovation and technology transfer in the context of trade. We show that the national knowledge stock on wind and solar PV technologies increased substantially in China. Estimation results however are puzzling. Growth in national knowledge does not play a significant role in determining exports of either technology components. Descriptively we highlighted that countries that have transferred more innovations to China in terms of patents on solar PV and wind energy technology also import more of the respective technology components. Yet, empirically we do not find any effect of bilateral knowledge transfer to China on technology component imports from China. One reason behind this could be that once technology, in terms of patents, is transferred to China from one country, the product produced with that knowledge or containing this knowledge can be exported to all countries and not just the specific country where the innovation originated. Furthermore, several data limitations and a reflection of the existing literature on innovation and the clean energy sector in China potentially help explain these results and require further research. The estimation techniques adopted in this study do not allow measuring different means of technology transfer, such as purchasing manufacturing equipment or hiring a skilled foreign trained workforce, as outlined by [de la Tour \(2011\)](#). Also, the literature suggests

that both industries moved from imitation and cooperation to indigenous innovation ([Lewis, 2011](#)). Yet, imitation is not likely to be patented. Furthermore, own knowledge generation only recently became more important ([Wu and Mathews, 2012](#)) and thus might not yet be reflected in the period analyzed. Additionally, the patent data used in this context does not control for innovations in the technology used for production of components used for electricity generation but only differentiate the latter. Further, although traded products are uniquely identified in international trade statistics, thus permitting a sector specific analysis, the product position in the production chain cannot be identified. However, knowledge transfer and innovation in production technologies and understanding whether upstream or final products are produced and traded might also be central in explaining Chinese industry development.

Appendix

Appendix 1: Nomenclature of solar photovoltaic and wind energy components in, HS 1996

HS Code	Explanation
Solar Photovoltaic (PV) components	
850440	Static converters [Inverters for converting DC power to AC power] - change solar energy into electricity.
850720	Other lead-acid accumulators [solar batteries], i.e batteries for energy storage in off-grid photovoltaic systems.
854140	Photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels; light emitting diodes.
Wind energy components	
841280	Other [Steam engines, windmill, without pumps
841290	Parts for Steam engines and windmills.]
841381	Pumps for liquids, whether or not fitted with a measuring device, other pumps
850231	Generating sets, electric, wind-powered
850239	Other generating sets
850240	Electric generating set and rotary converters [set combining an electric generator and either a hydraulic turbine or a sterling engine]
730820	Wind Turbine Towers

Sources: OECD, Eurostat (1999); Steenblik, R. (2005, 2006) Wind, I. (2008).

Appendix 2: Development of Chinese exports and imports of components for potential renewable energy use and export and import market shares compared to selected countries

