Static and dynamic policy effects on renewable energy components' trade

Evidence from solar photovoltaics and wind energy

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Executive Summary

Growing concerns about climate change and energy issues worldwide have highlighted the urgent need to tackle them. As renewable energy (RE) is widely recognized as the main solution to these problems, it has made major strides worldwide during 1998-2015. International trade in RE components has witnessed significant growth during this period, spurred by increasing demand and favorable policies, such as feed-in tariff (FIT) and renewable portfolio standards (RPS).

Most researchers have studied the relationship between RE components trade and favorable policies considering economic concerns under climate and energy issues. Most past empirical studies have referred to the Porter hypothesis (PH), which assumes the positive effect of environmental or energy policy on innovation and other economic performances, such as productivity and export competitiveness.

However, past empirical studies on the effect of RE policies on trade have some drawbacks. The literature on PH lacks the rationale for the policy effect in the empirical analyses of its validity. The model in the literature also lacks the interaction between innovation and policy, although the strong version of PH assumes that the innovation induced by the policy might lead to competitiveness.

Therefore, this research reveals whether and how FIT and RPS affect the export of solar photovoltaics (PV) and wind energy components. We develop a novel methodological setting with a two-fold policy effect based on the theo-

retical foundation to examine PH in a stricter setting. The static effect is the effect on exports through the direct shift in price and quantity levels with FIT and RPS. We confirm that policies in both exporter and importer countries can affect exports, as the theoretical analysis suggests that manufacturers can benefit from any of them. Hence, this reveals that the policy can affect the import demand for PV and wind energy components. Meanwhile, the dynamic effect is the innovation effect on exports only when policies are in force. This can be facilitated by additional profits for manufacturers.

Second, we apply separate estimation methods for each policy effect. We employ a matching estimator to examine the static effect to minimize bias from the other covariates. To estimate the dynamic effect, the interaction term between policy and innovation variables is added. A positive effect of the interaction on exports, and hence the positive dynamic effect, can be considered evidence of the narrowly strong version of PH.

The estimation results show that FIT and RPS in importer countries are positively associated with their PV imports, while those in exporter countries show a negative effect. As for wind energy, FIT in exporter countries might positively affect exports. The dynamic policy effect is significant only for wind energy, providing supportive evidence of a narrowly strong version. This research provides robust evidence of a narrowly strong PH with a refined methodology, which has not been found in the literature.

This dissertation contributes to the strand of research on PH by integrating theoretical and empirical analyses. The distinction between static and dynamic policy effects can be utilized to estimate the effect of policies in both exporter and importer countries. This theoretical observation reveals that the static policy effect can affect both exports and imports, which has not been explicitly considered in the literature. Separate methodologies enable us to estimate two types of policy effects along with the theoretical foundation. Specifying the dynamic policy effect makes it possible to examine PH by eliminating potential bias in the model of past studies. This might have

led to the robust results on the positive dynamic policy effects, providing empirical evidence of the narrowly strong version of PH.

Keywords: Renewable energy; Feed-in tariff; Renewable portfolio standards; Innovation; International trade; Porter hypothesis

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List of Abbreviations

ATE Average Treatment Effect

ATT Average Treatment effect on the Treated

CEPII Centre d'Études Prospectives et d'Informations Internationales

EGs Environmental Goods

EU European Union

EC European Commission

FE Fixed Effects

FIT Feed-in Tariff

GDP Gross Domestic Products

HS Harmonized System

IEA International Energy Agency

IRENA International Renewable Energy Agency

km kilometers

MR Multilateral Resistance

NEA Nuclear Energy Agency

OECD Organisation for Economic Co-operation and Development

OECD-EPAU OECD Environment Directorate's Empirical Policy Analysis Unit

PH Porter Hypothesis

PV Photovoltaics

RE Renewable Energy

REN21 Renewable Energy Policy Network for the 21st century

RES-E RE Sourced Electricity

RMSE Root Mean Square Errors

RPS Renewable Portfolio Standards

US United States

USD US Dollars

US ITA United States International Trade Administration

Chapter 1

Introduction

1.1 Background: Dissemination of renewable energy and the components' trade

An increase in the global demand for renewable energy (RE), along with favorable policies, has led to the rapid growth of the components' trade. This, in turn, has made trade disputes in components a prominent issue.

Growing concerns about energy and climate change have led to the vast deployment of RE during 1998-2015. Figure 1.1 shows the growing trend of electricity generation from photovoltaics (PV) and wind energy sources. RE is considered one of the main ways of tackling climate change (Stokes, 2016) with abundant potential (IRENA, 2019). Further , it could be a solution to the energy security issue, which calls for lesser dependence on fossil fuel imports, especially in countries with a scarcity of such resources (Fuentes et al., 2020; Pidgeon et al., 2008). The vulnerability of the incumbent energy system, which is considered responsible for climate change, could also be one of the factors influencing the penetration of RE (Mathews and Reinert, 2014).

Therefore, an increasing number of countries are looking at RE as the new

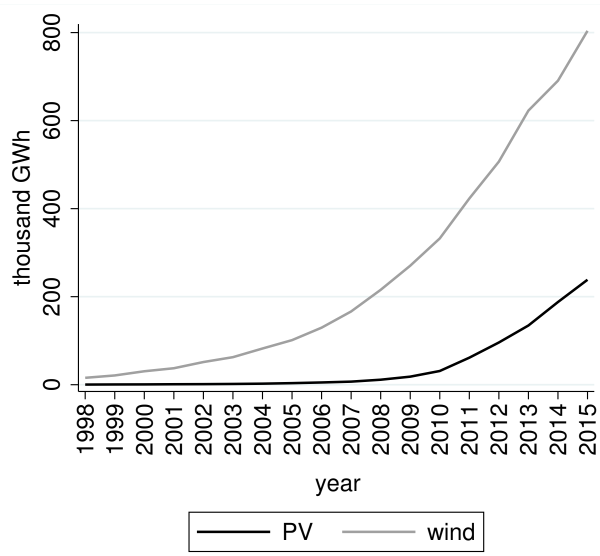


Figure 1.1: Global solar PV/wind energy electricity generation: 1998-2015 (IEA, 2019)

engine of economic growth (Mori and Takehara, 2018), driving its growth (Song, 2015). The Organisation for Economic Co-operation and Development (OECD) has set "green growth" as the agenda for tackling climate change while fostering sustainable economic growth. Under the agenda, environmental goods (EGs), including RE components, have been designated as the main constituents of "green growth" and discussed for tariff exemption in international trade (Steenblik, 2005). In this context, RE has been placed under the "environmental industry" (Jänicke, 2012) that can generate increasing returns (Mathews, 2012). Emerging economies like China and India have followed suit in developing a "green industry" and "green jobs" (Yi, 2013). The global market is dominated by the top 10 companies with scale economies in production. Chinese manufacturers account for one-third of the global wind turbine market, followed by manufacturers in other countries; Vestas, Siemens, and General Electric. China also accounts for 75% of

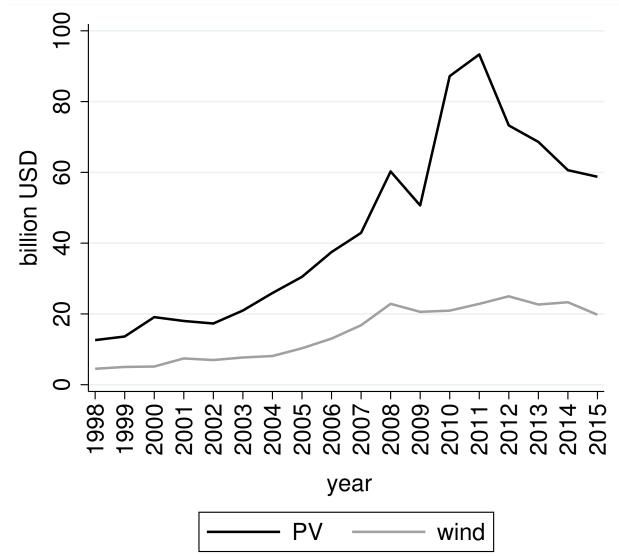


Figure 1.2: Global PV/wind energy compenents export: 1998-2015 (CEPII, 2019)

the global PV market, followed by Korea and Malaysia(REN21, 2020).

As discussed above, the RE market has become a key driver of green growth spurred by growing demand and economic opportunities due to favorable policies, such as feed-in tariff (FIT) and renewable portfolio standards (RPS). In particular, PV and wind energy have shown prominent growth in component exports (Ogura and Mori, 2015) and electricity generation. Figure 1.2 shows that worldwide exports of PV and wind energy components have grown during 1998-2015, although those of PV seem to have stagnated after 2011. Therefore, countries have sought to develop the RE industry, which may have pushed growth in the trade of components to meet the increasing demand.

Table 1.1 demonstrates the change in the top 5 countries in export/import of and electricity generation from PV and wind energy during 2000–2015. It shows that major exporter and importer countries tend to have a consider-

Table 1.1: Top 5 countries of PV/wind energy export, import, electricity generation: Change in every 5 years from 2000 to 2015

PV	2000			2005			2010			2015		
	Export	Import	Gen.	Export	Import	Gen.	Export	Import	Gen.	Export	Import	Gen.
1.	USA	USA	JPN	CHN	USA	JPN	CHN	DEU	DEU	CHN	USA	CHN
2.	CHN	DEU	USA	JPN	DEU	DEU	DEU	ITA	ESP	DEU	DEU	DEU
3.	JPN	JPN	DEU	DEU	CHN	USA	JPN	USA	JPN	KOR	CHN	JPN
4.	DEU	GBR	AUS	USA	JPN	CHN	USA	CHN	USA	USA	KOR	USA
5.	MEX	FRA	CHN	MYS	KOR	AUS	KOR	FRA	ITA	JPN	MEX	ITA
Wind	2000			2005			2010			2015		
	Export	Import	Gen.	Export	Import	Gen.	Export	Import	Gen.	Export	Import	Gen.
1.	USA	USA	DEU	USA	USA	DEU	DNK	USA	USA	DEU	USA	USA
2.	DEU	MEX	USA	DNK	DEU	ESP	DEU	CAN	CHN	CHN	DEU	CHN
3.	JPN	DEU	ESP	DEU	MEX	USA	USA	GBR	ESP	USA	GBR	DEU
4.	DNK	FRA	DNK	JPN	GBR	DNK	CHN	DEU	DEU	DNK	MEX	ESP
5.	ITA	GBR	IND	ITA	CHN	IND	JPN	TUR	IND	ESP	CAN	IND

Data source: Trade: CEPII (2019), electricity: IEA (2019)
Note: AUS: Australia, CAN: Canada, CHN: China, DNK: Denmark, FRA: France, DEU: Germany, IND: India, ITA: Italy, JPN: Japan, KOR: South Korea, MYS: Malaysia, MEX: Mexico, ESP: Spain, TUR: Turkey, GBR: United Kingdom, USA: United States
Gen.: Electricity generation

ably large amount of electricity generation from RE sources (PV: Germany, Japan, and the US; wind: Germany, the US, and Spain). This implies that countries have utilized trade to meet the global and domestic demands for PV and wind energy components. The table also indicates that some emerging economies have been major PV exporters (China, Malaysia), and had ample wind energy electricity (India). In particular, China has been the top exporter of both since the mid-2000s, while other major importers increased electricity generation in 2010. Emerging economies have taken center stage in the global production of PV components, and this shift has led to trade disputes between the EU and US (EC Directorate General for Trade, 2016; US ITA, 2012). Their export share has grown in recent years and, as of 2011, stood at approximately 40% (Ogura, 2020). This suggests that RE policies can impact the overall trade; both export and import of PV and wind energy components.