	Solar Photovoltaik					Wind				
	1996	2000	2004	2008	2010	1996	2000	2004	2008	2010
Export Development Index (2000=100)										
Germany	81	100	163	586	717	123	100	208	997	901
China	39	100	277	1587	2681	48	100	356	1774	1216
Denmark	84	100	114	239	380	87	100	228	627	575
Japan	59	100	155	247	253	59	100	135	394	225
Korea, Rep.	128	100	206	461	0	98	100	181	364	0
Spain	59	100	396	511	1931	56	100	147	572	995
United Kingdom	68	100	92	178	142	129	100	95	176	132
United States	54	100	84	151	163	129	100	187	386	583
Import Development Index (2000=100)										
Germany	71	100	207	619	1073	58	100	273	415	530
China	23	100	403	810	1254	102	100	258	323	278
Denmark	89	100	117	256	216	167	100	164	558	497
Japan	60	100	130	177	204	37	100	222	355	253
Korea, Rep.	54	100	224	557	0	94	100	186	347	0
Spain	69	100	187	3693	1005	133	100	134	443	222
United Kingdom	61	100	78	137	126	114	100	149	466	827
United States	53	100	91	153	181	44	100	115	821	475
Global export share in percent										
Germany	15.9	11.2	13.4	17.1	15.9	10.2	7.5	9.5	15.8	16.1
China	5.0	7.4	15.0	30.6	39.1	1.1	2.0	4.4	7.7	5.9
Denmark	1.9	1.3	1.1	0.8	1.0	10.3	10.8	15.0	14.3	14.8
Japan	15.8	15.3	17.5	9.9	7.7	3.5	5.3	4.4	4.5	2.9
Korea, Rep.	3.2	1.4	2.2	1.7	0.0	0.7	0.7	0.7	0.5	0.0
Spain	0.7	0.6	1.8	0.8	2.4	2.1	3.4	3.1	4.2	8.2
United Kingdom	8.0	6.8	4.6	3.2	1.9	7.8	5.4	3.2	2.0	1.7
United States	14.9	15.9	9.9	6.3	5.2	18.5	12.9	14.8	10.6	18.1
Global import share in percent										
Germany	11.2	8.4	12.9	15.5	20.7	8.0	8.7	15.2	7.8	11.4
China	1.4	3.2	9.6	7.8	9.3	8.3	5.1	8.5	3.6	3.5
Denmark	0.9	0.6	0.5	0.4	0.3	1.9	0.7	0.8	0.9	0.9
France	5.6	4.7	3.5	3.4	4.8	9.4	5.5	3.0	2.3	2.5
Italy	3.7	2.8	2.8	4.3	13.9	3.1	2.4	2.1	2.5	2.4
Japan	9.6	8.5	8.1	4.5	4.0	1.2	2.0	2.9	1.6	1.3
Korea, Rep.	3.0	2.9	4.8	4.8	0.0	4.4	3.0	3.6	2.2	0.0
Netherlands	2.5	3.7	3.7	2.3	3.8	2.0	1.7	1.9	1.7	1.6
Spain	1.5	1.1	1.6	12.6	2.6	5.7	2.7	2.3	2.6	1.5
United Kingdom	7.4	6.4	3.7	2.6	1.9	6.9	3.8	3.6	3.8	7.7
United States	30.5	30.5	20.3	13.8	12.7	9.9	14.0	10.4	25.0	16.6

Appendix 3: Trade related sector specific indicators of competitiveness of China and selected countries by components for potential renewable energy use

	Solar Photovoltaik					Wind				
	1996	2000	2004	2008	2010	1996	2000	2004	2008	2010
Relative World Market Share (RWS) ⁽¹⁾										
Germany	1.2	1.1	1.1	1.5	1.4	0.8	0.7	0.8	1.4	1.4
China	1.5	1.8	2.1	3.0	2.9	0.3	0.5	0.6	0.7	0.4
Denmark	1.8	1.6	1.3	1.0	1.3	9.9	13.3	17.7	18.6	19.9
Japan	1.5	1.8	2.5	1.7	1.2	0.3	0.6	0.6	0.8	0.4
Korea, Rep.	0.9	0.4	0.7	0.5		0.2	0.2	0.2	0.2	
Spain	0.2	0.3	0.8	0.4	1.1	0.8	1.6	1.3	2.0	3.9
United Kingdom	1.2	1.2	1.0	0.9	0.5	1.2	1.0	0.7	0.6	0.5
United States	1.0	1.2	1.1	0.7	0.6	1.3	1.0	1.6	1.2	2.0
Relative Trade Position (RTP) ⁽²⁾										
Germany	0.1	0.0	-0.1	0.0	-0.2	0.1	-0.2	-0.3	0.2	0.0
China	0.5	0.3	0.1	0.6	0.6	-0.8	-0.5	-0.4	0.2	0.1
Denmark	0.3	0.3	0.3	0.3	0.5	0.7	0.8	0.9	0.9	0.9
Japan	0.2	0.2	0.3	0.3	0.3	0.5	0.3	0.1	0.4	0.3
Korea, Rep.	0.0	-0.4	-0.5	-0.5		-0.7	-0.7	-0.7	-0.7	
Spain	-0.4	-0.4	0.0	-0.9	-0.1	-0.4	0.0	0.0	0.1	0.6
United Kingdom	0.0	-0.1	0.0	0.1	0.0	0.1	0.0	-0.2	-0.4	-0.7
United States	-0.4	-0.4	-0.4	-0.4	-0.4	0.3	-0.2	0.1	-0.5	-0.1
Revealed Comparative Advantage (RCA) ⁽³⁾										
Germany	1.0	0.9	0.6	0.8	0.6	1.1	0.5	0.4	1.2	0.9
China	3.0	1.7	1.1	2.5	3.2	0.1	0.3	0.4	1.1	1.0
Denmark	1.8	2.0	1.9	1.9	3.4	6.0	11.8	16.1	13.8	13.2
Japan	1.1	1.1	1.3	1.7	1.5	2.4	1.4	0.9	1.8	1.4
Korea, Rep.	1.1	0.3	0.3	0.3		0.2	0.1	0.1	0.2	
Spain	0.5	0.7	1.5	0.1	1.2	0.5	1.4	1.6	2.0	5.8
United Kingdom	1.1	1.0	1.3	1.6	1.3	1.3	1.2	0.9	0.6	0.2
United States	0.7	0.8	0.9	0.8	0.8	3.0	1.2	2.5	0.6	1.7