Amid the growing trade in EGs, including RE components, previous studies have focused on the relationship between environmental and energy policies and exports (Costantini and Mazzanti, 2012; Groba, 2014; Kuik et al., 2018). The literature has mainly focused on the policies of "exporter" countries. This is because these studies are based on the Porter hypothesis (PH), which suggests the "dynamic" effect of environmental regulation on competitiveness by improving innovative capacity (Porter and van der Linde, 1995). However, the estimated effects of RE policies remain unclear with a weak significance (Groba, 2014; Groba and Cao, 2014).

Further, the literature has not clearly distinguished between the "static" and "dynamic" effects of RE policy, which can directly affect the trade of RE components by changing the market's cost/benefit structure. In the estimates, the suggested innovation effects do not always include policy effects and vice versa. Therefore, the dynamic effects with individual innovation or policy variables might include a bias from other variables, which may provide spurious evidence of PH. Hence, making a clear distinction between static and dynamic policy effects is essential to examine the hypothesis.

Moreover, scant attention has been paid to the policy effect on imports, which is another static aspect of policy effects, although trade disputes on RE components indicate the negligible influence of induced demand on imports (Wu and Salzman, 2014; Karttunen and Moore, 2018). Hattori and Chen (2022) argue that introducing FIT in Japan might have induced PV imports, mainly from China, without accompanying policies such as import restrictions. Amid rising competition in the global PV market, India has introduced FIT with a local content requirement for assisting its domestic manufacturers (Wu and Salzman, 2014). The country has been dependent on imports to meet its ambitious RE target (Janardhanan, 2022). These countries- and trade issue-specific analyses indicate that the policies of importer countries might considerably affect RE component exports, inducing their demand.

1.2 Research question and the structure of the dissertation

Against this backdrop, our basic research question is whether and how RE policies have affected the export of PV and wind energy components during 1998-2015. Therefore, this research first makes a clear distinction between "static" and "dynamic" policy effects by revisiting the theoretical analysis on policy effects. We intend to solve the bias from misspecification that remained in past studies by distinguishing between the two policy effects and applying separate estimation methods for each.

Two hypotheses on the static effect and one on the dynamic effect are set based on the review and theoretical analysis. These two types of policy effects on PV and wind energy component exports are separately estimated.

Here, we assume that the static effect of domestic FIT and RPS on exports might be positive if manufacturers in exporter countries have gained export competitiveness through the additional profit generated from the favorable policies (Hypothesis 1-1). This hypothesis refers to the hypothetical settings in previous empirical analyses of EG trade based on PH (Costantini and Crespi, 2013; Groba, 2014; Groba and Cao, 2014). Based on the analysis, we can compare it with the other hypotheses shown below. Referring to the literature on the trade analyses of RE components, we assume that export competitiveness is measured by bilateral export value; the country's exports to the other country.

Conversely, the effects of those two policies in importer countries might be positive if the import of components has been induced to fulfill the increased demand (Hypothesis 1-2). This hypothesis is based on the potential effects of RE policy on imports, which have been indicated in the descriptive studies on the RE industry (Wu and Salzman, 2014; Hattori and Chen, 2022). Further, the theoretical foundation is confirmed in the graphical observation on policy effects below. As previous empirical studies have not focused sufficiently on the effect of importer-country policies on trade, we intend to analyze the effect explicitly with the hypothesis.

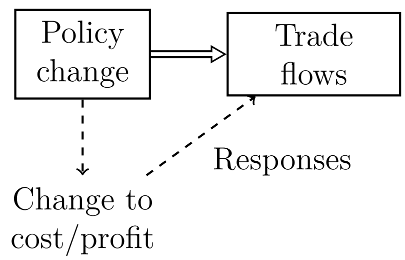
Meanwhile, the dynamic policy effect is assumed to be positive if the innovative capacity can be associated with exports when the policies are in force; hence, the (narrowly) strong version of PH is valid (Hypothesis 2). To find empirical evidence of the narrowly strong PH, it is essential to specify the innovation effect only when the policy is in force. However, the literature has misspecified the effect of adding innovation and policy variables individually. We consider the interactive effect of policy and innovation and examine the narrowly strong PH in stricter conditions compared with previous studies.

This dissertation is organized as follows: Chapter 2 reviews the theoretical implications and previous empirical analyses of RE policy effects on EG trade, including RE components, based on PH. The chapter concludes by outlining the gaps in the previous studies. Based on these gaps, the chapter reconfirms the theoretical implication of policy effects on both export and import of RE components. Chapter 3 estimates the "static" effect of FIT and RPS, while Chapter 4 estimates the "dynamic" effect on the export of PV and wind energy components. Based on the theoretical implication reviewed in Chapter 2, we examine the effect of policies in exporter and importer countries on the static effect. Chapter 5 discusses the estimation results in Chapters 3 and 4, and Chapter 6 concludes the dissertation.

Chapter 2

Review and the Hypotheses: Renewable Energy Policy Effect on the Components' Trade

Existing empirical studies on the relationship between environmental or energy policies and trade are based on the dynamic policy effect represented by the Porter hypothesis (Porter and van der Linde, 1995). However, empirical studies have not confirmed the theoretical foundation of the policy effect. This chapter reviews the theoretical foundation of RE policy's "static" and "dynamic" effects. Empirical studies on the policy effect on the trade of EGs, including RE components, are then reviewed to explore what the existing studies have revealed. This chapter makes a clear theoretical distinction between the two types of RE policy effects and clarifies the outcomes and challenges through the review.



Note: author's modification referring to Dechezleprêtre and Sato (2017)

Figure 2.1: Diagram of the static policy effect on the trade of RE components

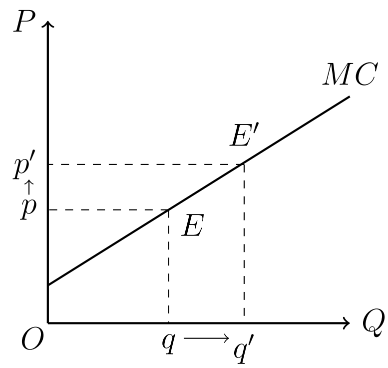
2.1 Theoretical foundation on the policy effect

The way policy affects export competitiveness can be divided into two types: "static" and "dynamic" efficiency (Menanteau et al., 2003). This section reviews the two kinds of policy effects to establish the foundation for the following analyses.

2.1.1 Static effect

First, we assume that the static effect of the policy refers only to the potential endogenous policy effect on trade by policy introduction. A policy can change the cost and profit for producers through a shift in price or quantity. Subsequently, producers respond to the shift to maximize their profit. Consequently, a change in the producers' profit may lead to a change in the trade of their products. This is represented by the Figure 2.1, which shows the relation between policy implementation and shift in trade.

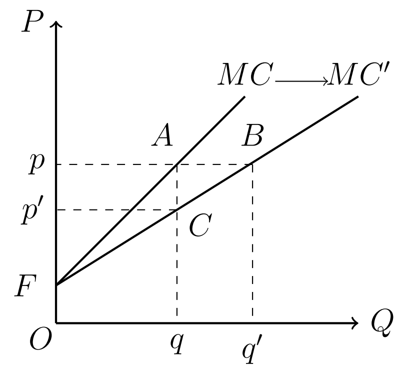
Referring to Menanteau et al. (2003), Figure 2.2 graphically demonstrates the effect of RE policy on producer surplus. FIT adds a premium to RE-sourced electricity (RES-E), while RPS sets the amount or share of the overall



Note: author's modification referring to Menanteau et al. (2003)

Figure 2.2: Static policy effect on producer surplus

RES-E. Assume an initial equilibrium E under the price p and the quantity q. If the policy sets a fixed tariff or targeted amount for RES-E, the market price or quantity shifts to p' or q', respectively. Subsequently, the equilibrium shifts to E'. The theoretical consequence of these policies can be expressed as the additional surplus of RES-E production ($pEE'p'$). The effectiveness of each policy depends on the marginal cost (MC) curve, as suggested in the "prices or quantities" debate by Weitzman (1974). Hence, RE policy can induce domestic market expansion by incentivizing manufacturers to produce RE components with the additional surplus. As mass-scale production creates the potential for widespread use (Hoppmann, 2018), domestic manufacturers may be able to expand by increasing the returns to scale (Algieri et al., 2011) and start exporting. RE policy can then enhance the export competitiveness of producers through the additional profit.



Note: author's modification referring to Menanteau et al. (2003)

Figure 2.3: Dynamic policy effect on producer surplus

2.1.2 Dynamic effect

Meanwhile, technological development or innovation can lead to an additional producer surplus. This is graphically represented in Figure 2.3. The shift in technology or innovation can be expressed by the shift in marginal cost curves (MC to MC'), reducing production cost. Suppose that MC changes to MC' with the innovation. If the initial price level is p, additional surplus from the innovation is represented by area of ABF. The quantity increases ($q \Rightarrow q'$) with reduced cost under MC', and additional surplus is generated by setting the target quantity to q; ACF. The price under such a quantitative policy can be lower at p'. Under both policy instruments, producer surplus is larger than the initial condition and is accompanied by a reduced marginal cost (MC'), suggesting that innovation can indeed lead to greater profit for producers.

As innovation can lead to additional profits, firms may encourage technological development if their profit attains a certain level. The "dynamic" efficiency can be attained through innovation aiming at further cost reduction. A policy can induce this effect as it enhances the profit for producers and scale of the domestic market (Menanteau et al., 2003). Subsequently, the innovation resulting from the shift in producer surplus may further improve domestic firms' productivity or international competitiveness by increasing the scale of the market. We assume that the innovation effect associated with policy implementation is a dynamic policy effect.