Sources: Authors calculations based on UNCTAD Comtrade (2012)

Notes: (1) A RWS value > 1 indicates that exports of a country in a specific product group account for a larger share of total exports of that country compared to the global average.

(2) A RTP value >0 indicates that national industries are better in targeting foreign markets than foreign industries are in targeting the national market.

(3) A RCA value > 1 indicates a comparative advantage of a country in the specific product group in terms of trade.

Appendix 4: Share of region and selected countries on Chinese exports and imports of potential renewable energy components (in percent)

	Photovoltaic								Wind							
	Export				Import				Export				Import			
	1996	2004	2008	2010	1996	2004	2008	2010	1996	2004	2008	2010	1996	2004	2008	2010
East Asian & Pacific	5.5	6.8	3.1	2.5	4.2	10.5	15.3	20.4	44.1	13.2	10.3	15.9	0.2	0.2	0.1	0.2
Malaysia	4.1	2.2	1.1	0.8	1.4	3.3	5.5	10.0	10.2	1.0	0.6	1.3	0.2	0.1	0.1	0.1
Thailand	0.3	1.3	0.6	0.4	1.8	3.9	5.1	3.9	12.4	3.7	0.9	1.3	0.0	0.1	0.0	0.0
Vietnam	0.1	0.2	0.4	0.4	0.0	0.0	0.2	0.4	3.6	1.0	2.8	4.3	0.0	0.0	0.0	0.0
Indonesia	0.2	0.6	0.5	0.4	0.2	1.8	1.8	2.0	4.9	5.7	3.9	4.8	0.0	0.0	0.0	0.0
Philippines	0.7	2.2	0.4	0.3	0.9	1.5	2.8	4.0	10.8	1.2	1.1	1.1	0.0	0.0	0.0	0.0
Eastern Europe	0.2	1.2	1.4	1.1	0.2	0.1	0.4	0.1	0.1	2.5	4.0	3.6	1.1	0.2	0.1	0.9
Russia	0.1	0.8	0.8	0.5	0.2	0.0	0.0	0.0	0.0	0.3	0.8	0.7	1.0	0.1	0.0	0.0
Ukraine	0.0	0.2	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.2	0.0	0.0	0.1	0.7
Latin America	0.5	1.6	1.9	1.7	0.0	0.1	0.2	0.1	2.7	3.8	3.6	3.0	0.0	0.3	0.0	0.0
Brazil	0.3	0.9	1.1	1.0	0.0	0.0	0.0	0.0	0.1	0.4	0.5	0.9	0.0	0.3	0.0	0.0
Mexico	0.7	1.8	1.4	0.9	0.0	0.8	0.7	0.4	0.0	0.8	0.3	0.3	0.8	0.1	0.0	0.0
Argentina	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	1.6	0.5	0.1	0.3	0.0	0.0	0.0	0.0
South Asia	0.2	1.7	3.3	2.2	0.0	0.5	0.5	1.0	4.3	3.7	16.8	11.4	0.0	0.0	0.2	0.4
India	0.0	1.4	2.8	1.7	0.0	0.5	0.5	1.0	0.8	0.6	14.3	8.6	0.0	0.0	0.2	0.4
OECD	93.0	86.7	87.9	90.5	95.5	88.7	83.5	78.4	32.8	61.9	49.4	50.5	98.6	99.3	99.5	98.5
Germany	4.9	11.5	19.2	25.0	5.3	6.3	15.3	17.1	0.9	3.8	1.9	2.6	10.7	14.1	18.8	14.5
Italy	1.8	1.8	4.6	15.5	1.0	0.8	1.6	1.2	0.2	2.1	1.6	1.3	2.8	2.8	7.6	4.5
Netherlands	1.4	4.3	4.4	12.9	0.2	0.2	0.4	0.3	0.0	0.7	0.5	1.1	1.1	1.3	1.5	1.2
United States	42.3	25.6	12.1	11.2	11.8	6.7	7.3	5.6	3.8	23.5	21.8	19.2	22.3	10.1	11.2	15.9
Japan	24.3	20.8	7.1	4.1	61.4	58.7	37.6	32.3	18.2	14.3	11.3	11.2	14.3	11.1	29.7	34.6
Australia	1.0	0.8	0.8	3.0	0.1	0.3	1.0	0.0	1.2	1.7	1.3	3.8	1.0	0.3	0.1	0.3
Korea, Rep.	1.4	6.5	5.9	2.8	7.4	6.6	8.1	11.0	2.3	3.3	2.6	2.6	2.9	1.7	2.4	3.7
France	3.9	2.4	1.9	2.6	1.6	2.4	1.1	2.4	1.3	1.1	0.5	0.5	3.5	36.9	1.6	5.5
Spain	0.6	0.5	21.7	2.1	0.1	0.4	0.3	0.1	0.0	0.7	0.9	0.4	24.2	4.3	8.2	5.6
Canada	0.7	1.2	0.4	0.8	1.2	0.4	0.5	0.3	1.7	2.5	1.3	0.9	0.7	0.1	0.3	0.1
United Kingdom	7.5	2.8	0.9	0.8	2.8	0.9	0.8	0.7	2.2	1.0	0.6	1.0	6.6	2.2	2.0	1.9
Turkey	0.1	0.9	0.6	0.5	0.0	0.0	0.0	0.0	0.4	2.3	1.7	2.7	0.0	0.0	0.0	0.1
Sweden	0.2	0.4	0.4	0.3	0.8	0.9	1.3	0.6	0.0	0.1	0.2	0.6	0.7	0.9	1.5	2.0
Denmark	0.0	0.1	0.1	0.2	0.3	0.5	0.7	0.5	0.0	0.3	0.9	0.3	3.4	6.8	7.5	2.0
Austria	0.2	0.2	0.1	0.1	0.0	0.2	0.8	0.7	0.0	0.0	0.1	0.3	0.7	0.4	1.0	0.5
Africa & Middle East	0.5	1.9	2.3	1.8	0.0	0.0	0.1	0.1	9.4	13.6	11.9	13.1	0.0	0.1	0.0	0.0
South Africa	0.1	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.1	0.7	1.1	0.6	0.0	0.1	0.0	0.0
Iran	0.1	0.2	0.3	0.2	0.0	0.0	0.0	0.0	7.4	1.6	0.2	1.4	0.0	0.0	0.0	0.0