Applying the theoretical analysis above, Menanteau et al. (2003) compared innovation incentives with price- and quantity-based policies. The dynamic effect is stronger with FIT because the additional profit (ABF) from innovation is allocated to producers, and they can invest a larger amount for another round of innovation (not spending out). Conversely, the authors conclude that the incentive for innovation is weakened under the quantity-based policy. This is because the surplus from technological progress (ACF) is allocated to consumers and taxpayers with the attributed price p. Moreover, surplus from green certificates and with a reduced marginal cost ($p'CF$) is less than before costs are lowered (pAF). Rather, RPS produces a stronger incentive to reduce RES-E production costs under static conditions with the available technology. This is because manufacturers are forced to be cost-competitive regardless of policy. This situation can encourage producers "to turn to foreign technology" (Menanteau et al., 2003, p.805) as long as foreign technology has a competitive edge. Ultimately, the researchers point to a duality in the impact of policy on technological innovation: cost response and dynamic effect.

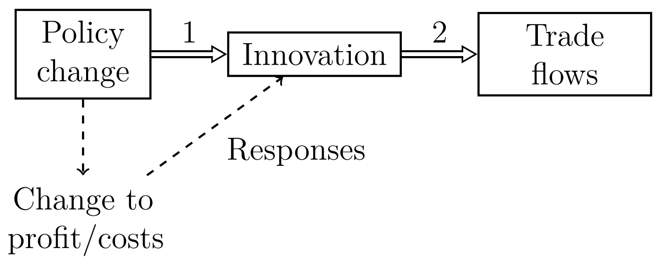
2.1.3 "Strong" version of Porter hypothesis as a dynamic effect

Empirical studies on the export of EGs and RE components have assumed PH, according to which the supply of such products provides an opportunity to benefit firms subject to environmental/energy regulations. This hypothesis argues that "well-designed environmental regulation" (Porter and van der

Linde, 1995, p.115) can contribute to innovation and enhance international competitiveness, which is otherwise unobtainable in the absence of such a regulation.

Jaffe and Palmer (1997) distinguished three versions to make PH more suitable for precise analysis. The first "narrow" version argues that certain types of environmental regulations stimulate innovation. Moreover, Ambec et al. (2013) interpreted this as flexible regulation, which economists often prefer over command-and-control-style regulation. The second "weak" version of PH considers a firm's response to regulation and encompasses innovation. Firms maximize profit differently when faced with the constraints of environmental regulation, which can lead to innovation. This version focuses on changes in volume, price, and investment (Dechezleprêtre and Sato, 2017). The third "strong" version of PH considers the innovation-benefit relationship and suggests that innovation via environmental regulation can exceed the costs of following regulations. As Dechezleprêtre and Sato (2017) argued, such benefits may include productivity growth and a boost in export competitiveness. Regarding international competitiveness, Jaffe and Palmer (1997) also cited the "narrowly strong" version, which suggests that a government may benefit from increased export competitiveness and increase domestic profit by inducing innovative policies.

To summarize, the "strong" or "narrowly strong" version of PH considers the dynamic relationship of policy and innovation to trade, which is shown by arrows 1 and 2 in Figure 2.4. However, the "narrow" or "weak" version explains the nexus between policy and innovation, which is represented by arrow 1 only. As a "well-designed" policy accompanies innovation in any case, PH assumes dynamic efficiency for producers.



Note: author's modification referring to Dechezleprêtre and Sato (2017)

Figure 2.4: Diagram of the dynamic policy effect on the trade of RE components

2.2 Empirical analyses on the trade of RE components

PH has invited criticism from researchers such as Jaffe and Palmer (1997), who point to its definitional ambiguity as an obstacle to precise economic analysis. Considering this fact and classification, researchers have attempted to analyze the validity of the hypothesis. Ambec et al. (2013) reviewed the studies, pointing to mixed evidence for the strong version, while there is a large body of evidence for the weak version, a positive correlation between environmental regulations and innovation. Their difference is primarily attributed to the discrepancy in outcomes, such as productivity and export performance.

Regarding the effect on export performance, which is involved in testing the (narrowly) strong version of PH, the literature provides supporting evidence using the gravity model common in trade analyses. Previous studies have applied export values from one country to another as a proxy for export performance and competitiveness. The literature has assumed the schematical relationship of strong PH as shown in Figure 2.4 instead of the theoretical implication. It assumes that the policy can improve export competitiveness if the policy variable is positively associated with the export values. Meanwhile, the literature has applied statistics on research and development expenditure (for example, Jaffe and Palmer, 1997) and patents related to RE technologies (for example, Johnstone et al., 2010) to calculate innovative capacity. The association between these statistics and exports is usually estimated to examine the relationship between the two. Subsequently, the association between two factors is estimated: export innovation and export policy.

Costantini and Crespi (2008) were the first to apply the gravity model to estimate the impact of environmental regulation on EG trade, finding a positive association with spending on environmental protection in the private sector. Costantini and Mazzanti (2012) also considered a dynamic setting to estimate the relationship between environmental regulation, innovative capacity, and the EU's export of EGs, finding their positive effect on high-tech EG exports. The result concluded that a strong or narrowly strong version of PH best describes EG trade, while the significance is relatively weak depending on the model specification. Regarding the effect of RE policy on RE component trade, Groba (2014) estimated how implementation and duration of RE policies would affect the export of PV components among OECD members and other countries, finding a positive (but weakly significant) relationship between tariff duration and exports. However, the author did not find a robust effect with policy dummies. Further, the study does not contain a substantial discussion on the negative effect of domestic policy on exports, as PH basically does not assume such an effect. Kuik et al. (2018) also found evidence that supports the strong version of PH by adding RE market share as a proxy for a policy outcome.

2.3 Remaining challenges in the literature

A few challenges remain in the literature on the policy effect on the export of RE components and (narrowly) strong PH on trade. This research focuses on two such aspects: insufficient consideration of the static effect of the policy and methodologies for the estimation of static/dynamic effects.

2.3.1 Static effect of the importer countries' policy

The review above shows that empirical literature on the strong version of PH has mainly focused on the relationship between policy implementation in exporter countries and the shift in the "export" of EGs, including RE components. However, country-specific analyses indicate that policies on the large-scale deployment of RE in "industrialized countries" (Germany, Japan, Spain, and the US) might have played a role in Chinese PV cells' production. This is coupled with the competitive advantage in such a labor-intensive process (de la Tour et al., 2011)) and the economies of scale in such a huge investment (Horii, 2022). Consequently, Hattori and Chen (2022) argue that import from China has penetrated through the introduction of FIT in Japan. In this context, the trade disputes on PV and wind energy components have occurred with local content requirements and anti-dumping duties by these importer countries (Wu and Salzman, 2014; Karttunen and Moore, 2018; Meckling, 2019).

These studies indicate that there has been a considerable effect of the importer's demand facilitated by favorable policies. However, empirical studies on the policy effect of importer countries have been limited to Groba and Cao (2014), who found a weak significant association between Chinese exports of PV/wind energy components and RE policies in importer countries. Hence, empirical evidence on the effect of RE policy on imports remains unclear.

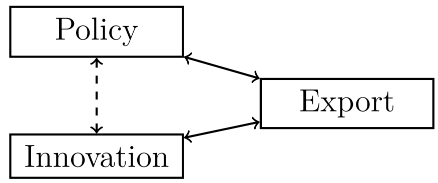


Figure 2.5: Trifold relationship in the literature: Lacking the consideration on the policy-innovation relationship

2.3.2 Methodologies for static and dynamic effect estimation

In estimating the policy effect on trade, previous empirical studies have included individual policy variables in the model in the form of policy dummies and duration of the policy. The proxies for innovative capacity are included in the same manner. Hence, this methodology does not specify the mutual relationship between policy and innovative capacity. The dashed line in Figure 2.5 represents this unclear policy-innovation relationship. In this methodology, the policy/innovation effect is estimated by mixing the individual effects. As innovation can be partly influenced by policy and vice versa, the policy/innovation effect estimates can be spurious. This indicates that the supportive results for the (narrowly) strong version of PH can be obscure with the methodologies focusing less on the policy-innovation relationship.

The policy effect might also be associated with other explanatory variables; the effect may be conditional on the gross domestic product (GDP). This indicates potential confounding between regressors, leading to spurious estimates of the policy effect. Hence, the estimates in the previous studies may have been affected by the bias from confounding.

Against these drawbacks, this research aims to explore whether and how RE policies have affected the export of PV and wind energy components. First, this research revisits the theoretical analysis on the policy effect and makes a clear distinction between "static" and "dynamic" policy effects.

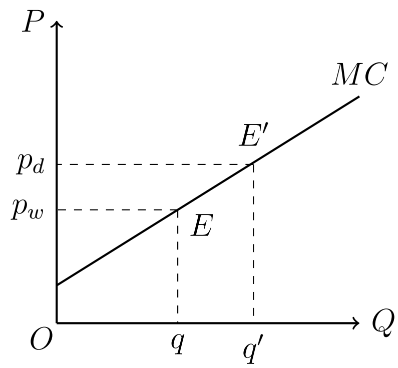


Figure 2.6: Shift in producer surplus from the gap in domestic and global prices

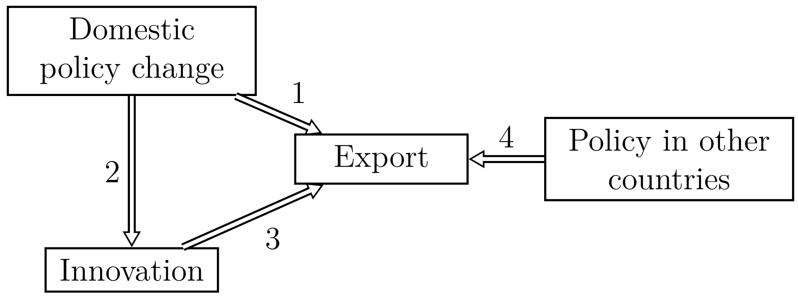
2.4 Revisiting the Theoretical Foundation: RE Policy Effect on the Import

As discussed earlier, the literature has paid scant attention to the policy effect on EG imports, including those of RE components, although the policies of exporter countries have been widely examined based on PH. This chapter reconfirms the theoretical implications of the relationship between RE policy and imports and establishes the foundation for the empirical analyses in 4. As previous empirical studies on the strong version of PH did not confirm the theoretical foundation, it is essential to examine the theoretical linkage between RE policy effect and RE component trade.

FIT and RPS are often referred to as "demand-pull" policies (Costantini et al., 2015), which aim to increase the domestic demand for RES-E. As already reviewed above, this increase in demand could induce innovation related to RE through additional profits for domestic manufacturers. However, the increase in producer surplus proposes another possible effect of the policy on "import" when we focus on how the increasing demand for additional RE components is fulfilled. Suppose the RE policy generates a gap between domestic and global prices, as shown in the gap between p_d and p_w in Figure 2.6. As long as the additional surplus from the gap $(p_d E' E p_w)$ exists, manufacturers of RE components can benefit from the potential increase in their profit from the policy. The profit opportunity resulting from the RE policy may attract domestic and overseas manufacturers because the demand facilitated by the policy can be fulfilled by exports to the market as well. Hence, the additional profit generated as a result of the policies can be eroded by the foreign manufacturers without accompanying policies for domestic manufacturers (Kwon, 2015). Moreover, the cost structure of RE component production might affect the stakeholders' strategy in the domestic market, as the manufacturers are still exposed to cost/price competition. In other words, the domestic market may be incentivized to rely on the technologies or products of other countries, as indicated by Menanteau et al. (2003). Hence, the domestic RE policy may also affect imports spurred by the domestic demand for RES-E, which is schematically demonstrated by vector 4 in Figure 2.7.