Appendix 5: Patents as innovation and technology transfer indicator - methodology

Innovation can be measured using different indicators such as R&D expenditure, number of researcher (input measure of the inventive process) and patents (output measure of inventive process). Different means of technology transfer are identified and used in the literature. The most common are licensing, foreign direct investment (FDI), international trade and movement of personnel. Yet, cross country data on most of these indicators when analyzing a specific sector is not available. Several researchers lined out that patent data, can be preferable as it provides disaggregated information on the innovation in terms of technology, inventor and applications process ([Griliches, 1990](#), [Jaffe, 1986](#)). This detailed information allows studying sector specific technology transfer and knowledge spillovers across countries ([Dechezlepretre et al., 2011](#)).

Consequently, this study adopts the approach by Dechezlepretre ([2009](#), [2011](#)) to account for innovation and technology transfer in solar photovoltaic (PV) and wind energy using the classifications scheme developed by Johnstone ([2010](#)) and provided by the WIPO IPC Green Inventory ([2012](#)) (Table 7).

National innovation is measures as the number of patents invented and filed for in country i ($InnoPatApp_{i,t}$). The number of innovations transferred from country i to j is measured through patents invented in country i and filed in j ($TransfPat_{i,j,t}$). To avoid duplications we use fractional counts of DOCDB patent families. In order to obtain the total number of innovations transferred from all i to j in a sector at time t ($TotTransfPat_{j,t}$) we use the sum of individual country transfers:

$$TotTransfPat_{j,t} = \sum_{j=1}^i TransfPat_{i,j,t} \quad i \neq j \quad (1)$$

The literature on innovation indicates that the productivity of knowledge strongly depends on the existing knowledge ([Porter and Stern, 2000](#), [Bosetti et al., 2008](#)). As the process until an innovation reaches the market might take several years it assumed that not only innovation today but also the stock of existing knowledge is relevant to determine its effect on production and export. In order to account for this lag we also use the perpetual inventory method to annual patent applications in wind energy and solar photovoltaic technology. Consequently, the stock of innovation and the stock of innovation, bilateral foreign knowledge stock and total foreign knowledge stock variables are calculated as follows:

$$KInno_{i,t} = (1 - \delta)KInno_{i,t-1} + InnoPatApp_{i,t} \quad (2)$$

$$KTransf_{ij,t} = (1 - \delta)KTransf_{ij,t-1} + TransfPat_{i,j,t} \quad (3)$$

$$KSumTransf_{jt} = \sum_{j=1}^i KTransf_{ijt} \quad (4)$$

and: $i \neq j$; $\delta = 0.15 (0.10)^{11}$

Hence, the stock of innovation ($KInno$) and transfer ($KTransf$) equals the respective stock at time t-1 minus its depreciation (δ) plus patent applications by residents of i in i or plus applications of residents of country i in filed in country j, respectively.

Table 7: Description for solar PV and wind energy technology relevant IPCs

IPC	Description
Solar Photovoltaics (PV)	
H01L 27/142, 31/00-31/078 H01G 9/20 H02N 6/00	Devices adapted for the conversion of radiation energy into electrical energy
H01L 27/30, 51/42-51/48	Using organic materials as the active part
H01L 25/00, 25/03, 25/16, 25/18, 31/042	Assemblies of a plurality of solar cells
C01B 33/02 C23C 14/14, 16/24 C30B 29/06	Silicon; single-crystal growth
G05F 1/67	Regulating to the maximum power available from solar cells
F21L 4/00 F21S 9/03	Electric lighting devices with, or rechargeable with, solar cells
H02J 7/35	Charging batteries
H01G 9/20 H01M 14/00	Dye-sensitised solar cells (DSSC)
Wind Energy	
F03D	Wind energy
H02K 7/18	Structural association of electric generator with mechanical driving motor
B63B 35/00 E04H 12/00 F03D 11/04	Structural aspects of wind turbines
B60K 16/00	Propulsion of vehicles using wind power
B60L 8/00	Electric propulsion of vehicles using wind power
B63H 13/00	Propulsion of marine vessels by wind-powered motors

Source: WIPO (2012) - IPC Green Inventory (<http://www.wipo.int/classifications/ipc/en/est/>)

¹¹ The literature commonly uses a depreciation rate of 15 percent (e.g., Guellec and van Pottelsberghe de la Potterie (2004)). We use this depreciation rate and conducted robustness checks with a depreciation rate of 10 percent. An initial knowledge stock is not calculated as, available from PATSTAT available data starts in 1980 which is used as initial year. Considering that solar photovoltaic and wind innovations before that time period were hardly existent, this is a valid approach. Furthermore, using the given rate any stock marginally higher than that given in 1980 is depreciated until 1996 which is the starting year of this analysis.

Appendix 6: Correlation Matrix for analysis of solar photovoltaic energy component imports