Contrary to overseas manufacturers, domestic manufacturers may not necessarily be incentivized to export, even if the export price is higher than the global price because of favorable policy. Rather, the policy can incentivize them to supply to the domestic market. Here, there is a contradiction between the (narrowly) strong version of PH and theoretical observations of policy effects on RE component exports and imports. Hence, it is worth examining the policy effect on both the export and import of RE components, coupled with past studies on country-specific PV industry and trade issues.

Based on the theoretical analysis, we assume that the static effect of domestic FIT and RPS on exports might be positive if manufacturers in exporter countries have gained export competitiveness through the additional profit generated from favorable policies (Hypothesis 1-1). The hypothesis refers to previous empirical analyses of EG trade based on the narrowly strong version of PH (Costantini and Crespi, 2013; Groba, 2014; Groba and



Note: Static effect: 1 (Hypothesis 1-1) or 4 (Hypothesis1-2)
Dynamic effect (or narrowly strong PH): $2 + 3$, Hypothesis 2 deals with arrow 3, assuming the effect of arrow 2 exists.

Figure 2.7: Diagram of static and dynamic policy effect on the trade of RE components

Cao, 2014). As the base model of the policy effect on the export of PV and wind energy components, we can compare it with those of the other hypotheses described below.

Nevertheless, the effect of policies on importer countries might be positive if exports to those countries have been induced to fulfill the increased demand (Hypothesis 1-2). The hypothesis refers to the potential effect of RE policy on imports, which has been indicated in descriptive studies on the RE industry (Wu and Salzman, 2014; Hattori and Chen, 2022). We shed light on another aspect of the RE policy effect empirically, as previous studies have not focused sufficiently on the effect of policies in importer countries on trade.

The dynamic policy effect is assumed to be positive if the innovative capacity can be associated with exports when the policies are in force; hence, the (narrowly) strong version of PH is valid (Hypothesis 2). Here, we consider the interactive effect between innovation and policy variables on exports to examine this hypothesis. The model considering the interaction might be more precise in terms of the analysis of the narrowly strong version of PH. This is because it assumes that the effectiveness of the innovation factor can be conditional on policy implementation. This research contributes to establishing the theoretical foundation and novel estimation methodology for empirical studies on the narrowly strong version of PH.

Figure 2.7 summarizes the overall linkage between the factors studied in this research. The static effect of the policy is shown by arrow 1 (domestic policy effect on exports: Hypothesis 1-1) or 4 (the effect of policies in importer countries on exports: Hypothesis 1-2). The dynamic effect is displayed by arrows 2 and 3, which show that the innovation effect on exports is subject to whether the domestic FIT or RPS is in force. These two arrows deal with Hypothesis 2, while they only account for arrow 3. Hypothesis 2 examines the difference inn whether the policy is in force (the effect of arrow 2 exists). The estimation method of the dynamic effect below elaborates it in the literature on the strong version of PH in EG trade, as it does not explicitly consider the relation shown by arrow 2.

Chapter 3

Analysis of the Static Policy Effect

Based on the review and theoretical foundation, this chapter presents the model for empirical analyses and shows the estimation results of both the static effect of FIT and RPS on the trade of PV and wind energy components. We must explicitly extract the policy effect from its mixed effects with other covariates to examine the static effect. However, conventional estimation methods in the literature essentially contain the bias from confounding; the interaction between the covariates. Therefore, this chapter presents the model, data, and estimation method for estimating the static effect of RE policy on PV and wind energy exports based on Ogura (2021).

With reference to the empirical literature, the gravity model for international trade was applied in this study to analyze the policy effect. As Tinbergen (1962) formulated this model to explain world trade, its theoretical foundation has been confirmed through subsequent research (Anderson, 1979; Bergstrand, 1985). This equation has been widely applied to analyze the effect of factors influencing trade value, such as free trade agreements, accession to the World Trade Organization, and bilateral trade (Anderson and van Wincoop, 2003; Rose, 2004; Baier and Bergstrand, 2007). The empirical literature on EG trade has also applied the model to find empirical evidence on a (narrowly) strong version of PH (Costantini and Crespi, 2008; Costantini and Mazzanti, 2012; Groba, 2014). The basic form of this equation is as follows:

$$\ln T_{ijt} = \alpha_0 + \alpha_1 \ln Y_{it} + \alpha_2 \ln Y_{jt} + \alpha_3 \ln D_{ij} + ... \quad (3.1)$$

T, Y and D denote bilateral trade, gross domestic products (GDP) in each country and the distance between exporter i and importer j countries in year t, respectively. GDP is a proxy for the scale of the economy in each country, and distance is one of the cost components of international trade. Hence, this equation assumes that GDP is positively correlated with bilateral trade while distance is negative. Other proxies for trade policies and cost factors were added to the equation to determine the overall effect on trade.

3.1 Model and data description

Based on the review and the challenges in Chapter 2, the model in Equation 3.2 is set to estimate the effect of FIT and RPS in both exporter and importer countries on the export of PV and wind energy components.

$$\begin{aligned} \ln X_{ijt} = & \alpha_0 + \alpha_1 \ln Y_{ijt} + \alpha_2 \ln D_{ij} \\ & + \alpha_3 \ln K_{it} + \alpha_4 REpol_{ijt} + \varepsilon_{ijt} \end{aligned} \quad (3.2)$$

In the equation above, X_{ijt} denotes the export of PV and wind energy components from exporter country i to importer country j in year t. Referring to the literature, this variable proxy the export competitiveness, and the policy effect is estimated. Previous empirical studies have selected auxiliary products as well as PV modules and windmill units, including converters and towers, as PV and wind energy components (Groba, 2014; Groba and Cao, 2014). We refer to Groba and Cao (2014) to select PV and wind energy products with designated 6-digit harmonized system (HS) codes (3 codes for PV and 6 codes for wind energy, listed in Table A.1 in Appendix). The trade data are extracted from the BACI database provided by Centre d'Études Prospectives et d'Informations Internationales (CEPII, 2019). Extracted trade data are aggregated as PV and wind energy components, respectively.

This study examined the effect of the sum of i and j's logged GDP; $TGDP_{ijt}$ as expressed in Equation 3.3. We assume that the variables might be positively associated with the export as assumed in the trade literature. The GDP data have been extracted from the World Bank's World Development Indicators database (World Bank, 2019).

$$TGDP_{ijt} = \ln Y_{it} + \ln Y_{jt} \tag{3.3}$$

D_{ij} denotes the distance between countries i and j. As mentioned above, bilateral distance is the cost component. Hence, we expect that the distance is negatively associated with the export. Dummy variables for sharing the common border and common language: $CNTG_{ij}$, $LANG_{ij}$ are also included in the model as the cost components. Both dummies are assumed to be positively associated with the export as the feature can have a higher possibility to the trade relationship. Data on these variables are extracted from the GeoDist database by CEPII (2015).

As the main components of PH analysis, the literature on PH has captured innovation variables with research expenditure and patent statistics (Jaffe and Palmer, 1997; Costantini and Mazzanti, 2012). This research also adds the knowledge stock variable to the model as the proxy for innovative capacity. With reference to Popp et al. (2011), the knowledge stock variable K_{it} is calculated by Equation 3.4 with patent PAT_{it} statistics of the technologies related to PV and wind energy OECD (2019).

$$K_{it} = \sum_{s=0}^{\infty} e^{-\delta_1(s)} \left(1 - e^{-\delta_2(s+1)}\right) PAT_{i(t-s)} \tag{3.4}$$

As for the RE policy; $REPol_{ijt}$, we focus on the effects of FIT and RPS as the two have been widely disseminated, eventually leading to the vast diffusion of RE, mainly PV and wind energy. The policy dummies on FIT or RPS are set during the periods of the study. The RE policy data in sample countries are extracted from IEA/IRENA (2019), based on the data compiled in OECD-EPAU (2013)[1]. Considering the heterogeneous effect of RE policy in exporter and importer countries, this study examines the individual effect of the policy; FIT and RPS dummies in country i and j are included in the model individually.

Previous empirical analyses on the narrowly strong version of PH assume that the policy will positively affect the competitiveness or export performance. Therefore, these studies regarded the policy's positive effect as evidential on the strong version of PH. However, the theoretical review above suggests that those in country i may not be associated with their export, or they can be related to declining export performance under more harsh competition with producers abroad. In this case, FIT/RPS_{it} can be negatively associated with X_{ijt}, which has been left out in the previous analyses.

Another implication from the theoretical review above is the effect of policies in country j on their import from country i. As explained in the last section, both FIT and RPS in j generate the surplus for RES-E, which can lead to the import of those components. This can incentivize the producers in i to export to j for obtaining additional profit generated as a result of the policies. In this situation, FIT/RPS_{jt} is positively associated with X_{ijt}.

[1]The data in 2012-2015 are complemented referring to IEA/IRENA (2019), as OECD-EPAU (2013) contains the data in 1998-2011.

Table 3.1: Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max	Unit
X_{PV}	55,440	14,269.12	128,270.4	0	8,820,500	thousand USD
X_W	55,440	4,742.861	29,774.87	0	1,137,958	thousand USD
Y	55,440	1,253.018	2,503.879	9.006	18,559.3	billion USD
D	55,440	6,708.843	4,862.032	59.617	19,711.86	km
$CNTG$	55,440	0.042	0.2	0	1	
$LANG$	55,440	0.072	0.259	0	1	
K_{PV}	55,440	127.014	583.08	0	5,535.577	
K_W	55,440	74.207	242.768	0	2,031.136	
FIT_{PV}	55,440	0.456	0.498	0	1	
FIT_W	55,440	0.461	0.499	0	1	
RPS	55,440	0.158	0.364	0	1	

Note: Obs.: Observations, Std. Dev.: Standard Deviations

The period of this study is between 1998 and 2015 due to the data availability of the sources. We selected 56 countries as the sample countries in this research as their policy data had been compiled in OECD-EPAU (2013) with the unified discipline. Those countries are listed in Table A.2. The summary statistics are shown in Table 3.1.

3.2 Estimation method

In Chapter 2, we mentioned that confounding among the regressors in the model can affect the estimates of the policy effect. However, bias from the confounding is inevitable with the standard gravity model, as it essentially incorporates covariates such as GDP and bilateral distances. Hence, the bias might inevitably affect the estimation with the model specified in Equation 3.2. Matching estimators have been applied to analyze the treatment effect of trade policies to deal with bias (Baier and Bergstrand, 2009; Kohl and Trojanowska, 2015). To estimate the average treatment effect (ATE) and the average treatment effect on the treated (ATT) with the gravity model, Baier and Bergstrand (2009) referred to Abadie and Imbens (2006) on the nearest-neighbor matching estimator, considering the large sample properties and conditional bias with more than one continuous variable. This is typical in empirical analyses using gravity models.

This study follows Baier and Bergstrand (2009) in the application with a matching estimator. Applying a matching estimator can also control the bias with the potential confounding in estimating the RE policy effect on the trade of RE components. Furthermore, matching estimators can be considered more appropriate estimates on the static effect. They extract the policy effect with matched samples by minimizing the bias from confounding with other covariates such as GDP and innovative capacity. Nevertheless, the estimation method has not been applied in the literature on EG trade.

The treatment effect on the export X_k in the matching estimator is explained as follows:

$$X_k^*(0) = \begin{cases} X_k, & \text{if } REPol_k = 0 \\ \frac{1}{M}\sum_{l \in J_M(k)} X_l, & \text{if } REPol_k = 1 \end{cases} \tag{3.5}$$

and

$$X_k^*(1) = \begin{cases} \frac{1}{M}\sum_{l \in J_M(k)} X_l, & \text{if } REPol_k = 0 \\ X_k, & \text{if } REPol_k = 1 \end{cases} \tag{3.6}$$

Also, the ATE and ATT can be expressed as:

$$ATE_M = \frac{1}{N}\sum_{k=1}^{N}\left[X_k^*(1) - X_k^*(0)\right] \tag{3.7}$$

$$ATT_M = \frac{1}{N}\sum_{REPol_k=1}\left[X_k - X_k^*(0)\right] \tag{3.8}$$

Here, X_k denotes the export for the unit k. The missing outcome, export value, is imputed from the above Equations 3.5 and 3.6 in the set of indices for the first M matches, $J_M(k)$, based on the index l in the N pairs of the countries. After the process, ATE is estimated with observation N, and the ATT estimators are obtained only for countries with RE policies in force. The treatment effects of FIT and RPS in the matching method are also applied to those in importer countries. Balanced plots of the matching econometrics are shown in Figures A.1 and A.2. The control and treated samples appeared to be well-matched in both PV and wind energy.

Based on the theoretical implication of the influence of RE policy, the static effect can affect export performance both positively and negatively. The policy might positively affect export performance if domestic manufacturers directly garner export performance through additional profits. However, it can negatively affect exports when they prioritize supply to the domestic market rather than export to other countries. Meanwhile, policies in importer countries can affect exports, as the additional profit in the country can also benefit manufacturers in other countries.

3.3 Estimation results: Static effect

The estimation results with a matching estimator, which examines the static effects of FIT and RPS, are shown in Table 3.2. All control variables were included in the estimation[2].

The results show the heterogeneity between PV and wind energy components. FIT and RPS in exporter countries show negative ATE and ATT on PV exports, while FIT in importer countries shows positive ATE and ATT. As for the positive effect on wind energy component exports, the literature also indicates the positive effect of domestic policies on exports (Groba, 2014;

[2]Balance plots of the covariates (sum of logged GDP of exporter and importer countries, bilateral distance, and knowledge stock variable) are displayed in Figures A.1 and A.2, indicating the covariates in the model are well matched in the estimation.

Kuik et al., 2018). However, the negative effect of FIT on the domestic policy effect on exports or the (narrowly) strong PH has not been found in previous empirical studies. The negative effect on PV indicates that manufacturers could have chosen to supply their products more to the domestic market than overseas with domestic FIT and RPS. Meanwhile, wind energy manufacturers could have garnered export performance by implementing domestic FIT.

The overall effect of policies in importer countries also differs between PV and wind energy. Both FIT and RPS for PV in importer countries show positive ATE and ATT. This indicates that demand growth in countries implementing the policies can enhance PV component exports. The cost structure of PV may have led to fulfilling the demand facilitated by FIT and RPS by imports. While the same result has been seen on ATT of RPS in importer countries on wind energy component exports, FIT in those countries shows negative results. As wind energy is more cost-competitive (IEA/NEA, 2015), RPS could import wind energy components. However, exports to countries with FIT may have been crowded out due to the policy level or accompanying policies that may be unfavorable for the export.

3.4 Summary: Examining Hypothesis 1-1 and 1-2

Estimates of the static effect differ between PV and wind energy. The negative effect of policies in exporter countries indicates that domestic PV manufacturers might concentrate on supplying to the domestic market rather than exporting. This result is the opposite of the assumed positive static effect of Hypothesis 1-1. Coupled with the positive effect of policies in importer countries on exports, which is in line with the effect suggested by Hypothesis 1-2, the demand for PV components induced by the policy in importer countries has been fulfilled mainly by imports throughout the period.

Table 3.2: ATE and ATT of FIT and RPS on PV/wind energy components' export

PV	Exporter countries		Importer countries	
	FIT_{it}	RPS_{it}	FIT_{jt}	RPS_{jt}
ATE	-0.141***	-0.655***	0.047**	0.256***
	(0.026)	(0.052)	(0.024)	(0.033)
ATT	-0.044	-0.275***	0.131***	0.331***
	(0.034)	(0.042)	(0.030)	(0.046)
Obs.	36,849	36,849	36,849	36,849
Wind	Exporter countries		Importer countries	
	FIT_{it}	RPS_{it}	FIT_{jt}	RPS_{jt}
ATE	0.188***	-0.043	-0.286***	0.023
	(0.030)	(0.038)	(0.025)	(0.039)
ATT	0.134***	0.066	-0.233***	0.199***
	(0.039)	(0.042)	(0.030)	(0.043)
Obs.	33,303	33,303	33,303	33,303

Note: Obs.: Observations
Abadie-Imbens robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Nevertheless, the positive effect of FIT for wind energy supports Hypothesis 1-1, which indicates that manufacturers of the components could have garnered export performance through domestic policy implementation. Manufacturers of wind energy components might have secured export performance with the surplus from FIT in their domestic market. This is reinforced by the negative treatment effect of policies in importer countries. The result indicates the difficulty of eroding profit through exports when FIT has been implemented.

Chapter 4

Analysis of the dynamic policy effect

This chapter examines the dynamic effects of FIT and RPS in exporter countries. Contrary to the static effect, the interaction between independent variables is explicitly specified to examine the dynamic effect. Hence, the standard estimation method of the gravity model is applied as follows:

4.1 Model specification

The standard gravity model can estimate the effectiveness of the covariates, including the policy effect relative to the other regressors, contrary to the matching estimator. Hence, this method can be more useful for examining the dynamic effect of handling the relation between specific regressors and interaction terms. Equation 3.2 is modified to the model below with the interaction between knowledge stock and policy variables.

$$\begin{aligned}\ln X_{ijt} =& \alpha_0 + \alpha_1 \ln Y_{ijt} + \alpha_2 \ln D_{ij} + \alpha_3 \ln K_{it} + \alpha_4 REPol_{ijt} \\ &+ \alpha_5 \ln K_{it} \times REPol_{ijt} + d_{ij} + d_t + \varepsilon_{ijt}\end{aligned} \tag{4.1}$$

4.2 Estimation method

Here, we focus on the potential effect of innovative capacity in the estimation of the dynamic policy effect on exports. In the estimation of the dynamic effect with model 4.1, the knowledge stock variable is assumed to be positively associated with exports in the conventional empirical analyses of PH (Costantini and Mazzanti, 2012; Groba and Cao, 2014). Further, the model explicitly distinguishes the effects of innovative capacity when FIT or RPS is in force (Ogura, 2020). The variable assumes that the effect of innovative capacity on exports might be conditional on FIT or RPS implementation. This study includes the interaction variables $K_{it} \times FIT/RPS_{it}$ in addition to the independent technology and policy variables, as shown in Figure 4.1. If there is a positive effect of the interaction term, this could be considered empirical evidence for the narrowly strong version of PH. However, policies can be a disincentive to be innovative or may not enhance export performance. The theoretical review indicates that producers may have to face competition with merely a little or no additional surplus resulting from the domestic policies and be forced to turn to foreign technology. In this case, bilateral exports might be negatively associated with the policy or interaction variables.

Anderson and van Wincoop (2003) have argued that there would be considerable bias caused by the multilateral resistance (MR), which is the effect from the factors that cannot be fully explained with the variables in the estimated models. This highlights that there should be considerable bias from omitted variables. To deal with the bias from MR, they suggested that including fixed effects (FE) of exporters and importers can improve the estimated results with the gravity model. Hence, the model also includes FE of the exporter-importer relationship and year (d_{ij}, d_j, d_t in Equation 4.1). We refer to Baier and Bergstrand (2009) and apply ordinary least squares with robust standard errors to estimate the relative effect of the regressors and compare the results with a matching estimator.

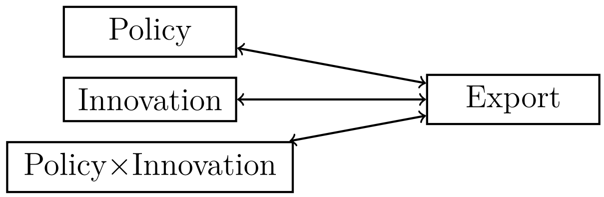


Figure 4.1: Correlation concerned with the analysis of dynamic effect

The positive association of the interaction between knowledge stock and policy variables to exports can be regarded as the positive dynamic effect of the policy; empirical evidence on the narrowly strong version of PH.

4.3 Estimation results: Dynamic effect

Tables 4.1 and 4.2 show the estimation results of the conventional models that include independent, innovative capacity, and policy variables only. Estimation results on the models incorporating the FE are shown in columns 4–6. Root mean square error (RMSE) is shown in the results referring to Baier and Bergstrand (2009) applied the statistics to examine fit of the models in their analysis of the standard gravity model. The indicator is smaller in the estimation with FE, which indicates more fitted estimates than that without considering MR. As suggested in the literature on international trade, standard gravity variables show robust estimates. Aggregated log of GDP ($TGDP_{ijt}$), sharing commom border ($CNTG_{ij}$) and official language ($LANG_{ij}$) are positively associated with the export of both PV and wind energy components. However, the bilateral distance between exporter and importer countries (D_{ij}) shows a negative effect.