	import (ln+1)	import	GDP capita _{it} ,ln	distance _{i-china} ,ln	area _i ,ln	import tariff _{it china s} ,ln	Δ GDP capita _{China t} ,ln	electricity gen _{it s} ,ln	taxmeasures _{it}	incentivetariffs _{it}	obligations _{it}	TechTransf _{i china s t-1} ,ln	Δ electricity gen _{s China t-1} ,ln	Δ ST central _{China t-1} ,ln	Δ ST local _{China t-1} ,ln	Δ KnowStock _{s China t-1} ,ln
import (ln+1)	1															
Import	0.39	1														
GDP per capita _{it} ,ln	0.25	0.17	1													
distance _{i-china} ,ln	-0.09	-0.12	0.07	1												
area _i ,ln	0.43	0.14	-0.26	0.18	1											
import tariff _{it china s} ,ln	0.01	-0.06	-0.38	0.19	0.21	1										
Δ GDPcapita _{China t} ,ln	0.40	0.18	0.13	0.00	0.00	0.10	1									
electricity gen _{it s} ,ln	0.38	0.79	0.24	-0.12	0.18	-0.18	0.11	1								
taxmeasures _{it}	0.48	0.16	0.35	0.03	0.08	-0.02	0.18	0.12	10							
incentivetariffs _{it}	0.40	0.15	0.46	0.12	-0.12	-0.14	0.24	0.12	0.52	1						
obligations _{it}	0.40	0.15	0.46	-0.14	-0.04	-0.21	0.17	0.16	0.40	0.37	1					
TechTransf _{i china s t-1} ,ln	0.59	0.40	0.58	-0.25	0.20	-0.28	0.15	0.50	0.33	0.32	0.50	1				
Δ electricity gen _{s China t-1} ,ln	0.24	0.14	0.07	0.00	0.00	-0.07	0.24	0.08	0.09	0.14	0.10	0.08	1			
Δ ST central _{China t-1} ,ln	0.15	0.07	0.04	0.00	0.00	0.07	0.42	0.04	0.05	0.08	0.04	0.05	0.32	1		
Δ ST local _{China t-1} ,ln	-0.04	0.10	-0.01	0.00	0.00	0.04	-0.10	0.03	-0.07	-0.06	-0.07	-0.02	-0.34	0.17	1	
Δ KnowStock _{s China t-1} ,ln	0.40	0.19	0.12	0.00	0.00	-0.01	0.71	0.12	0.18	0.22	0.19	0.14	0.53	0.45	-0.18	1

Appendix 7: Correlation Matrix for analysis of wind energy component imports

	import (ln+1)	import	GDP capita _{it} ,ln	distance _{i-china} ,ln	area _i ,ln	import tariff _{it china s} ,ln	Δ GDP capita _{China t} ,ln	electricity gen _{it s} ,ln	taxmeasures _{it}	incentivetariffs _{it}	obligations _{it}	TechTransf _{i china s t-1} ,ln	Δ electricity gen _{s China t-1} ,ln	Δ ST central _{China t-1} ,ln	Δ ST local _{China t-1} ,ln	Δ KnowStock _{s China t-1} ,ln
import (ln+1)	1.00															
Import	0.36	1.00														
GDP per capita _{it} ,ln	0.05	0.05	1.00													
distance _{i-china} ,ln	-0.14	-0.10	0.07	1.00												
area _i ,ln	0.45	0.22	-0.26	0.18	1.00											
import tariff _{it china s} ,ln	0.13	0.05	-0.45	0.08	0.24	1.00										
Δ GDPcapita _{China t} ,ln	0.48	0.18	0.13	0.00	0.00	0.22	1.00									
electricity gen _{it s} ,ln	0.48	0.46	0.27	0.04	0.20	-0.07	0.24	1.00								
taxmeasures _{it}	0.30	0.08	0.35	0.03	0.08	-0.16	0.18	0.38	1.00							
incentivetariffs _{it}	0.19	0.07	0.46	0.12	-0.12	-0.29	0.24	0.39	0.52	1.00						
obligations _{it}	0.27	0.03	0.46	-0.14	-0.04	-0.23	0.17	0.32	0.40	0.37	1.00					
TechTransf _{i china s t-1} ,ln	0.42	0.28	0.61	-0.18	0.19	-0.23	0.18	0.53	0.32	0.35	0.55	1.00				
Δ electricity gen _{s China t-1} ,ln	0.39	0.24	0.11	0.00	0.00	0.10	0.74	0.23	0.11	0.17	0.10	0.17	1.00			
Δ ST central _{China t-1} ,ln	0.19	0.07	0.04	0.00	0.00	0.08	0.42	0.09	0.05	0.08	0.04	0.06	0.35	1.00		
Δ ST local _{China t-1} ,ln	-0.06	0.08	-0.01	0.00	0.00	-0.07	-0.10	0.01	-0.07	-0.06	-0.07	0.00	0.42	0.17	1.00	
Δ KnowStock _{s China t-1} ,ln	0.50	0.24	0.13	0.00	0.00	0.12	0.83	0.27	0.15	0.23	0.16	0.19	0.82	0.27	0.06	1.00

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