Among the variables of concern in this study, knowledge stock (K_{it}) is positively associated with the export of PV components, while the positive effect has turned insignificant for wind energy component exports with FE. Estimates on the policy variables are common to the results of the static

Table 4.1: Technology and policy effect on PV export

	(1)	(2)	(3)	(4)	(5)	(6)
$\ln TGDP_{ijt}$	0.733***	0.736***	0.295***	1.244***	1.242***	1.226***
	(0.021)	(0.006)	(0.006)	(0.097)	(0.097)	(0.097)
$\ln D_{ij}$	-0.862***	-0.853***	-0.862***	-0.998***	-0.998***	-0.998***
	(0.038)	(0.037)	(0.038)	(0.040)	(0.040)	(0.040)
$CNTG_{ij}$	0.564***	0.556***	0.550***	0.391***	0.391***	0.391***
	(0.192)	(0.192)	(0.192)	(0.145)	(0.145)	(0.145)
$LANG_{ij}$	0.327***	0.349***	0.347***	0.548***	0.548***	0.548***
	(0.116)	(0.115)	(0.114)	(0.097)	(0.097)	(0.097)
$\ln K_{it}$	0.382***	0.392***	0.402***	0.080***	0.079***	0.077***
	(0.017)	(0.017)	(0.018)	(0.022)	(0.022)	(0.022)
FIT_{it}	-0.132**		-0.154***	0.075**		0.076**
	(0.058)		(0.059)	(0.033)		(0.033)
RPS_{it}		-0.252***	-0.271***		0.086**	0.088**
		(0.063)	(0.064)		(0.043)	(0.043)
Constant	-24.66***	-24.87***	-24.63***	-56.50***	-56.35***	-55.51***
	(1.137)	(1.135)	(1.133)	(5.445)	(5.445)	(5.450)
Obs.	36,849	36,849	36,849	36,849	36,849	36,849
exporter FE	no	no	no	yes	yes	yes
importer FE	no	no	no	yes	yes	yes
year FE	no	no	no	yes	yes	yes
RMSE	2.115	2.114	2.112	1.466	1.466	1.466

Note: Obs.: Observations, FE: Fixed effects, RMSE: Root Mean Square Errors
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4.2: Technology and policy effect on wind energy export

	(1)	(2)	(3)	(4)	(5)	(6)
$\ln TGDP_{ijt}$	0.746***	0.745***	0.742***	1.164***	1.146***	1.151***
	(0.019)	(0.019)	(0.019)	(0.111)	(0.111)	(0.111)
$\ln D_{ij}$	-0.853***	-0.867***	-0.855***	-1.089***	-1.089***	-1.089***
	(0.036)	(0.035)	(0.036)	(0.042)	(0.042)	(0.042)
$CNTG_{ij}$	0.563***	0.560***	0.575***	0.566***	0.566***	0.566***
	(0.162)	(0.163)	(0.162)	(0.146)	(0.146)	(0.146)
$LANG_{ij}$	0.773***	0.766***	0.745***	0.575***	0.575***	0.575***
	(0.114)	(0.114)	(0.115)	(0.104)	(0.104)	(0.104)
$\ln K_{it}$	0.429***	0.426***	0.410***	-0.023	-0.022	-0.024
	(0.017)	(0.018)	(0.019)	(0.026)	(0.026)	(0.026)
FIT_{it}	0.210***		0.236***	-0.026		-0.020
	(0.053)		(0.053)	(0.035)		(0.036)
RPS_{it}		0.205***	0.242***		0.057	0.053
		(0.066)	(0.067)		(0.041)	(0.042)
Constant	-26.55***	-26.30***	-26.45***	-54.95***	-53.94***	-54.19***
	(0.966)	(0.962)	(0.965)	(6.268)	(6.282)	(6.273)
Obs.	33,303	33,303	33,303	33,303	33,303	33,303
exporter FE	no	no	no	yes	yes	yes
importer FE	no	no	no	yes	yes	yes
year FE	no	no	no	yes	yes	yes
RMSE	2.035	2.036	2.033	1.685	1.685	1.685

Note: Obs.: Observations, FE: Fixed effects, RMSE: Root Mean Square Errors
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

effect estimation only when the model does not incorporate FE.

However, policy variables positively affect PV exports, although the influence is relatively unclear with a weaker significance. The significant effect of knowledge stock and policy variables on wind energy component exports also turned insignificant when FE were considered.

The estimates suggest that the innovative capacity and policies of exporter countries can positively affect PV exports. Both variables can affect the PV export performance of exporters independently, while significant results have not been detected for wind energy. Nevertheless, the policy effect may be weaker relative to the other standard gravity variables and overall omitted factors.

Table 4.3 and 4.4 show the estimation results of the interaction terms between FIT/RPS and knowledge stock variables. The results suggest different aspects of the policy effect through innovative capacity. The overall effect of knowledge stock is the same as those in Tables 4.1 and 4.2 and indicates the positive effect of knowledge stock on PV exports only. However, only wind energy component exports have a significant association with the interaction between knowledge stock and FIT and RPS, which offsets the overall negative effect of knowledge stock. This can be regarded as empirical evidence on the narrowly strong version of PH. The innovation effect on exports is positive when FIT and RPS are in force in exporter countries. As for PV, however, no significant effect of the policies has been found when the model incorporates FE, although the interaction with FIT shows a positive effect without FE.

The standard gravity variables show robust estimates, indicating a positive association of summed log GDP, common border, and official language. Nevertheless, the distance between exporter and importer countries is negatively associated with PV and wind energy component exports.

Table 4.3: Dynamic policy effect on PV export

	(1)	(2)	(3)	(4)	(5)	(6)
$\ln TGDP_{ijt}$	0.730***	0.736***	0.734***	1.232***	1.247***	1.226***
	(0.021)	(0.021)	(0.021)	(0.098)	(0.098)	(0.098)
$\ln D_{ij}$	-0.864***	-0.850***	-0.860***	-0.998***	-0.998***	-0.998***
	(0.038)	(0.038)	(0.038)	(0.040)	(0.040)	(0.040)
$CNTG_{ij}$	0.559***	0.556***	0.548***	0.391***	0.391***	0.391***
	(0.192)	(0.192)	(0.192)	(0.145)	(0.145)	(0.145)
$LANG_{ij}$	0.320***	0.353***	0.345***	0.548***	0.548***	0.548***
	(0.116)	(0.115)	(0.114)	(0.097)	(0.097)	(0.097)
$\ln K_{it}$	0.342***	0.398***	0.374***	0.084***	0.080***	0.080***
	(0.021)	(0.017)	(0.023)	(0.021)	(0.022)	(0.021)
FIT_{it}	0.133		0.066	0.033		0.043
	(0.081)		(0.084)	(0.044)		(0.045)
RPS_{it}		-0.332***	-0.334***		0.018	0.025
		(0.085)	(0.088)		(0.046)	(0.047)
$\ln K_{it}\times$	0.072***		0.060***	-0.014		-0.009
FIT_{it}	(0.081)		(0.020)	(0.012)		(0.012)
$\ln K_{it}\times$		-0.038	-0.076***		-0.033*	-0.028
RPS_{it}		(0.028)	(0.024)		(0.019)	(0.018)
Constant	-24.66***	-24.93***	-24.70***	-55.95***	-56.63***	-55.54***
	(1.134)	(1.139)	(1.135)	(5.466)	(5.473)	(5.492)
Obs.	36,849	36,849	36,849	36,849	36,849	36,849
exporter FE	no	no	no	yes	yes	yes
importer FE	no	no	no	yes	yes	yes
year FE	no	no	no	yes	yes	yes
RMSE	2.113	2.113	2.111	1.466	1.466	1.466

Note: Obs.: Observations, FE: Fixed effects, RMSE: Root Mean Square Errors
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4.4: Dynamic policy effect on wind energy export

	(1)	(2)	(3)	(4)	(5)	(6)
$\ln TGDP_{ijt}$	0.745***	0.747***	0.741***	1.192***	1.135***	1.160***
	(0.019)	(0.019)	(0.019)	(0.110)	(0.110)	(0.109)
$\ln D_{ij}$	-0.857***	-0.865***	-0.859***	-1.088***	-1.089***	-1.089***
	(0.036)	(0.035)	(0.036)	(0.042)	(0.042)	(0.042)
$CNTG_{ij}$	0.559***	0.559***	0.573***	0.567***	0.566***	0.567***
	(0.162)	(0.163)	(0.161)	(0.146)	(0.146)	(0.146)
$LANG_{ij}$	0.768***	0.772***	0.736***	0.575***	0.575***	0.575***
	(0.114)	(0.114)	(0.114)	(0.104)	(0.104)	(0.104)
$\ln K_{it}$	0.369***	0.435***	0.337***	-0.062**	-0.029	-0.070***
	(0.022)	(0.019)	(0.027)	(0.028)	(0.026)	(0.027)
FIT_{it}	0.536***		0.642***	0.155***		0.175***
	(0.087)		(0.092)	(0.055)		(0.056)
RPS_{it}		0.312***	0.222**		0.196***	0.204***
		(0.078)	(0.110)		(0.061)	(0.064)
$\ln K_{it}\times$	0.102***		0.126***	0.065***		0.066***
FIT_{it}	(0.022)		(0.023)	(0.016)		(0.016)
$\ln K_{it}\times$		-0.050	-0.034		0.066***	0.058**
RPS_{it}		(0.034)	(0.034)		(0.023)	(0.024)
Constant	-26.68***	-26.40***	-24.70***	-56.52***	-53.34***	-54.79***
	(0.960)	(0.972)	(1.135)	(6.231)	(6.217)	(6.160)
Obs.	33,303	33,303	33,303	33,303	33,303	33,303
exporter FE	no	no	no	yes	yes	yes
importer FE	no	no	no	yes	yes	yes
year FE	no	no	no	yes	yes	yes
RMSE	2.033	2.036	2.030	1.684	1.684	1.684

Note: Obs.: Observations, FE: Fixed effects, RMSE: Root Mean Square Errors
Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 4.5: Summary of overall innovation effect and dynamic effect of FIT and RPS

Innovation effect on PV export						
	without FE			with FE		
K_{it}	+***	+***	+***	+***	+***	+***
Dynamic effect						
$K_{it} \times FIT_{it}$	+***		+***	-		-
$K_{it} \times RPS_{it}$		-	-***		-*	-
Innovation effect on wind energy export						
	without FE			with FE		
K_{it}	+***	+***	+***	-**	-	-**
Dynamic effect						
$K_{it} \times FIT_{it}$	+***		+***	+***		+***
$K_{it} \times RPS_{it}$		-	-		+***	+**

Note: FE: Fixed effects
*** p<0.01, ** p<0.05, * p<0.1

4.4 Summary: Examining Hypothesis 2

Table 4.5 summarizes the variables of interest in this research: the overall innovation effect and the effect subject to FIT or RPS. It shows heterogeneous results between the estimates with and without FE, while a positive innovation effect with the interaction to FIT is common in wind energy exports. Here, we depend on the results with FE, as the estimates deal with the potential bias from MR, such as omitted variables.

The positive effect of the knowledge stock on exports has only been detected for wind energy when FIT or RPS is implemented. We found no significant effect of knowledge stock on PV exports under any of those policies in force in exporter countries, although a positive effect of overall knowledge stock has been found only for PV. Hence, Hypothesis 2 is valid only for wind energy, while no significant evidence has been found on PV. The positive dynamic effect for wind energy components can be considered evidence of the narrowly strong version of PH.

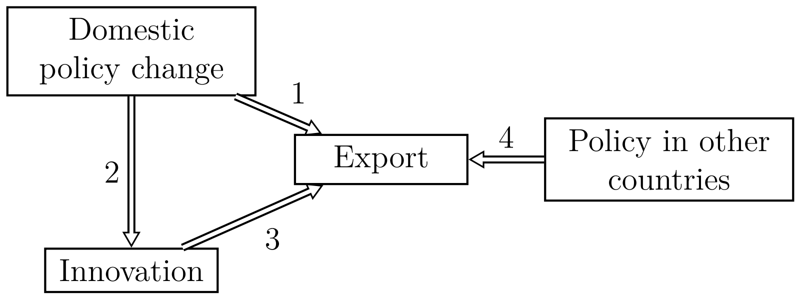
Chapter 5

Discussion

We assume that the static effect of domestic FIT and RPS on exports might be positive if the manufacturers have gained export competitiveness through additional profit (Hypothesis 1-1). Conversely, the effect of policies in importer countries might be positive if component imports have been induced to meet the demand (Hypothesis 1-2). Meanwhile, the dynamic policy effect is assumed to be positive if the innovative capacity can be associated with exports when the policies are in force (Hypothesis 2). These hypothetical settings are summarized in 5.1.

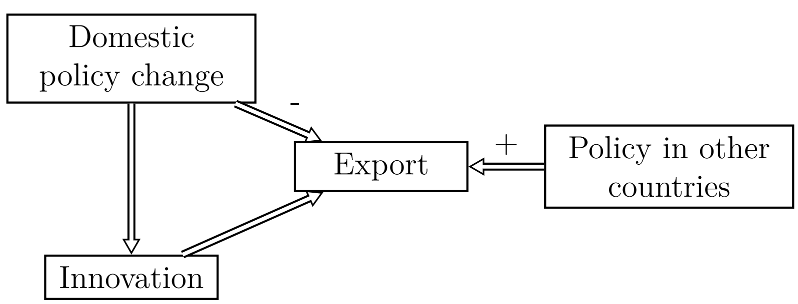
The estimation results in Chapter 3 show that Hypothesis 1-1 is valid with the FIT for wind energy only, while the results on FIT and RPS for PV support Hypothesis 1-2. Hence, the static effect of domestic FIT on exports is positive, while FIT and RPS in importer countries might also have generated the static effect on their PV imports. A similar trend has been observed in the estimates on the dynamic effect in Chapter 4. Hypothesis 2 is valid only for wind energy, which shows the empirical evidence on the narrowly strong version of PH. These results are summarized in Figures 5.2 and 5.3 with the static and dynamic effect signs.

The trends in both static and dynamic effects of FIT and RPS highlight the contrast between PV and wind energy, positive static and dynamic im-



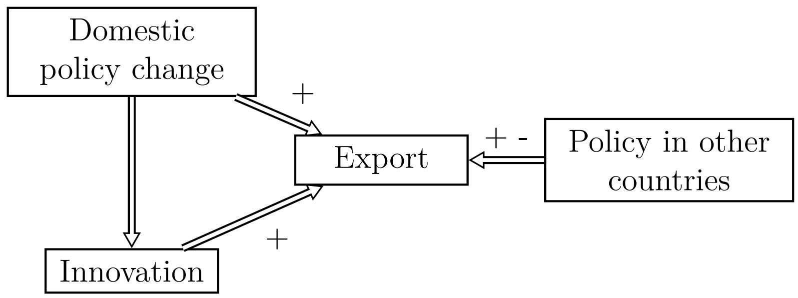
Note: Static effect: 1 (Hypothesis 1-1) or 4 (Hypothesis1-2)
Dynamic effect (or narrowly strong PH): $2 + 3$, Hypothesis 2 deals with arrow 3, assuming the effect of arrow 2 exists.

Figure 5.1: Diagram of static and dynamic policy effect on the trade of RE components (Figure 2.7)



Note: No sign: no significant effect, or not examined in this research.

Figure 5.2: Summary of static and dynamic policy effect on PV trade



Note: No sign: no significant effect, or not examined in this research.
+ -: negative effect of FIT and positive effect of RPS

Figure 5.3: Summary of static and dynamic policy effect on wind energy components' trade

pacts on wind energy exports, and negative static effect on PV exports. In the case of wind energy exports, the positive effect of policies is supported by the conventional theoretical review in Sections 2.1.1 and 2.1.2. The theoretical observation of the static effect presented in Section 2.4 might be valid for PV export.

The characteristics of each industry might explain this contrast. Schmidt and Huenteler (2016) reveal the "design-intensive" feature of the wind energy industry. They argue that the design and system integration capabilities of wind energy are held only by a limited number of manufacturers that are already competitive in the global market. These capabilities were built up in time-consuming learning-by-doing and learning-by-using processes. As exemplified by the industrial development in Germany (McDowall et al., 2013), favorable policies might enhance the profitability and competitiveness of domestic manufacturers, which could help retain profits in the domestic market. Further, license agreements to the manufacturers in China might affect the policy effect. This is because they may have included an embargo on the export of wind energy components, which eventually retained the dynamic effect for EU/US manufacturers (Mori, 2022). Hence, the positive static effect might have eventually led to the dynamic effect.

However, Schmidt and Huenteler (2016) have described the PV industry as "manufacturing-intensive", which is founded on efficient production. Based on the quick catch-up of Chinese PV cell manufacturing, they pointed out the importance of a large global market for technology transfer through trade (de la Tour et al., 2011) and low-cost capital for manufacturing plant financing, such as low-cost or free land grants (Horii, 2022). Further, Hoppmann et al. (2014) acknowledge that the German market has been dependent on imports from China, as the country has more price-competitive manufacturers. Mori (2022) indicates that the price competitiveness of Chinese manufacturers might be the key to retaining the scale of the economy. This is because exporting to countries with growing demand for PV was the only way to accomplish it without major preferential treatment for components.

Coupled with the relatively large global market (shown in Figure 1.2), price competition in the global market might have been more influential than the policy effect through innovation. The large global market, which can be a proxy for the global innovation process (Zhang and Gallagher, 2016), reinforces competitiveness, as shown by the overall positive effect of the innovation variable. Hence, the export performance of domestic PV manufacturers might not have been maintained by FIT and RPS only, as the high price competition in the global PV market is still present (Hattori and Chen, 2022). Accompanying policy instruments, such as local content requirements, a countermeasure against dumping, or export subsidies, may be required to maintain export competitiveness for PV components. However, it might induce trade disputes (Bougette and Charlier, 2015; Hughes and Meckling, 2017).

Meanwhile, the negative effect of FIT in exporter countries might also be influenced by the importance of the home market for supporting domestic wind energy manufacturers. This is because major exporters such as Denmark have expanded overseas after the saturation of the home market (Lewis and Wiser, 2007). The competitiveness of countries with FIT may have been rigid for wind energy as well, owing to the design-intensive feature. From this standpoint, the feature of a certain RES, which cannot be captured only by patent statistics, might be the key, as it can secure the profit level to attain dynamic efficiency. As for the positive ATT of RPS, it might be led simply by the growing demand in importer countries. This is because quantity-based policies such as RPS incentivize the introduction of lower-cost RES-E (Menanteau et al., 2003).

The influence of the industrial characteristics might not also be controlled in the matching estimation because the knowledge stock variable is constructed only by patent statistics, which may not fully reflect the design features of PV and wind energy systems. Considering this, some portion of the policy coefficients in the estimation can include the effect of industrial characteristics. Hence, the contrasting policy effect might show the heterogeneity of PV and wind energy technologies and industries. As the price or quantity levels are set under FIT and RPS, the additional profit distribution and incentives need to be considered carefully to maintain export competitiveness.

Chapter 6

Conclusion

RE components have witnessed prominent growth during 1998-2015, led by growing global demand on the back of favorable policies. Referring to PH, which indicates the positive effect of policies on innovation and further economic consequences, the literature has examined the relationship between RE policies and components' trade. Nevertheless, the literature has lacked the theoretical foundation on the policy effect. Past empirical analyses on PH may have been spurious, ignoring the difference between the direct policy effect on the cost/profit and its interactive effects with innovation.

Against these drawbacks, this research has examined the effect of FIT and RPS on the trade of PV and wind energy components. We established the theoretical foundation and solved the bias from misspecification that remained in the past studies. We set the three hypotheses based on the distinction of static and dynamic policy effects. The two hypotheses on the static effect are as follows: the policies in exporter countries positively affect exports if the additional profit enhances domestic manufacturing (Hypothesis 1-1); the policies in importer countries positively affect exports if the demand induced by the policy is fulfilled by imports (Hypothesis 1-2). For the dynamic policy effect (the narrowly strong version of PH), we hypothesized that innovation positively affects exports when the policies are in force as the policies can enhance exports through innovation if the effect is valid (Hypothesis 2).

We apply the separate estimation methods to examine the hypotheses. A matching estimator is applied for examining the static effect to cancel out the confounding of other covariates. The model with the interaction between policy and innovation variables is involved for examining the dynamic effect to capture the influence from the innovation only when the policies are in force.

The estimation results on wind energy components support Hypothesis 1-1 and 2, indicating the positive static and dynamic policy effects on exports. The supportive evidence on Hypothesis 2 shows that the estimates are the empirical evidence on the narrowly strong version of PH. The positive static effect could have been the fundamental of the consequent dynamic effect. This is because it shows that the additional profit from the policy might have been retained in the domestic market. Further, the countries have garnered export competitiveness through innovation. Conversely, the results on PV exports support Hypothesis 1-2, indicating that domestic policies might have induced imports. This indicates that imports have eroded the static policy effect on the surplus in the domestic market under the sheer price competition that might have resulted from the huge global market.

This dissertation contributes to the strand of research on PH by integrating theoretical and empirical analyses. The distinction between static and dynamic policy effects based on the theoretical observation can discuss the effect of policies in exporter countries and that of importer countries. Separate methodologies enable the estimation of the two types of effects of FIT and RPS along with the theoretical foundation. Specifying the dynamic policy effect with the interaction term to innovation variable allows us to examine PH by eliminating the potential bias in the model used in past studies. Through the theoretical foundation and application of the separated methodologies, the estimation results have reached the evidence of the narrowly strong version of PH in the wind energy components trade. Further, the integration of theoretical and empirical analyses has led to the reasoning of the descriptive studies with the estimation results. This has not been accomplished with obscure estimates on the policy effect in past studies. Examining the trade of EGs, including RE components, might contribute to the future diffusion of the products that manage mitigating climate change, environmental degradation, and maintaining economic performance, which might eventually lead to sustainable development.

There is scope for further research. Other products related to RE, such as biofuel (Costantini and Crespi, 2013), can be used in future studies, as we focused only on PV and wind energy components. Moreover, the characteristics of each RE product have not been fully considered in the estimation. This may be partly assessed with the inclusion of appropriate proxies. Another scope of research is an area- or country-specific study. For example, some Asian countries have emerged as the main exporters in Figure 1.1, and we referred to some descriptive studies on the development of Chinese RE industries (Lewis and Wiser, 2007; de la Tour et al., 2011; Hoppmann et al., 2014; Horii, 2022). Hence, future studies may examine the area- or country-specific trend of RE components' trade, as Ogura (2022) has already examined the trend in East Asia.

Appendix A

Appendix

A.1 Balance plot in the matching estimation

Figures A.1 and A.2 display the balance plots as a result of the matching estimation in section 3.1. These plots show the comparison of raw state and matched samples of the sum of logged GDP of exporter and importer countries, bilateral distance between the two countries, and the knowledge stock of exporter countries. The results indicate that the samples are matched well compared to the raw state in any covariates of the estimated model.

A.2 Complements

This dissertation has referred to Groba and Cao (2014) for the definition of PV and wind energy components. HS codes designated for each component are displayed in table A.1. The description of each classification has been referred to United Nations Statistics Division (2018).

Also, the country list analyzed in this dissertation is shown in table A.2. 56 countries have been compiled in OECD-EPAU (2013) regarding the information on their RE policy implementation and the level including FIT and RPS. This dissertation also analyzed the countries after the database.

Table A.1: HS codes of PV/wind energy components in this study

HS 1996 Code	Description
Solar photovoltaics	
850440	Static converters
850720	Other lead-acid accumulators
854140	Photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels; light emitting diodes
Wind energy components	
730820	Towers and lattice masts
841290	Parts of hydraulic/pneumatic/other power engines
841381	Other pumps; liquid elevators - Pumps
850231	Other generating sets - Wind-powered
850239	Other generating sets - Other
850240	Electric rotary converters

Source: Groba and Cao (2014), United Nations Statistics Division (2018)

Table A.2: Country list in this study

Algeria	Denmark	Iceland	New Zealand	South Africa
Argentina	Egypt	Israel	Norway	Tanzania
Austria	Finland	Japan	Peru	Thailand
Belarus	France	Jordan	Poland	Turkey
Belgium	Germany	Kenya	Portugal	Uganda
Australia	Estonia	Italy	Russia	United Kingdom
Brazil	Greece	South Korea	Serbia	United States
Canada	India	Malaysia	Slovakia	Uruguay
Bulgaria	Hungary	Latvia	Slovenia	
Chile	Indonesia	Mexico	Spain	
China	Iran	Morocco	Sweden	
Czech Republic	Ireland	Netherlands	Switzerland	

Countries compiled in OECD-EPAU (2013)

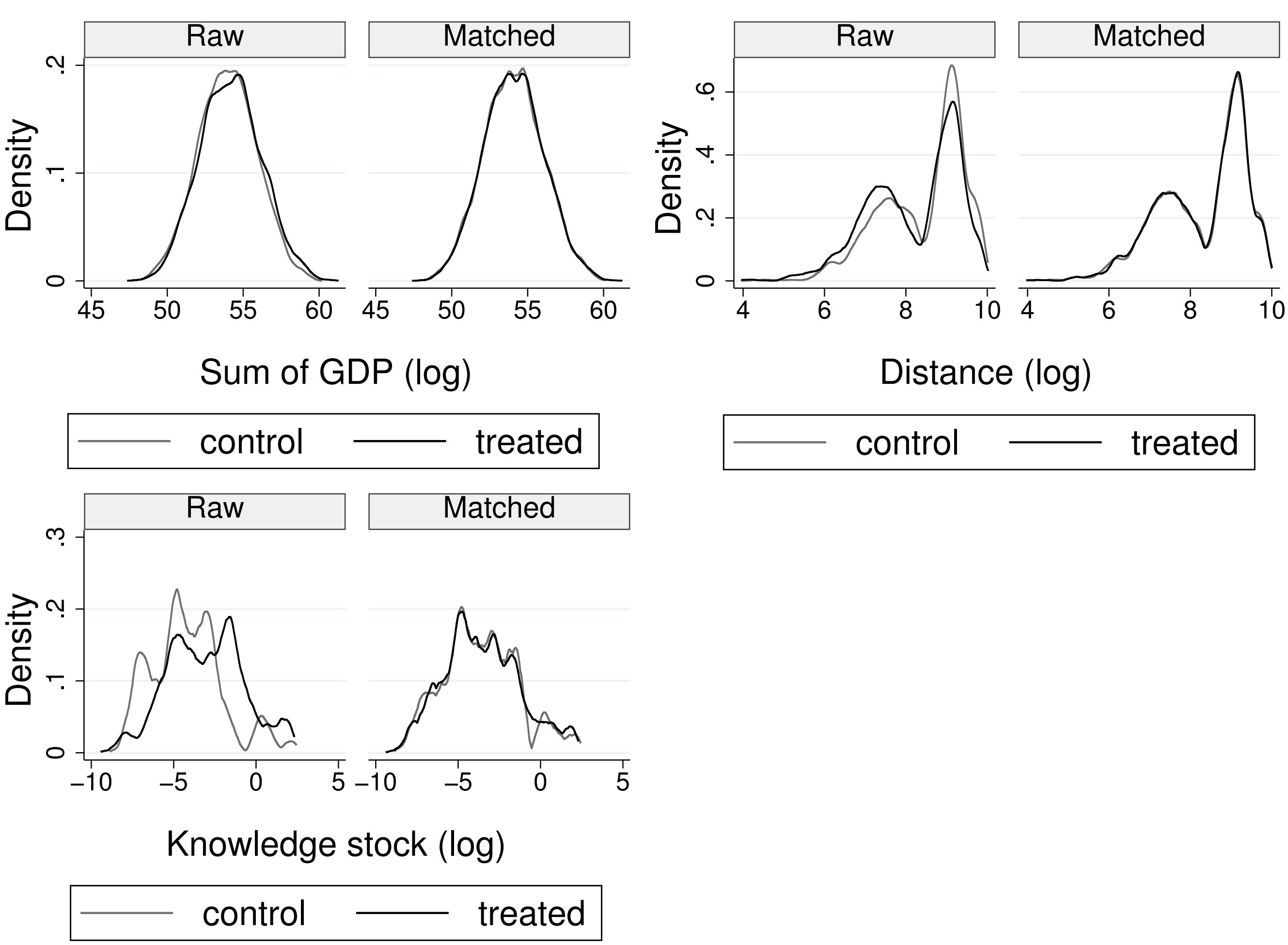


Figure A.1: Balance plot: PV

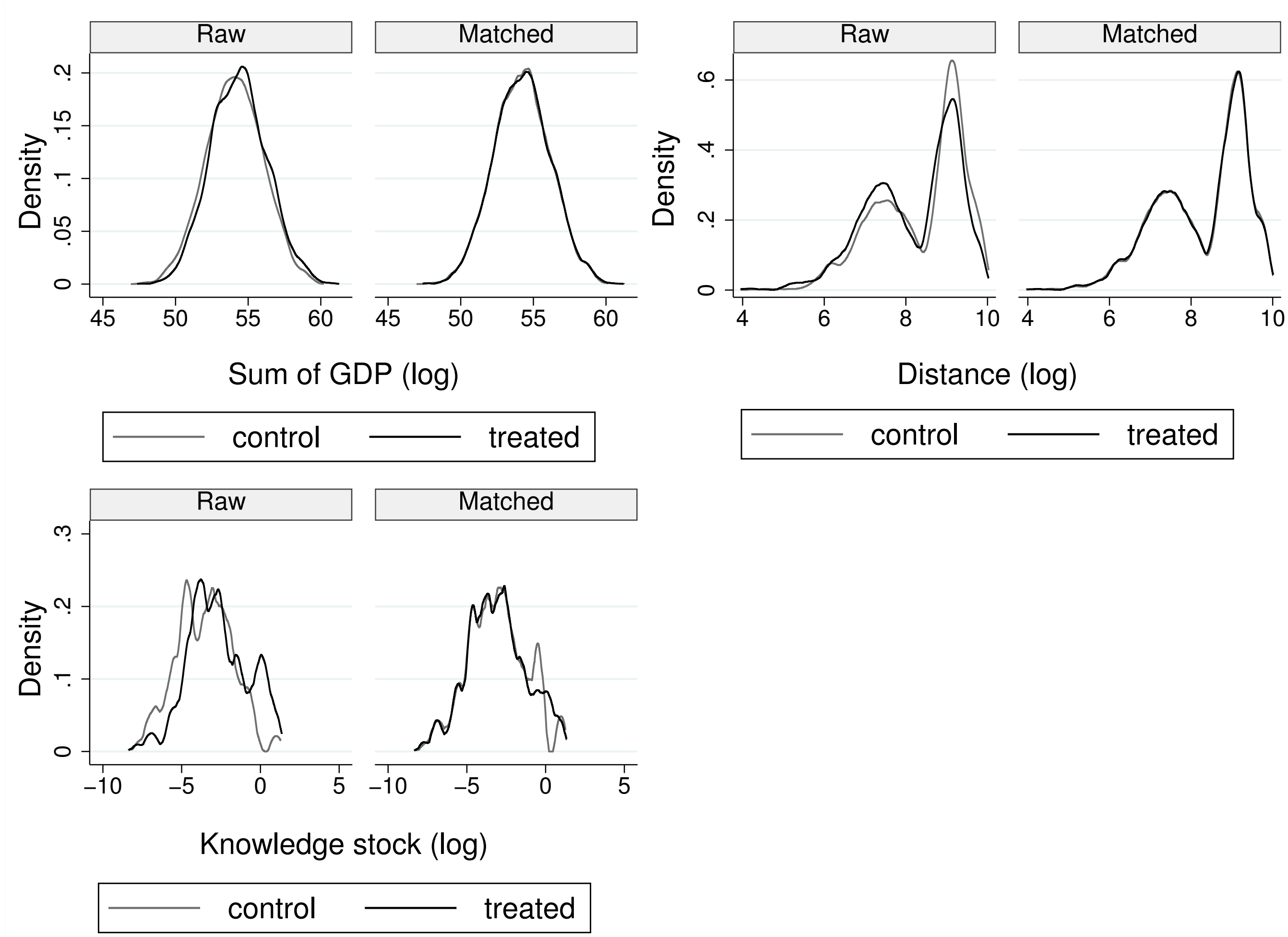


Figure A.2: Balance plot: Wind energy

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